IMPACT OF LAND FRAGMENTATION AND RESOURCE OWNERSHIP ON PRODUCTIVITY AND EFFICIENCY: THE CASE OF RICE PRODUCERS IN BANGLADESH

SANZIDUR RAHMAN AND MIZANUR RAHMAN

Abstract

The paper analyzes the impact of land fragmentation and ownership of resources on productivity and technical efficiency in rice production in Bangladesh using farm level survey data. Results reveal that land fragmentation has a significant detrimental effect on productivity and efficiency as expected. The elasticity estimates of land fragmentation reveal that a one percent increase in land fragmentation reduces rice output by 0.05 percent and efficiency by 0.03 percent. On the other hand, ownership of key resources (land, family labour, and draft animals) significantly increases efficiency. The mean elasticity estimates reveal that a one percent increase in family labour and owned draft animal improve technical efficiency by 0.04 and 0.03 percent, respectively. Also, a one percent increase in the adoption of modern technology improves efficiency by 0.04 percent. The mean technical efficiency in rice production is estimated at 0.91 indicating little scope to improve rice production per se using existing varieties. Policy implications include addressing structural causes of land fragmentation (e.g., law of inheritance and political economy of agrarian structure), building of physical capital (e.g., land and livestock resources), improvements in extension services and adoption of modern rice technology.

JEL Classification: O33, Q18, and C21.

Keywords: Stochastic production frontier, efficiency elasticity, land fragmentation, resource ownership, rice, Bangladesh

1. Introduction

Land is the major source of wealth and livelihood in rural Bangladesh, as in other South Asian countries, although the land person ratio is one of the lowest in the world estimated at 0.12 ha (FAO, 2001). The agricultural sector in Bangladesh, dominated by rice production, is already operating at its land frontier and has very little or no scope to increase the supply of land to meet the growing demand for food for its increasing population (Rahman, 2003). The expansion in crop area, which was the major source of production growth until the 1980s, has been exhausted and the area under rice started to decline thereafter (Husain et al., 2001). The conversion potential from local to modern varieties of rice has stagnated at 69 percent of total rice area (BBS, 2000), implying that the principal solution to increase food production lies in raising the productivity of land given the existing varietal mix. This is further complicated by the shrinking availability of land per farm holding, as the long established debate of inverse size- productivity relationship has now been weakened (Ram et al., 1999) in favour of positive size-productivity relationships (Wattanutchariya and Jitsanguan, 1992). In Bangladesh, the size-productivity relationship varies across regions depending on the level of technological development and environmental opportunities. The relationship is positive in technologically advanced regions, whereas the classic inverse relationship still exists in backward areas (Toufique, 2001).

In addition to shrinking availability of land for farming, land fragmentation[1] is on the rise in Bangladesh. Table 1 presents farm dynamics and the extent of land fragmentation based on three censuses of agriculture and livestock over the past three decades. The number of farm holdings initially increased rapidly but then slowed down and there has been a major shift in the composition of farm size groups. Unlike the experience in East Asian countries, e.g., Japan and

[1] Land fragmentation here refers to farming of a number of non-contiguous owned or leased plots (or parcels) of land as a single production unit (McPherson, 1982).

Korea, where farm sizes are getting larger as the number of operational holdings are going down (Niroula and Thapa, 2005), Bangladesh is experiencing rapid decline in farm sizes coupled with an increase in the number of operational holdings. The average farm size shrank to a level (0.68 ha) at which it is unlikely to sustain livelihoods[2]. The number of small farms increased dramatically at the expense of a reduction in the number of large and medium sized farms. The situation deteriorates further when one considers the fragmentation of total land holdings into parcels. Overall, the number of fragments per holding as well as average size of fragments declined in Bangladesh. Nevertheless, the average size of fragments increased for the large farm size categories, implying that some consolidation is taking place for this size group, perhaps through purchase or simple appropriation from marginal or landless farmers through an exploitative tenurial system.

Table 1 further reveals that not only the availability of land in Bangladesh is shrinking, but also another key farm resource endowment, the ownership of a draft animal, which is used exclusively to substitute for farm power requirements in land preparation and the transportation of agricultural products, is also declining rapidly. Furthermore, although landlessness is on the rise, the number of agricultural labour households is decreasing, which potentially has implications for the size and operation of the hired labour market.

[Insert Table 1 here]

A host of supply side and demand side arguments exist to explain the persistence of land fragmentation. The supply side arguments treat land fragmentation as an exogenous imposition on farmers as a result of inheritance laws, population pressure and scarcity of land (McPherson, 1982, Bentley, 1987). The demand side explanations view land fragmentation as a positive choice by farmers in order to reduce risk from natural disasters (such as floods, droughts),

[2] "Small farmers with less than 1 ha of landholdings cannot fulfil their subsistence requirements through agriculture … " (Niroula and Thapa, 2005).

promote crop diversification, as well as to ease allocation of labour over cropping seasons (Fenoaltea, 1976; Ilbery, 1984, Tan, 2005).

Studies of the constraints imposed by land fragmentation on productivity and efficiency in agriculture are mixed and inconclusive. For example, Blaikie and Sadeque (2000) highlight that land fragmentation is becoming a critical constraint in increasing productivity in Nepal, India and other nearby regions. In contrast, farmers in the highly land fragmented regions of Malaysia and Philippines do not consider it as a problem in paddy farming (Hooi, 1978; Wong and Geronimo, 1983; cited in Niroula and Thapa, 2005). In case of China, Wu et al., (2005) conclude that land fragmentation does not have any significant impact on productivity, whereas Wan and Cheng (2001) conclude that land fragmentation reduces productivity. Similar contrasting arguments exist on the effects of land fragmentation on efficiency. For example, Schultz (1953) views land fragmentation as the misallocation of the existing stock of agricultural land, implying it as a source of inefficiency. Dovring and Dovring (1960) identify distance between parcels as the main source of inefficiency created by land fragmentation. Recent studies, Sherlund et al., (2002) and Tan (2005) conclude that the increase in the number of plots has a positive relation with technical efficiency in rice production in Cote d'Ivoire and China, whereas Parikh and Shah (1994) and Wadud and White (2000) report that land fragmentation reduces efficiency in rice production in Pakistan and Bangladesh, respectively.

