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A Model to Measure Achieved Levels of Technical Efficiency of African Farmers

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Abstract

This paper uses a stochastic frontier production function to estimate parameters for the efficient allocation of resources in agriculture. Using data gathered by US AID on small-scale agricultural production in Jamaica, we provide a framework that can be used to assess alternative input choices by African agricultural producers and public policymakers. Use of the stochastic frontier production function permits a decomposition of the degree of technical inefficiency from random errors. As with comparable studies, we find that farmer participation in any agricultural development project must be built into project design at the outset if new technologies are to be successful.

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Prologue

Sub-Saharan Africa is the world's poorest region. Twenty-five of the thirty-five countries have per capita annual incomes of under $400; life-expectancy averages forty-nine years and daily caloric intake is stuck at around 90 percent of the minimum recommended levels. In the first decade of independence (1965-1975), average annual economic growth rates regularly outperformed the rest of the world. The last 12 years have seen major setbacks. The promise of self-sustaining growth carries less hope of realization today. As evidence consider the following: agricultural.and industrial production have faltered; the threat of famine is today more real; physical infrastructure has deteriorated; the continent is toiling under insupportable debt; Africa's share of the world market for a variety of goods has shrunk.

Given the overwhelming importance of agriculture to countries at this stage of development, a realistic agenda for recovery must include a painstaking identification of the biases impeding the success of small to medium scale farming. Many of these biases result from inward looking policies designed to promote rapid industrialization, such as exchange rate policies, taxation practices, subsidies to industry and a system of preferential import duties. Sadly though, they may also result from actions taken to ensure a robust agricultural sector, such as the pattern of distribution of subsidies and complementary inputs among farmers as well as the activities of parastatal marketing boards.

While there are innumerable causes and symptoms of this eclipse, the absence of significant increases in agricultural productivity must be a prime reason for this stagnation. For the agricultural sector to provide an adequate food supply to a growing population while permitting an orderly transfer of workers to the industrial sector, its individuel production units must achieve significant increases in technical efficiency levels.,

Most farming concerns in Sub-Saharan Africa are small family units with b arely enough resources to adequately work the land, and in the absence of a credible social insurance scheme, survival becomes the primary preoccupation thus reducing their willingness to try new methods and modern inputs. These constraints limit the extent to which small .rural farms throughout the Third World can improve the living standards of those so desperately dependent on such improvements. It is against this background that we explore the attempts to build a replicable model of technically efficient peasant farming in another part of the Third World.

Introduction

Economists make a point of differentiating between allocative and technical efficiency, the former referring to an agent's achieving the optimal mix, the latter to his ability to extract the maximum output from a given level of input. By traditional indicators, peasant farming in the third world would appear to be grossly inefficient. After all most of these are family-operated concerns that lack the financial resources to acquire modern farming equipment, and to hire additional labor at planting and reaping time. With no reason to expect government assistance in the event of a crop failure, survival rather than maximizing output bec omes the primary focus of production. Nevertheless the question of whether peasant farmers are efficient even though their behavior deviates from that of the unconstrained profit maximizing firm, has remained as an unresolved issue in the Agricultural Development literature.

Development projects have spread through much of the Third World with the express purpose of eliminatinq these constraints. Opinions differ sharply on how effective they have been.[1] The Second Integrated Rural Development Project (IRDPII) sponsored by USAID was one such project aimed at creating a replicable model of efficient peasant farming in the Two-Meetings and Pindars River Watersheds in the hilly country of central Jamaica. It ran from 1977 to 1983, and its channels of assistance to participating farmers included various input and land improvement subsidies, technical guidance by special extension personnel, together with a program to upgrade the area's physical infrastructure.

The twin purpose of this paper is to determine and contrast the levels of technical efficiency of participating and non-participating farmers, and to assess the over all wisdom of the nature of the search for a replicable model of efficient peasant farming. In the first section we review the evolution of the present malaise in Jamaica's agricultural sector. The second section outlines the stochastic frontier production model, and the specification that will be used in this study. The next section analyzes the empirical results obtained from this specification of the production function. Thé final section draws out some of the policy implications for the impl anentation of an integrated rural development project.

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[1] See Lele for a detailed discussion of the challenges facing these organizations in the field. This book was among the first to emphasize the importance of pre-implementation surveys.

The Setting

Jamaica's agricultural sector employs approximately 20 percent of the labor force. Indeed this century has witnessed a consistent decline in this proportion, down from 39 percent in 1960 and 65 percent in 1900. However, productivity in this sector has lagged behind the national average. In 1980, the value-added per worker in the agricultural sector was US $1,066, as compared with $7,445 and $43,995 in the Manufacturing and Mining sectors respectively.

One of the factors contributing to the relative and absolute decline in the agricultural workforce has been the high level of rural to urban migration; the percentage of the total population living in urban centers increased from 34 percent in 1960 to 41 percent by 1980. Contrary to the idealized results of the labor transfer models in economic development theory, this movement has not been accompanied by any significant improvement in cropping techniques and so worker productivity has stagnated. Table 1 shows that four times during the decade of the 70's real agricultural output declined. Table 2 bears out a more sobering fact: that over the last 20 years Jamaica's agricultural sector performed worse than that of every major country group classification.

Table 1
Real Rate of Growth of GDP and Selected Industries

Industrial Sector	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Agriculture	5.9	13.3	1.8	-6.0	1.3	-0.3	2.5	3.2	9.6	-9.7	-7.4
Mining	29.1	6.9	6.4	14.3	8.5	-20.2	-20.5	17.5	2.5	-1.6	9.9
Manufacturing	6.1	2.3	11.7	0.7	-3.5	2.3	-4.9	-7.1	-6.0	-4.8	-11.7
Real GDP	12.0	3.1	9.2	2.8	-5.	-0.6	-6.1	-1.7	-0.3	-1.5	-5.4

Source: *National Income and Product*; Jamaica Department of Statistics.

Table 2
Average Annual Growth Rate of Agricultural Output

Country Group	1960-1970	1970-1980
Developing Countries	2.8	2.7
Industrial Market Economies	2.1	2.0
Nonmarket Industrial Economies	3.2	1.7
Total World	2.6	2.2
Jamaica	1.5	0.7

Source: *World Development Report*, 1982, page 41.

For more than a hundred years Agriculture has been dichotomized into two subsectors that compete for the nations limited supply of flat arable land; the ex port crop and the domestic crop sectors. The export crops have had much of the country's physical infrastructure concentrated around'their operations, and have enjoyed easy access to ancillary services including those of Government. Indeed, in addition to performing the role of shock absorber for adverse output and price fluctuations in the export crops sector, Government has often permitted its missions abroad to act as unofficial trade representatives for these companies. As Government has traditionally given a high priority to meeting the every need of large scale Agriculture, this sector's precipitous decline in the 1970's destroyed any illusion of a coherent strategy for agricultural advancement.

In recent years the authorities have turned their attention to the multitude of poor rural peasant farmers who dominate the domestic crops sector. A maze of government supported projects, often jointly funded by foreign sponsors has mushroomed; they include Operations Land Lease, Food Farms, Self-Help as well as the First and Second Integrated Rural Development Programs. These projects have belatedly begun to wrestle with some of the time-honored problems confronting peasant farmers such as poorly devised price and marketing policies, the inadequacy of sound physical infrastructure in rural areas, antiquated land tenure patterns, the inability to take advantage of technological advances, minimal extension services and poorly functioning credit institutions.

Most of these efforts, though well-intentioned, have not met with much success thus far, as evidenced by the fact that a majority of the projects have been terminated prematurely. There seems to be several' explanatory factors here. First, major farming innovations generally require intensive aresspecific research well in advance of implementation. The suddenness with which Government had to act in the early 1970's precluded all but the most rudimentary economic and cropping methods research. A more significant issue was the apparent perception by many of the planners that communicating the new techniques to the small farmers, was the sole ingredient for success. A third handicap was that little effort was expended on the installation of reliable monitoring mechanisms to indicate what did or did not work.