Apart from land fragmentation, ownership of key production resources such as, land, draft animal power and family labour can also potentially impact efficiency. The main argument in favour of resource ownership is the timeliness of operation as well as control over the quality of the resource. For example, owner operators are likely to be more efficient than tenants or sharecroppers as they could hold on to the best quality of land while renting or leasing out relatively poorer quality land. And since control over land is high, the owner operator is able to conduct all required farming operations in a timely manner. There is a belief that farmers in developing countries overuse family labour and hence likely to be inefficient in production. However, a large pool of family labour may enable farmers to use labour on time particularly during the peak season when hired labour becomes relatively scarce (Dhungana et al., 2004). Similar arguments can be put forward for draft animal power ownership. First, the rental market for draft power is relatively smaller than the hired labour market and can result in acute shortages during the peak season for ploughing, particularly in Bangladesh. Second, ownership of draft power enables the farmer to plough and prepare the land at the right time. However, no single study has examined the influence of all these key resources jointly on efficiency. Only a few studies used any one of these resources, e.g., either tenurial status or family labour but none used ownership of draft animal power. Even then, the results are mixed. For example, Helfand and Levine (2004) concluded that tenants are more efficient than the sharecroppers and owners in Brazil, whereas Rahman (2003) concluded that owner operators are more efficient than tenants in Bangladesh. Tzouvelekas et al., (2001) note that family operated farms are relatively more inefficient than farms using hired labour in olive farming in Greece, whereas Dhungana et al., (2004) conclude that use of family labour is positively related with efficiency in rice farming in Nepal. On the other hand, Battese et al., (1996) conclude that both hired and family labour are equally efficient in wheat production in India.

Given this backdrop, the present study sets out to analyze explicitly the impact of land fragmentation on productivity as well as on technical efficiency in rice farming, using farm level survey data in Bangladesh. In addition, the study also analyzes the joint impact of the ownership of three key resources (land, family labour and draft animal power) on technical efficiency. The paper proceeds as follows: section 2 describes the analytical framework, the study area and the data; section 3 presents the results and discusses policy implications; and section 4 draws some conclusions.

2. Research Methodology

2.1 *Analytical framework*

Application of the stochastic production frontier framework is appropriate to analyze the impact of land fragmentation and resource ownership on productivity and efficiency. Three basic hypotheses are tested: (a) whether land fragmentation affects productivity; (b) whether land fragmentation affects production efficiency; and (c) whether resource ownership affects production efficiency. The impact of land fragmentation on productivity is captured by specifying 'number of plots farmed[3]' as an independent variable in the stochastic production frontier function. The impact of land fragmentation on efficiency is examined by placing the same in the 'inefficiency effects model' in addition to resource ownership variables and indicators representing other farm characteristics to explain the underlying causes of deviation from the frontier.

In the stochastic production frontier framework, the output (rice production) is treated as a stochastic production process and is defined as (Aigner et al., 1977):

$$Q_i = f(X_i; A).\exp(\varepsilon_i) \quad (1)$$

where X is the (NxJ) matrix of the inputs, Q is the ($Nx1$) vector of output, f(.) is the best practice production frontier, A is the technology parameter vector, and the i subscripts individual farm households, respectively.

The error term ε_i is composed of two components:

$$\varepsilon_i = v_i - u_i \quad (1a)$$

---

[3] The potential indicators to measure land fragmentation are: the number of plots, average plot size, average distance of plots to dwellings, and the Simpson index (Tan, 2005). Wadud and White (2000) used average plot size as the indicator. We have used 'number of plots' as the indicator of land fragmentation for two reasons: (a) to avoid collinearity between average plot size and total land under cultivation in the specified production function; and (b) to provide an explicit measure of the impact of an increase in the number of plots on productivity as well as on efficiency.

where the component v_is are assumed to be identically and independently distributed $N(0, \sigma_v^2)$ two sided random errors, independent of the u_is, representing random shocks, such as exogenous factors, measurement errors, omitted explanatory variables, and statistical noise. The u_is are non-negative random variables, associated with inefficiency in production, which are assumed to be independently distributed as truncations at 0 of the normal distribution with mean, $\mu_i = \delta_0 + \sum_d \delta_d W_{di}$ and variance $\sigma_u^2(| N(\mu_i, \sigma_u^2) |)$, where W_{di} is the dth explanatory variable associated with inefficiencies of farm i and δ_0 and δ_d are the unknown parameters.

The production efficiency of the farm i is defined as:

$$EFF_i = E[\exp(-u_i) | \varepsilon_i] \qquad (2)$$

where E is the expectation operator. This is achieved by obtaining the expressions for the conditional expectation u_i upon the observed value of ε_i. The method of maximum likelihood is used to estimate the unknown parameters, with the stochastic production frontier and the inefficiency effects functions estimated simultaneously. The likelihood function is expressed in terms of the variance parameters, $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$ (Battese and Coelli 1995).

2.2 The study area and sample of farmers

Primary data for the study pertains to a farm survey of rice producers conducted during early 2000 in the Barisal district located in the southern part of Bangladesh, which in turn is located 162 km away from the capital city, Dhaka. The district is composed of 10 *thanas* (subdistricts), 86 unions and 1,069 villages. Samples were collected from four villages in two subdistricts, *Hizla Thana* and *Muladi Thana*, respectively. A total of 298 farm households were selected following a multistage stratified random sampling procedure. Factors considered in stratification include degree of uncertainty (i.e., risk of flooding) at the subdistrict level, type and distance from the local market, transport and road facilities of the villages at the union level, and farm holding size and tenurial classes of the farmers at the village level, respectively (for details, see Rahman, 2004). Detailed input and output data were collected for the *Aman* (monsoon) season rice of the crop year 1999 because rice produced in this season provides the bulk of the foodgrain supplies in Bangladesh, and farmers largely produce local varieties of rice which is dependent on monsoon rain. In Barisal district, 69.5 percent of the total cultivated area is devoted to *Aman* rice production (BBS, 2000).

2.3 The empirical model

The production structure of rice farmers in Bangladesh is specified using a single output multiple input stochastic production frontier. The general form of the extended flexible translog stochastic production frontier for the i^{th} farm is defined as:

$$\ln Y_i = \alpha_0 + \sum_{j=1}^{6} \alpha_j \ln X_{ij} + \tfrac{1}{2} \sum_{j=1}^{6} \sum_{k=1}^{6} \beta_{jk} \ln X_{ijk} \ln X_{ijk} + \tau_m D_{im}$$
$$+ \phi_p \ln L_{ip} + \tfrac{1}{2} \sum_{p=1}^{1} \sum_{j=1}^{6} \varphi_{pj} \ln L_{ipj} + v_i - u_i \qquad (3)$$

and

$$u_i = \delta_0 + \sum_{d=1}^{8} \delta_d Z_{id} + \psi_q L_{iq} + \zeta_i^* \qquad (3a)$$

where the dependent variable *Y* is the aggregate of rice output produced (kg per farm) in the *Aman* season; *X's* are the inputs, *L* is the variable representing land fragmentation; and *D* is the dummy variable used to account for the zero values of input use[4]; *v* is the two sided random error and *u* is the one sided half normal error in eq. (3); and ln is the natural logarithm; *Zs* in eq. (3a) are the variables representing resource ownership as well as farm

[4] Inputs containing zero values for some observations are specified as $ln\ \{max\ (X_j, 1 - D_j)\}$ following Battese and Coelli, (1995). However, the interaction effects of these dummy variables in a translog framework are avoided in order to preserve degrees of freedom.

specific characteristics to explain inefficiency; L is the land fragmentation variable, ζ is the truncated random variable; $\alpha_k, \beta_0, \beta_j, \tau_m, \varphi_p, \psi_q, \delta_0,$ and δ_d are the parameters to be estimated.