The overall picture that emerges is that of an agricultural sector struggling to adjust to major structural changes but with the vast majority of its operators still shackled to poverty and unable bec ause of low productivity, to meet the food demand of a national population that is expected to grow at an annual rate of 2 percent for the rest of this century.

Problems Confronting the Small Farmer

The peasant farmer operates on holdings that many consider too small to permit economic efficiency. Between 1954 and 1968, the percentage of land in the over-500 acres category increased from 40 to 45 percent, and even though the under-5 acres category increased from 13 to 15 percent, by the end of the period it accounted for 78 percent of all farms up from 70%. The 1978 census showed that the typical peasant farmer was operating a slightly larger holding but the fact that most of this incremental acreage came from the redistribution of unused estate land, suggests that he had the additional burden of working more fragmented holdings than before.

It is estimated that 40 percent of the land small farmers operate is not owned by them. The many tenure arrangements such as rent in any of its many forms, family land, or joint ownership may be discouraging farmers from cultivating semi-permanent crops even when it can be shown that the land has a comparative advantage in producing these crops. Periodic shortages of labor can also hurt the small farmer especially if his holding is next to a big estate. In fact, in cases where farms of all sues border on factories and construction sites, the reserve price of labor as set by a comparison of the wages offered by these alternative employers, is quite often higher than even the large estates can afford to pay. This labor shortage exerts a negative impact on the timeliness of planting and reaping exercises, further reducing his productivity.

Many of these small farms are located on hilly terrain, which makes it extremely difficult to use heavy equipment. In any case, the majority of these small farmers cannot afford to invest in capital beyond the most elementary hand tools. In the latest agricultural census, there were very few ploughs in the under 5 acre category, a situation exacerbated by the fact that renting of farm equipment is almost non-existent in this category.

In addition to the above, several other constraining factors can be quickly cited. First, a farmer may own land which has a clear advantage in producing one or two cash crops, but instead he produces a large number of crops with a high subsistence component. He does this to ensure adequate nutrition and to reduce the possibility of starvation due to crop failure of one or two high potential crops. A variety of crops also assures him navre stable employment throughout the year and less severe labor short ages at harvest time. Second, he may not be making fullest use of the best available methods because the agricultural technology that is a prerequisite to its adoption (e.g., roads, irrigation, terracing) is not in place. Further, it may be the case that the technology was rated best based upon input prices avail able to researchers but below those confronting f armers using small quantities and located in isolated areas[2]. In addition, the high proportion of subsistence consumption coupled with inadequate credit facilities, does not leave the rural farmer with an adequate cash flow to finance the adoption of technological advances.

Against this background it is possible that the peasant farmer can be making rational economic choices, weighing all of the circumstances attending his existence, while appearing to be inefficient vis-a-vis the unconstrained profit maximizing model of the neoclassical theory of the firm.

Goals of the Study

The deepening crisis facing the agricultural sector in the last fifteen years, has prompted a major rethinking of public policy. This reformulation has resulted in the creation of a network of programs to promote domestic crops and, in a few cases, selected export crops.

In the light of this recasting of official priorities, there is the need for an in-depth study to establ ish the util ization pattern of available resources among Jamaican small farmers, as well as to measure and attempt to explain differences in productive efficiency. Such an exercise would be useful in that it will delineate the constraints within which small farmers operate and given the limited resources of the typical small farmer, would indicate which factor of production yields the maximum output per dollar spent, thus providing a realistic reference point for agricultural policy planning.