A total of six production inputs (X) are used in the stochastic production frontier model and eight variables representing resource ownership and other socio-economic characteristics[5] of the farm (Z) are included in the inefficiency effects model as predictors of technical inefficiency. Table 2 presents the definitions, units of measurement, and summary statistics for all the variables.

[Insert Table 2 here]

3. Results

From the information provided in Table 2, we see that the average farm size is small (0.78 ha) and the average level of land fragmentation is 4.4 with a range from a single plot farm to a maximum of a 21 plot farm[6]. Only 27 percent of the farmers are owner operators, the number of working members in the family is 1.9 persons and the number of working animals is only 1.2. Seventy three percent of the farmers have some education[7] and 34 percent had extension contacts. Level of modern technology adoption is low, because only 33 percent of the farmers produced modern varieties of rice in addition to traditional varieties.

The Maximum Likelihood Estimation (MLE) procedure is used to estimate the parameters of the stochastic production frontier and inefficiency effect models jointly in a

---

[5] Choice of these variables (e.g., experience, education, non-agricultural work, extension contact, etc.) is based on existing literature (e.g., Coelli et al., 2002; Rahman, 2003; Wadud and White, 2000; Tzouvelekas, et al., 2001; Sherlund et al., 2002).

[6] The figures are slightly lower than the national averages presented in Table 1 but exactly match the data for the Barisal district as a whole (not shown), thereby, providing confidence in the representativeness of the selected households for this study.

[7] Barisal district as a whole is regarded as a relatively highly literate part of the country based on literacy rate

single stage[8] using STATA Version 8 (Stata Corp, 2003). Two versions of the model were estimated. In Model 1, the land fragmentation variable is included in the production function, and in Model 2 the same is included in the inefficiency effects function.

3.1 Productivity effects of land fragmentation

The second column of Table 3 presents MLE estimates of the extended translog stochastic production frontier which incorporates the land fragmentation variable including full interactions with production inputs in order to account for its total effect on productivity. A test of hypothesis on the choice of functional form (Cobb-Douglas vs. translog) confirms that the choice of translog production function is a better representation of the production structure for both models (Table 4).

All basic resource inputs except seed significantly influence rice production. The pesticide variable recorded some zero observations, and was therefore, corrected with dummy variables as mentioned in footnote 4. Contrary to expectation, labour seems to be the dominant factor followed by draft power services and fertilizers. Output elasticity of labour is estimated at 0.31 (0.33 in Model 2) indicating that a one percent increase in labour use will increase output by 0.31 percent[9] (Tables 3 or 5). Land fragmentation significantly reduces rice

---

information.

[8] The single-stage approach is considered superior to the conventionally used two-stage approach wherein the first stage involves estimation of the stochastic production frontier and the prediction of inefficiency effects under the assumption that these inefficiency effects are identically distributed with one-sided error terms. The second stage involves the specification of a regression model for predicted inefficiency effects, which contradicts the assumption of an identically distributed one-sided error term in the stochastic frontier (Battese and Coelli, 1995).

[9] All the resource input variables (including land fragmentation) were mean-differenced prior to estimation. Therefore, the coefficients on the first order term can be read directly as elasticities. Nevertheless, the figures are reproduced in Table 5 for ease of exposition.

output as expected[10]. The test of null hypothesis that the effect of land fragmentation on productivity (including its input interactions) is jointly zero is strongly rejected at 1 percent level of significance (Table 4). The output elasticity of land fragmentation with respect to productivity is estimated at -0.05, implying that for a one percent increase in the number of plots, output is reduced by 0.05 percent. Increasing returns to scale prevails in rice production in Bangladesh (Tables 3 and 5). The null hypothesis of constant returns to scale is rejected in favour of increasing returns to scale for both models (Table 4).

[Insert Tables 3, 4 and 5 here]

3.2 Efficiency effects of land fragmentation and ownership of resources

Given the robust detrimental effects of land fragmentation on rice productivity, we next investigate its influence on technical efficiency. We also investigate the joint influence of the ownership of key resources (land, family labour and draft animal power) on technical efficiency. Prior to the discussion of these effects, we briefly highlight the farm specific efficiency scores presented in Table 6. The mean efficiency level is estimated at 91 percent (92 percent in Model 2) indicating that rice production can be increased by 9 [(100-91)/91] percent by improving technical efficiency alone with no additional use of resources. The minimum efficiency level is 62 percent (63 percent in Model 2) while the maximum is 99 percent. The estimates are slightly higher than those reported by Rahman (2003), Coelli et al., (2002), and Wadud and White (2000) on Bangladeshi rice production.

[Insert Table 6 here]

Among the nine variables selected to explain technical inefficiency, the coefficients on the seven of them were significantly different from zero at 1 percent level with consistent expected signs (lower panel of Table 3, column 4). The null hypotheses with regard to the existence of inefficiency and validity of the specified predictors of inefficiency were tested

[10] We have allowed full interaction of the land fragmentation variable with all the production inputs.

and rejected at the 5 percent level of significance for both specifications (Table 4).

The detrimental impact of land fragmentation on technical efficiency in rice farming is high as expected. The elasticity[11] estimate reveals that a one percent increase in the number of parcels reduces technical efficiency by 0.03 percent (Table 5). Ownership of key resources, i.e., land, family labour and draft animal power, seem to have a significant influence in increasing efficiency. The null hypothesis of 'no influence of resource ownership on efficiency' was tested and strongly rejected at the 5 percent level of significance at least for both specifications. Owner operators, in other words, land owners perform significantly better than tenants or part tenants. The elasticity estimate reveals that a one percent increase in the proportion of owner operators will increase efficiency by 0.01 percent (Table 5). The reason may lie with the quality of land. In general, tenants receive less than an ideal type of land from the landlords to farm, which may lead to lower efficiency. Farm households with higher numbers of family labour operate at a higher level of efficiency. The elasticity estimate reveals that a one percent increase in the number of family labourers will increase efficiency by 0.05 percent (Table 5). The implication is that the substitution of family farm workers with hired labour does affect rice production efficiency. This may be due to the unavailability of hired labour services at peak periods, particularly in rice growing regions. A similar effect is evident with respect to the ownership of draft animals. The elasticity estimate reveals that a one percent increase in the number of owned draft animal power will increase efficiency by 0.03 percent (Table 5). This may again be due to unavailability of hired animal power

[11] The coefficients in the inefficiency effects model show only the direction of influence but do not provide information on the magnitude of influence. We computed technical efficiency elasticities for these predictors by adopting the framework of Frame and Coelli (2001). As a result, we are able to provide a specific measure of responsiveness of each predictor on technical efficiency, which is not commonly seen in the existing literature (for details see Appendix A).

services at the right time, particularly during peak planting season.

Among the farmers' socio-economic characteristics, education does not seem to have a significant role in improving efficiency. The influence of extension contact is significant, as expected in a country like Bangladesh where extension service is nascent. Opportunities for off farm work, and hence access to non-agricultural income reduces technical efficiency, as expected. Adoption of modern rice technology significantly improves efficiency. The elasticity estimate reveals that a one percent increase in the proportion of modern rice adoption will increase efficiency by 0.04 percent (Table 5).

3.3 Policy Implications

The results of this study clearly reveal that productivity and efficiency are adversely affected by land fragmentation in Bangladesh, a key institutional factor that has the potential to be redressed through appropriate policy instruments. In fact, its detrimental impact on productivity and efficiency is higher than compared to other constraints that the farmers face. The access to extension services is also a significant constraint, yet another important institutional factor equally amenable to policy adjustments. Most importantly, ownership of key resource endowments (i.e., land, family labour and draft animal power) is another major factor. The elasticity estimate reveals that the combined effect of a one percent increase in the ownership of these resources can improve technical efficiency by 0.08 percent, and hence deserve proper attention.

Land fragmentation is not only accelerating the pace of degradation and constraining agricultural development, but also discourages farmers from adopting agricultural innovations (Niroula and Thapa, 2005). Although the Green Revolution has been vigorously promoted in Bangladesh over the past four decades, there are significant regional variations in adoption levels. Only a third of the sample farmers cultivated modern rice in addition to traditional rice varieties, although we have demonstrated the positive impact of modern technology adoption on efficiency (Table 3). Land fragmentation may partly be responsible for the slow and uneven diffusion of modern technology in Bangladesh. Khan (2004) rightly points out that increasing fragmentation of land in Bangladesh is a cause of worry rather than an indication of a well-functioning land market as the World Bank claims. The general implication of a liberalised land market is that it could enable landowners to consolidate their plots by selling land further away from home and purchasing land closer to home and/or existing plots. In this way, the farmer could mitigate the constraints imposed by a wide scatter of plots to some extent.

Land consolidation measures aimed at preventing land fragmentation have been largely unsuccessful in South Asia for several reasons, including demographic, economic and cultural factors (Niroula and Thapa, 2005). For example, the consistently declining land person ratio over time shows the importance of demographic pressure in Bangladesh (Table 1). Presence of this demographic pressure together with inheritance laws, which divide land equally amongst all brothers and half of brothers' share to sisters (occasionally), provides a powerful tendency towards increasing land fragmentation (Khan, 2004). Historically, land is seen as the ultimate source of wealth in rural Bangladesh. Farmers tend to hold onto even a tiny parcel of land, which may still provide subsistence support for few crucial months in a year. The redistributive land reform policies undertaken in Bangladesh, such as setting a ceiling on land ownership of a maximum of 11 ha per farmer, has been largely unsuccessful. This is because dividing the land between members of a household circumvents the problem easily, and enables the household to retain the total land holding which usually exceeds the maximum limit of 11 ha. Also, redistribution of land (including those reclaimed from rising *Char* lands in coastal areas) to a landless population had little impact. This is because of the mismatch between the numbers of eligible members versus the total area reclaimed, thereby, resulting in the redistribution of small parcels of land to a small number of households.

Furthermore, such programmes only add to vested political popularity rather than address the issue of landlessness per se. On the other hand, rural development programmes aimed at land consolidation via forming cooperatives also failed largely due to the power wielding of the landed elites. These elites often turn out to be the landlords, village leaders, as well as key players in the management of these cooperatives, thereby, resulting in poor participation of small holder farmers.

Therefore, the main policy thrust should be aimed at addressing the structural causes underlying the process of land fragmentation. These include among others, the law of inheritance and the political economy of the agrarian sector in Bangladesh. The latter conventionally favours accumulation of land by vested individuals and groups with factional connections up to the top end of the national political hierarchy. With respect to the law of inheritance, modifications are required to implement measures that would discourage splitting land into tiny parcels amongst heirs.

Our reservation about the success of the radically redistributive land reform suggested by Griffin et al., (2002) is largely based on two considerations plus a review of past performance discussed above. First, is the technical and economic limitation, and second, is the political economy of the agrarian structure in Bangladesh. Griffin et al., (2002) made a strong theoretical case for truly radical land reform aimed at transferring land from large landowners to small owner operated holdings to improve productivity and efficiency. Their argument is based on the classic premise of inverse size-productivity relationship, which has now been weakened to some extent (Toufique, 2001; Ram et al., 1999; Wattanutchariya and Jitsanguan, 1992) However, even such ideal compulsory redistribution (probably impossible to implement) would leave each landless household with only 0.21 ha of land, which is unviable as a livelihood resource. Khan (2004) concludes that strategies of institutional (land) reform that focus only on technocratic issues (as above) will not work unless the political nature of the problem in specific countries (e.g., Bangladesh) is addressed in some way. He further stresses that without addressing the political economic forces at work, no amount of loans from the World Bank to carry out institutional reforms would have any discernible effect on the big picture, with which we clearly agree. Hence, it is imperative that an array of wide ranging cross-sectoral policies is devised to address this complex issue of land fragmentation instead of concentrating only on narrowly defined land reform measures.

The other sensible approach would be to undertake massive rural infrastructural development aimed at promoting non-farm employment and income generating opportunities. This would divert people away from the already overcrowded agricultural sector, thereby, releasing pressure on land, and hence, the process of land fragmentation. Tan (2005) provides evidence that the presence of land rental markets and off farm employment reduces land fragmentation by 2 and 15 percent respectively in China. Wu et al., (2005) conclude that farm productivity under a comprehensive agricultural development[12] (CAD) programme added 1.5 percent to household productivity in China.