For this microeconomic study we propose to use a production function framework and to employ appropriate techniques to develop and estimate a frontier production function which should be helpful in suggesting the extent of the potential for increasing individual farm output using the best available cropping methods. Of the many agricultural assistance programs proposed and implemented over the years, we choose to focus on the five-year Second Integrated Rural Development Project, for three reasons. First, this was the most comprehensive farmer assistance project, and the most intensive as measured by the dollar expenditure per acre over a specified time period[3]. Second,

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[2] In practice this was often the case for imported inorganic fertilizer in the hilly areas of Central Jamaica.

[3] For a fifteen square mile area, a US $22 million commitment in 1977 seemed more than adequate. From Jamaica's standpoint it was not a good bargain. USAID and the Government of Jamaica would each put up

unlike other programs where interest diminished with time, the stated goals were implemented with great consistency. The third reason is that our survey provides us with reasonably good data on this project.

The primary purpose of this study is to make an empirical determination regarding the effectiveness of IRDPII in improving the technical efficiency of those farmers who participated. To this end data were collected during the period June to August, 1982, in a multi-stage selection process from the Two Meetings Watershed. From IRDPII's list of farmers, our sample of participating farmers (80)was randomly selected.The non-participating sample (72) was also randomly selected from a list that was specially made up with the assistance of extension officers from the Ministry of Agriculture, who were working in these sub-watersheds. Data were collected on personal characteristics, resource use, acquisition of inputs, as well as crop production and disposal. Table 3 contains a listing of the final included variables as well as their means, standard deviations and maximum values for both groups.

Measuring Technical Efficiency

A firm is tèchnically efficient when it produces the maximum 1evel of output for a given level of input on the assunption that technology is fixed. Fron the earliest attempts to bridge the gap between theoretical and applied economics, the measurement of technical efficiency has generated considerable controversy. One of the earl iest empirical efforts was the 1inear programming model, Aigner and Chu (1968), Bowles (1966), Timmer (1971), which was arrived at by constraining the error term of a stochastic Cobb-Douglas production function to one side of the estimated production surface. The problem was that this amounted to an assumption that all firms were technically efficient except for random noise, and then proceeding to make inferences regarding the potential of firms from this average production function.

A further problem was that this formulation was shown to be especially sensitive to outliers in the data set. The chance constrained version of the linear programming model evades this problen by eliminating from the estimation procedure the firms closest to the frontier. Any firm producing beneath this frontier was automatically considered technically inefficient in its resource utilization. But this creates a different problem because it would imply that a firm beset by external events, e.g., floods or prenature machine failure, is technically inefficient in the way it utilizes resources.

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half of that total with the American share coming in the form of a $2 milion grant and a $9 million loan, with the proviso that the loan proceeds must be exhausted before the grant money could be used. Also, the loan was a tied loan leading to the acquisition of inputs that were often unsuited to local conditions.

Table 3
Preliminary Statistics on Production

	Participating Group				Non-Participating Group			
	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum
Output	10092.5	10012.6	2500.0	49300.0	5947.8	5146.0	1500.0	30500.0
Land	4.1	3.9	0.5	20.0	3.2	3.6	0.3	16.0
Family Labor	273.7	101.1	130.0	570.0	297.1	157.5	120.0	760.0
Hired labor	23.0	24.0	1.0	90.0	13.9	14.0	1.0	58.0
Fertilizer	24.1	22.9	1.0	111.0	8.7	5.5	1.0	24.0
Other Resources	2686.2	2677.8	300.0	1304.0	1256.2	1016.6	200.0	4720.0

Source: Rawlings *op.cit.*. Note that the measurement units are as previously indicated.

The stochastic frontier production model, Aigner, Chu and Lovell (1977), gets around this problem by decomposing the error term into two parts. In addition to the error terni of the previous model, they specify a stochastic component reflecting random variation in input quantity, possibly resulting from external events such as mentioned above. The practical significance of this improvement is that a firm suffering crushing losses because of events beyond its control need not be viewed as technically inefficient by the Aigner-Chu-Lovell formulation with its more comprehensive disturbance term. In Appendix A, we present the derivation of the stochastic frontier production function, while Appendix B gives a precise decomposition of the error term used to improve technical efficiency measurement as mentioned above.