The argument in favour of enhancing agricultural extension services is straight forward. Injection of resources is required to improve the physical and infrastructural facilities of the agricultural extension system as a whole. Not only investment is necessary, but also the core of the discipline requires all round improvement to make it attractive, remunerative and effective as compared to its peer workforce, e.g., members of Thana civil administration or health and other service sectors. The present level of coverage by each block supervisor (the lowest administrative level for agricultural extension) is in the region of 650 farmers to 1 with a spread of at least 50-70 sq km, which clearly indicates the difficulty

[12] CAD, launched in 1988, is a land development programme aimed at inducing investment by farm households, cooperatives and the state to improve the infrastructure of farming, particularly, quality of land (Wu et al., 2005).

of rendering effective support to all eligible farmers[13]. Few large non-governmental organizations (NGOs), such as BRAC, PROSHIKA, UBINIG, etc., provide supplementary agricultural extension support, which is largely confined to vegetable production and kitchen gardening, targeted exclusively at their clientele of women from landless households, and hence limited in scope and content.

The other important area of intervention is in the livestock sector which needs revitalization as it has a direct impact on farming efficiency. The draft animal is the most important source of farm power in Bangladesh, although the livestock sector is in total neglect from a policy perspective. The market for draft power transaction is highly fragmented as well. Landlords and tenants share draft animal power costs instead of the commonly practiced sharing of fertilizer and irrigation costs in areas of draft power shortage because of its high rental rates (Rahman, 1998).

We also see that the use of family labour improves technical efficiency significantly. The implication is that households with large pool of family labour are perhaps able to use labour at the right time, particularly during peak periods. Reduction of agricultural labour households between the census periods (Table 1) indicates tightening of the hired labour market, at least during peak planting and harvesting times. Such a situation points towards a combination of policies aimed at promoting labour saving technologies as well as the smooth functioning of the hired labour market.

4. Conclusions

The present study analyzes the impact of land fragmentation on productivity and efficiency in rice production in Bangladesh. The study also examines the influence of the ownership of key

[13] The Department of Agricultural Extension has a total of 23,954 employees including 460 Upazila Agricultural Officers, 963 Agricultural Extension Officers, and 18,338 Class III employees who are predominantly the block supervisors (DAE, undated).

resource endowments on technical efficiency, which is not commonly explored in the literature. Results demonstrate that land fragmentation is an influential predictor of technical inefficiency and loss of productivity. Ownership of resource endowments (land, family farm labour and draft animal) significantly increases technical efficiency, indicating that the substitution of family labour and owned draft animal with hired labour and animal power services has a detrimental effect on efficiency. Access to extension services as well as adoption of modern rice technology significantly improves efficiency, as expected. Off farm work, on the other hand, reduces efficiency, as expected.

The policy implications are clear. First, policies geared towards addressing the structural causes of land fragmentation are vital. These include, modification of the law of inheritance, regulations to prevent land fragmentation, rural infrastructural development and the promotion of non-farm income and employment opportunities in order to release pressure on the land, and hence retard the process of land fragmentation. Second, policies that positively encourage building up of physical resources, e.g., the draft animal, by developing the livestock sector as a whole. Third, the improvement of extension services which has been consistently highlighted in the literature as well. The key is to have an effective mechanism in place to reap the benefits of extension services which remains elusive in many developing countries. And fourth, is to increase the adoption of modern rice technology. However, this would require concerted effort not only to develop new varieties suited for varied and/or rainfed conditions, but also to effectively disseminate them to farmers. Although a total of 38 rice varieties have been produced by the Bangladesh Rice Research Institute during 1970–1999, only a few are widely available at farm level. As Ahmed (2001: 70) points out, “mere availability at research stations does not guarantee that farmers will be able to make use of it. The delivery of this technology to farmers is the crux of the problem in increasing rice production”, which will remain a formidable challenge for policy makers.

References

Ahmed, R. 2001. *Retrospects and Prospects of the Rice Economy of Bangladesh*. The University Press Limited, Dhaka, Bangladesh.

Aigner, D.J., Lovell, C.A.K., Schmidt, P. 1977. Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6: 21 – 37.

Battese, G.E., Coelli, T.J. 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20, 325-332.

Battese, G.E., Malik, S.J., Gill, M.A. 1996. An investigation of technical inefficiencies of production of wheat farmers in four districts of Pakistan. *Journal of Agricultural Economics*, 47: 37-49.

BBS, 1981. *Statistical Yearbook of Bangladesh 1980*. Bangladesh Bureau of Statistics, Dhaka. Bangladesh.

BBS, 1986. *The Bangladesh Census of Agriculture and Livestock: 1983-84, Volume 1*. Bangladesh Bureau of Statistics, Dhaka. Bangladesh.

BBS, 1999. *Census of Agriculture, 1996: Structure of Agricultural Holdings and Livestock Population, National Series, Volume 1*. Bangladesh Bureau of Statistics, Dhaka. Bangladesh.

BBS, 1999a. *Census of Agriculture, 1996: Agricultural Sample Survey, National Series, Volume 2*. Bangladesh Bureau of Statistics, Dhaka. Bangladesh.

BBS, 2000. *Statistical Yearbook of Bangladesh 1999*. Bangladesh Bureau of Statistics, Dhaka. Bangladesh.

Bentley, J. 1987. Economic and ecological approaches to land fragmentation: in defence of a much-aligned phenomenon. *Annual Review of Anthropology*, 16: 31-67.

Blaikie, P.M., Sadeque, S.Z., 2000. *Policy in the High Himalayas: Environment and Development in the Himalayan region*. ICIMOD, Kathmandu.

Coelli, T., Rahman, S., Thirtle, C., 2002. Technical, allocative, cost and scale efficiencies in Bangladesh rice cultivation: a non-parametric approach. *Journal of Agricultural Economics*, 53: 607 – 626.

DAE, undated. Department of Agricultural Extension, Ministry of Agriculture, Dhaka, Bangladesh. http://www.bangladeshgov.org/moa/dae/dae.htm#10.

Dhungana, B.R., Nuthall, P.L., Nartea, G.V. 2004. Measuring the economic efficiencies of Nepalese rice farms using Data Envelopment Analyses. *The Australian Journal of Agricultural and Resource Economics*, 48: 347-369.

Dovring, F., Dovring, K. 1960. *Land and labour in Europe in 1900-1950*. The Hague: Martinus Nyhoff.

FAO, 2001. *Supplements to the Report on the 1990 World Census of Agriculture. Statistical Department Series (9a)*. Food and Agriculture Organisation, Rome. http://www.fao.org/es/ess/census/wcahome.htm

Fenoaltea, S. 1976. Risk, transaction cost and the origin of medieval agriculture. *Exploration in Economic History*, 13: 129-151.

Frame, W.S., Coelli, T.J. 2001. U.S. Financial services consolidation: the case of corporate credit unions. *Review of Industrial Organisation*, 18: 229-242.

Griffin, K., Khan, A.R., Ickowitz, A. 2002. Poverty and the distribution of land. *Journal of Agrarian Change*, 2: 279-330.

Husain, A.M.M., Hossain, M., Janaiah, A. 2001. *Hybrid rice adoption in Bangladesh: socio-economic assessment of farmers' experiences*. BRAC Research Monograph Series No. 18. BRAC, Bangladesh, Dhaka.

Ilbery, B.W. 1984. Farm fragmentation in the Vale of Evesham. *Area*, 16: 159-165.

Khan, M.H. 2004. Power, property rights and the issue of land reform: a general case illustrated with reference to Bangladesh. *Journal of Agrarian Change*, 4: 73–106.

Kodde, D., Palm, F., 1986. Wald criteria for jointly testing equality and inequality restrictions. *Econometrica* 54: 1243-1248.

McPherson, M.F. 1982. *Land fragmentation: a selected literature review*. Development Discussion Paper No. 141. Harvard Institute for International Development, Harvard University.

Niroula, G.S., Thapa, G.B. 2005. Impacts and causes of land fragmentation, and lessons learned from land consolidation in South Asia. *Land Use Policy*, 22: 358-372.

Parikh, A., Shah, K. 1994. Measurement of technical efficiency in the North-West frontier province of Pakistan. *Journal of Agricultural Economics*, 45: 132-138.

Rahman, M. 2004. The application of frontier approaches to model the efficiency of rice producers in Bangladesh. Unpublished Ph.D. thesis. Imperial College London at Wye, Kent, UK.

Rahman, S. 1998. Socio-economic and environmental impacts of technological change in Bangladesh agriculture. Unpublished Ph.D. thesis. Asian Institute of Technology, Bangkok, Thailand.

Rahman, S. 2003. Profit efficiency among Bangladeshi rice farmers. *Food Policy*, 28: 487 – 503.

Ram, K.A., Tsunekawa, A., Sahad, D.K., Miyazaki, T. 1999. Subdivision and fragmentation of land holdings and their implication in desertification in the Thar Desert, India. *Journal of Arid Environments*, 41: 463-477.

Schultz, T. W. 1953. *The Economic Organization of Agriculture.* New York: McGraw Hill.

Sherlund, S.M., Barrett, C.B., Adesina, A.A. 2002. Smallholder technical efficiency controlling for environmental production conditions. *Journal of Development Economics*, 69: 85 – 101.

STATA Corp, 2003. *STATA Version 8*. Stata Press Publications, College Station, Texas, USA.

Tan, S. 2005. Land fragmentation and rice production: a case study of small farms in Jiangxi Province, China. Ph.D. thesis. Wageningen University.

Toufique, K.A. 2001. *Structural constraint to agricultural growth: an explanation of the farm size productivity relationship in Bangladesh*. Working Paper. Bangladesh Institute of Development Studies, Dhaka.

Tzouvelekas, V., Pantzios, C.J., Fotopoulos, C. 2001. Technical efficiency of alternative farming systems: the case of Greek organic and conventional olive growing farms. *Food Policy*, 26: 549-569.

Wadud, M. White, B. 2000. Farm household efficiency in Bangladesh: a comparison of stochastic frontier and DEA methods. *Applied Economics*, 32: 1665-1673.

Wan, G., Cheng, E. 2001. Effects of land fragmentation and returns to scale in the Chinese farming sector. *Applied Economics*, 33: 183-194.

Wattanutchariya, S. Jitsanguan, T. 1992. Increasing the scale of small-farm operations in Thailand. Food & Fertilizer Technology Centre http://www.fftc.agnet.org/library/article/eb344a.html

Wu, Z., Liu, M., Davis, J. 2005. Land consolidation and productivity in Chinese household crop production. *China Economic Review*, 16: 28-49.

Helfand, S.M., Levine, E.S., 2004. Farm size and determinants of productive efficiency in Brazilian Centre-West. *Agricultural Economics*, 31: 241-249.

Appendix A

Derivation of marginal effects and elasticity of technical efficiency[14]

The predicted technical efficiency using the conditional expectation for the i^{th} firm is:

$$
\begin{aligned}
TE_i &= E[\exp(-u_i) \mid \varepsilon_i) = e_i \\
&= \left\{ \frac{1-\Phi(\sigma_* - \mu_{*_i}/\sigma_*)}{1-\Phi(-\mu_{*_i}/\sigma_*)} \right\} \exp(-\mu_{*_i} + \tfrac{1}{2}\sigma_*^2) \\
&= (B/C)A \\
&= AD
\end{aligned}
$$

where

$$\mu_* = (1-\gamma)z_i\delta - \gamma e_i,$$

$$\sigma_*^2 = \gamma(1-\gamma)\sigma_s^2,$$

$$A = \{\exp(-\mu_{*_i} + \tfrac{1}{2}\sigma_*^2)\}$$

$$B = \{1-\Phi(\sigma_* - \mu_{*_i}/\sigma_*)\}$$

$$C = \{1-\Phi(-\mu_{*_i}/\sigma_*)\}$$

$$D = \left\{ \frac{1-\Phi(\sigma_* - \mu_{*_i}/\sigma_*)}{1-\Phi(-\mu_{*_i}/\sigma_*)} \right\}$$

we wish to obtain the partial derivative of the technical efficiency measure with respect to the j^{th} element of the z vector. Use of chain rule we have:[15]

$$\frac{\partial TE}{\partial z_j} = \frac{\partial TE}{\partial \mu_*} * \frac{\partial \mu_*}{\partial z_j} \qquad (a1)$$

Furthermore, we have:

---

[14] The derivation strategy essentially follows from Frame and Coelli (2001). However, the details of formula used in the derivation are slightly different due to the definition of technical efficiency used in the STATA software.