The Formal Model

Given our research objectives, the generalized stochastic frontier model can be expressed for our two groups of farmers as:

$$Y_{ip} = A_{op} + A_{1p} L_p + A_{2p} Nf_p + A_{3p} Nh_p + A_{4p} F_p + A_{5p} R_p + E_i$$

and

$$Y_{in} = A_{on} + A_{1n} L_n + A_{2n} Nf_n + A_{3n} Nh_n + A_{4n} F_n + A_{5n} R_n + E_i$$

where the subscript p in the first model indicates that it applies to the participating group and the subscript n in the second equation indicates that it applies to the non-participating group.

Y = The maximum attainable output for a given level of all inputs, and will be measured as the value of gross output in dollar amounts.

L = Land area cultivated, measured in acres.

Nf = Fami1y 1abor uti1i zed, measured in man-days .

Nh = Hired 1 abor util ized and also measured in man-days.

F = Inorganic fertilizer used and measured in dollar amounts.

R = Seeds, fertilizer and pesticides used and measured in dollar amounts[4].

Recall that the error term is really a composite of two terms:

Vi which represents a symmetric random variation in input application due to unanticipated events; and

Ui which is an indicator of an agent's ability to use the "best practice" technology, and effectively measures the level of technical efficiency.

Since a major aim of IRDPII was to minimize the effects of unanticipated events, we would expect that the symmetric variance of the participating group would be absolutely less than that of the non-participating group.

Hypothesis 1 Vip<Vin

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[4] It should be noted that expressing some variables in value terms and somein physical units does not create a problem. Assuming that identical input prices faced all firms, the results of our model should differ from that of a model completely specified in physical terms only to the extent of having a different intercept. The intercept of such a model should look like:
$\bar{a}_o = a_o + a_4(\log Pf) + a5(\log PR) - \log(PQ)$, where: the left hand term is the intercept that results from a model completely specified in physical terms, Pi are the prices of the variables (of our model) specified in value terms. However, the elasticities from the two models will be identical, i.e., $\bar{a}_1 = a_1, \bar{a}_2 = a_2, \bar{a}_3 = a_3, \bar{a}_4 = a_4, \bar{a}_5 = a_5$. For an expanded discussion of this issue, see Cline (1970), page 66, footnote 1.

where p indicates the participating group and n indicates the nonparticipating group.

Further we may reason ably expect that in the case of the partIcipating group, it should account for a smaller proportion of total variance.

The program stressed new farming techniques~and modern inputs. The me ans of inputs presented below in Table 4, suggest that at the time of the survey, non-participating farmers lagged on both counts. We therefore expect that participating farmers achieved a higher level of technical efficiency than did non-participating farmers.

Hypothesis 2 Uip<Uin

where it must be remembered that Ui (the measure of technical efficiency) is the negative one-s ided component of the total variance, and really shows the extent to which an individual farm's product falls below the group production frontier.

Empirical Results

The estimated coefficients of the stochastic fronder model are presented in Table 4. Separate estimates are shown for the participating and the non-participating group. The ancillary parameters are our prime focus. The variance of the composite disturbance term is almost identical (.199 and .198) for the IRDPII and the non-IRDPII respectively. Recall that the negative (or at least non-positive) one-sided disturbance reflects the extent to which a firm's product falls below its frontier due to technical inefficiency while the symmetric disturbance shows random variation of the frontier across farms due to un expected developments such as luck, climate or perhaps errors in measuring output.

For IRDPII farms, the symmetric variance is less than one-third of total variance (.063 as against 199). The corresponding ratio for Non-IRDPII f arms is approximately one-half (.095 as against .198)[5]. The implication of this finding is that there is relatively less variation of the frontier across IRDPII farms, which in turn suggests that chance factors such as drought or flood, have a smaller impact on production on these farms.