[15] The i^{th} subscript is dropped from this point forward for the ease of exposition.

$$\frac{\partial \mu_*}{\partial z_j} = (1-\gamma)\delta_j \qquad (a2)$$

$$\frac{\partial A}{\partial \mu_*} = -A = A'$$

$$\frac{\partial B}{\partial \mu_*} = \frac{1}{\sigma_*}\{1-\phi(\sigma_* - \mu_{*_i}/\sigma_*)\} = B'$$

$$\frac{\partial C}{\partial \mu_*} = \frac{1}{\sigma_*}\{1-\phi(-\mu_{*_i}/\sigma_*)\} = C'$$

and

$$\frac{\partial D}{\partial \mu_*} = \frac{CB'-BC'}{C^2} = D'$$

Using these results, we obtain:

$$\begin{aligned}\frac{\partial TE}{\partial \mu_*} &= AD'+DA' = A(D'-D)\\ &= A\left\{\left[\frac{CB'-BC'}{C^2}\right]-\frac{B}{C}\right\}\\ &= \frac{A}{C^2}(CB'-BC'-CB)\end{aligned}$$

Thus, using this result and equations (a1) and (a2) we obtain the marginal effect of technical efficiency of the i^{th} firm with respect to j^{th} z vector as:

$$\frac{\partial TE_i}{\partial z_{ij}} = \frac{A}{C^2}(CB'-BC'-CB)(1-\gamma)\delta_j \qquad (a3)$$

and the elasticity of technical efficiency of the i^{th} firm with respect to j^{th} z vector as:

$$\eta TE_{ij} = \frac{\partial TE_i}{\partial z_{ij}}\frac{z_{ij}}{\overline{TE}_i} \qquad (a4)$$

Table 1. Farm dynamics and land fragmentation in Bangladesh.

Variables	1977 Census	1983-84 Census	1996 Census
Farm holdings, operation size, draft animal ownership and labour			
Number of farm holdings (‘000)	6,257.00	10,045.30	11,798.24
Percentage of small farms (0.02 – 1.01 ha)	49.72	70.34	79.87
Percentage of medium farms (1.01 – 3.03 ha)	40.85	24.72	17.61
Percentage of large farms (above 3.03 ha)	9.40	4.94	2.52
Absolute landless households as percent of total holdings (farm + non-farm)	--	8.67	10.18
Average farm size (ha)	1.42	0.93	0.68
Per capita net cultivated area (ha)	0.11	0.10	0.06
Draft animal per holding (number)	--	1.60	1.25
Draft animal per capita (number)	0.28	0.26	0.18
Agricultural labour households (% of farm holdings)	--	31.06	25.60
Number of persons engaged in agricultural work (as self-employed and family helper) per holding (farm + non-farm)			
All holdings (number)	--	--	1.63
Owner holdings (number)	--	--	1.54
Owner-cum-tenant holdings (number)	--	--	2.24
Tenant holdings (number)	--	--	0.82
Changes between inter-census periods (%)			
Number of farm-holdings	--	60.54	17.45
Number of small farms (0.02 – 1.01 ha)	--	127.13	33.35
Number of medium farms (1.01 – 3.03 ha)	--	-2.85	-16.33
Number of large farms (above 3.03 ha)	--	-15.91	-40.00
Number of absolute landless households	--	--	51.47
Average farm size	--	-34.51	-26.88
Per capita net cultivated area	-29.73	-3.85	-44.00
Draft animal per holding	--	--	-21.88
Draft animal per capita	--	-7.14	-30.77
Agricultural labour households	--	--	-3.19
Land fragmentation			

Average fragments per farm holding (number)	9.6	--	6.0
Small farms	5.9	--	4.5
Medium farms	11.5	--	10.9
Large farms	20.4	--	17.4
Average size of fragments (ha)	0.16	--	0.12
Small farms	0.08	--	0.08
Medium farms	0.16	--	0.16
Large farms	0.24	--	0.28

Source: Computed from BBS, (1981, 1986, 1999, and 1999a).

Table 2. Definition, measurement and summary statistics of variables

Variables	Measure	Mean	Standard deviation	Minimum	Maximum
Inputs and output					
Rice output	Kg per farm	2168.58	1260.09	320.00	6680.00
Land cultivated	Hectare	0.79	0.42	0.16	2.33
Fertilizers	Kg of active nutrients (N, P, and K) per farm	46.29	31.56	4.59	214.09
Labour	Persons-days per farm	86.68	48.21	16.45	255.21
Draft power	Animal pair-days per farm	23.31	12.71	3.24	72.04
Seed	Kg per farm	39.53	21.76	7.48	129.10
Pesticides	Mg/ml of active ingredients per farm	3.47	4.38	0.00	25.92
Cow dung	Kg per farm	298.78	412.23	0.00	2631.88
Cow dung users	Dummy (1 = Used cow dung, 0 = No)	0.50	0.50	0.00	1.00
Pesticide users	Dummy (1 = Used weedicides, 0 = No)	0.56	0.50	0.00	1.00
Technical inefficiency predictors					
Age experience ratio	Number	14.93	7.51	5.80	60.00
Education of the farmer	Dummy (1 = have some education, 0 = No)	0.73	0.44	0.00	1.00
Number of working members in the household	Number	1.91	0.93	1.00	5.00
Number of working animal in the households	Number	1.23	1.86	0.00	11.76
Off-farm working hours	Hours per month	59.13	73.75	0.00	240.00
Extension contact	Dummy (1 = if had contact in the past year, 0 = No)	0.34	0.47	0.00	1.00
Tenurial status	Dummy (1 = if owner operator, 0 = No)	0.27	0.44	0.00	1.00
Cultivated modern variety	Dummy (1 = if also produced modern rice varieties, 0 = No)	0.33	0.47	0.00	1.00
Land fragmentation	Number of plots farmed	4.44	2.97	1.00	21.00
Total number of observations		298			

Table 3. Average production function and stochastic production frontier estimates of rice production.

Variables	Stochastic frontier model 1		Stochastic frontier model 2	
	Coefficient	t-ratio	Coefficient	t-ratio
Production function				
Constant	7.6639	341.61***	7.6770	357.59***
ln Land	0.2083	2.81***	0.1611	2.14**
ln Labour	0.3138	6.53***	0.3306	6.81***
ln Fertilizer nutrients	0.2513	13.92***	0.2403	13.57***
ln Animal power	0.2061	3.99***	0.2300	4.41***
ln Seed	0.0235	0.57	0.0212	0.5
ln Pesticides	0.0654	5.94***	0.0709	6.28***
ln $(Land)^2$	1.8901	1.38	2.3519	1.70*
ln $(Labour)^2$	0.0310	0.06	0.1665	0.33
ln $(Fertilizer)^2$	-0.0114	-0.16	-0.0095	-0.13
ln $(Animal\ power)^2$	-0.6207	-1.31	-0.5830	-1.24
ln $(Seed)^2$	0.0525	0.15	0.1067	0.28
ln $(Pesticides)^2$	-0.0314	-1.84	-0.0393	-2.26**
ln Land x ln Labour	-1.0113	-0.82	-1.6056	-1.3
ln Land x ln Fertilizer	-0.7449	-1.55	-0.4784	-1.01
ln Land x ln Animal power	-1.4590	-1.11	-1.7854	-1.32
ln Land x ln Seed	-0.4216	-0.32	-0.6722	-0.51
ln Land x ln Pesticides	0.1265	0.79	0.1114	0.69
ln Labour x ln Fertilizer	0.0845	0.29	0.1186	0.4
ln Labour x ln Animal power	1.3599	1.47	1.4358	1.57
ln Labour x ln Seed	-0.0943	-0.12	-0.2122	-0.26
ln Labour x ln Pesticides	0.1216	1.18	0.0809	0.78
ln Fertilizer x ln Animal power	0.5925	1.78*	0.5112	1.52
ln Fertilizer x ln Seed	-0.1437	-0.48	-0.2240	-0.72
ln Fertilizer x ln Pesticides	0.0535	1.48	0.0531	1.45
ln Animal power x ln Seed	0.5496	0.63	0.9358	1.05
ln Animal power x ln Pesticides	-0.3276	-3.15***	-0.3234	-3.01***

ln Seed x ln Pesticides	-0.0146	-0.15	0.0164	0.17
Pesticide users	-0.0900	-5.07***	-0.0927	-5.09***
Land fragmentation and its interactions				
ln Land fragmentation	-0.0450	-3.52***	--	--
ln (Land fragmentation)^2	-0.0003	-0.01	--	--
ln Land fragmentation x ln Land	-0.0405	-0.12	--	--
ln Land fragmentation x ln Labour	-0.3544	-2.05**	--	--
ln Land fragmentation x ln Fertilizer	0.1436	2.33**	--	--
ln Land fragmentation x ln Animal power	0.2515	0.99	--	--
ln Land fragmentation x ln Seed	-0.0064	-0.03	--	--
ln Land fragmentation x ln Pesticides	-0.0291	-1.36	--	--
Model diagnostics				
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.013	3.34***	0.012	4.52***
$\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$	0.77	8.48***	0.73	7.52***
Log likelihood	325.32	--	316.32	--
Technical inefficiency predictors				
Constant	0.2107	4.42***	0.1576	3.26***
Age-experience ratio of the farmer	-0.0001	-0.07	0.0007	0.56
Education of the farmer	-0.0225	-0.81	-0.0290	-1.18
Number of working members in the HH	-0.0474	-2.02**	-0.0365	-2.22**
Number of working animal in the HH	-0.0416	-2.23**	-0.0364	-2.81***
Off-farm working hours	0.0003	1.64*	0.0003	1.80*
Extension contact	-0.0749	-1.44	-0.0704	-1.87*
Tenurial status	-0.1038	-1.74*	-0.0612	-1.72*
Cultivated modern variety	-0.1721	-2.67***	-0.1819	-3.53***
Land fragmentation			0.0130	2.87***
Total number of observations	298		298	

Note: All the resource input variables were mean-differenced prior to estimation and therefore the coefficients on the first order term can be read directly as elasticities (see also footnote # 9).
*** significant at 1 percent level (p<0.01)
** significant at 5 percent level (p<0.05)
* significant at 10 percent level (p<0.10).

Table 4. Hypothesis tests

Null Hypothesis	Stochastic frontier model 1	Stochastic frontier model 2
Choice of functional form – Cobb-Douglas vs. Translog Model (H_0: $\beta_{jk} = 0$ for all jk)		
Likelihood Ratio test statistic (χ^2)	54.52	19.63
Degrees of freedom	28	21
p-value (Prob > χ^2)	0.002	0.020
Decision	Reject	Reject
Production structure exhibits constant returns to scale (H_0: $\Sigma\alpha_j = 1$ for all j)		
Likelihood Ratio test statistic (χ^2)	15.80	13.16
Degrees of freedom	1	1
p-value (Prob > χ^2)	0.000	0.000
Decision	Reject	Reject
No effect of land fragmentation on productivity (H_0: $\varphi_{pj} = 0$ for all pj)		
Likelihood Ratio test statistic (χ^2)	27.41	--
Degrees of freedom	8	--
p-value (Prob > χ^2)	0.000	--
Decision	Reject	--
No inefficiencies present in the model[a] (H_0: $\mu = \gamma = 0$)		
Likelihood Ratio test statistic (χ^2)	325.32	316.32
Degrees of freedom	3	3
p-value (Prob > χ^2)	0.000	0.000
Decision	Reject	Reject
No inefficiency effects (H_0: $\delta_d = 0$ for all d)		
Likelihood Ratio test statistic (χ^2)	15.67	19.63
Degrees of freedom	8	9
p-value (Prob > χ^2)	0.049	0.020
Decision	Reject	Reject
Efficiency effects of all owned resources are jointly		

zero (H_0: $\delta_3 = \delta_4 = \delta_7 = 0$)		
Likelihood Ratio test statistic (χ^2)	7.43	12.88
Degrees of freedom	3	3
p-value (Prob > χ^2)	0.054	0.005
Decision	Reject	Reject

Note: [a] = Since the test involves testing of γ parameter, it has a mixed χ^2 distribution. The mixed $\chi^2_{3,0.95} = 7.05$ and is taken from Table 1 (Kodde and Palm, 1986).

Table 5. Production and efficiency elasticities.

Variables	Stochastic frontier model 1	Stochastic frontier model 2
Production elasticities		
Land	0.2083***	0.1611**
Labour	0.3138***	0.3306***
Fertilizer nutrients	0.2513***	0.2403***
Animal power	0.2061***	0.2300***
Seed	0.0235	0.0212
Pesticides	0.0654***	0.0709***
Returns to scale in rice production	1.0030	1.0540
Land fragmentation	-0.0450***	--
Efficiency elasticities[a]		
Experience	0.0007	-0.0060
Education	0.0086	0.0124
Family labour (Owned working labour)	0.0478**	0.0410**
Owned working animal	0.0271**	0.0264***
Owned land (Tenurial status)	0.0144*	0.0094*
Off-farm work	-0.0094*	-0.0092*
Extension	0.0132	0.0138*
Modern technology	0.0304***	0.0360***
Land fragmentation	--	-0.0330***

Note: Likelihood Ratio (LR) test failed to reject the null hypothesis of Constant Returns to Scale in rice production in both the models (see Table 4).
[a] = based on the formulation presented in Appendix A.
*** significant at 1 percent level (p<0.01)
** significant at 5 percent level (p<0.05)
* significant at 10 percent level (p<0.10).

Table 6. Technical efficiency in rice production.

Variables	Stochastic frontier model 1	Stochastic frontier model 2
Efficiency levels		
Up to 70 percent	0.34	0.34
71 – 80 percent	5.70	8.72
81 – 90 percent	24.16	28.52
90 and above	69.80	62.42
Mean efficiency level	0.923	0.908
Standard deviation	0.062	0.068
Minimum	0.622	0.629
Maximum	0.990	0.990
Number of observations	298	298