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[5] The sum of the Non-IRDPII symmetric and one-sided variance differs slightly from its total variance due to a rounding error.

σ_u is the estimated standard deviation of the negative one-sided component of the disturbance term.

Table 4 also makes clear that for IROPII farms, the one-sided component forms a relatively greater proportion of total variance than it does for NonIRDPII farms. This implies that the former experience greater variation of actual output beneath the frontier.

The last entry in Table 4 measures technical inefficiency and is calculated as:

$\sigma_u \sqrt{\frac{2}{\pi}}$, where:

Table 4
Parameter Estimates for the Stochastic Frontier Model

Variables	IRDP-II		Non-IRDP-II	
	Coeff.	T-Ratio	Coeff.	T-Ratio
Constant	5.606	4.9	5.122	4.4
Land	0.247	2.6	0.227	2.0
Family Labor	0.196	1.0	0.379	1.6
Hired Labor	0.049	0.4	0.141	1.6
Fertilizer	0.215	3.3	0.215	2.4
Other Resources	0.209	1.9	0.081	0.7
Ancillary Parameters				
Total Variance	0.199	3.9	-0.198	3.3
Symmetr ic Variance	0.063	1.8	0.095	2.6
One sided Variance	0.136	1.8	0.102	1.1
Mean of one-sided variance	-0.294	-3.3	-0.255	-2.2

The level of measured technic al efficiency for the Non-IRDPII group, 74.5% is somewhat higher than that of the IRDPII group, 70.6%. Technical inefficiency levels of 29.4% and 25.5% seem rather high but fit within the range of corresponding estimates made elsewhere[6].

There are several problems involved in interpreting these results. First, most of the T-Ratios are borderline; second, unlike the Linear Programming model, the Stochastic Frontier model does not purport to make statements about firm-specific levels of technical efficiency.

Looking first at the estimates of the variance of the symmetric error, we see that it is smaller for the IRDPII f armers. This tends to support the view that the program's intensive farmer outreach effort might have succeeded in reducing the impact of unexpected events upon farming, perhaps the best example being the ill-effects of weather. Of greatest interest to us, however, are the one-sided error terms, estimates of technical efficiency. On the one hand it can be argued that with the same level of

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[6] These range from a low of 2% in Aigner, et.al. (1977), to a high of 37.5% in Lee, L.W. and W.G. Tyler "The Stochastic Fronteir Production Function and Average Efficiency: An Empirical Analysis," *Journal of Econometrics* (1977). The Aigner, et.al. finding seems rather low but it must be noted that they used statewide and not individual firm data. The last sentence of their famous article is instructive in this regard: "....Whether this finding, based upon statewide pre-establishment aggregates would continue to hold for the individual establishments themselves is yet another interesting questio to be answered." Aigner, et.al. (1977), page 35.

exposure to the program's teaching services and physical resources, IRDPII f arms should exhibit greater uniformity of achieved levels of technical efficiency, than farms that did not benefit fron any of the above.

On the other hand though, farmers entered the program with widely varying levels of education and with differing levels of motivation built upon their divergent views about what would be required of thon in order to extract the maximum benefit from participating. Thus, one might expect widely different effects of the IRDPII program on the level of technical efficiency of the participants[7]. Also, since we are estimating an envelope production function, the fact that a few farmers developed considerable skill at the new techniques taught (e.g., the proper time sequencing of chemical fertilizer application) while others may have made only marginal improvements, would certainly show the latter as having observed output levels further beneath potential when compared with the position of the bulk of the non-participating group relative to their frontier; recall that the latter were more uniform in their methods and were not in any adjustment phase. In other words, our results suggest that the IRDPII had the salutary effect of shifting outward the production frontier facing participating farmers[8].

The last two lines of Table 4 appear to bear out the latter point of view. They show that there was a greater tendency for participating farms to fall further below potential than was true for the non-IRDPII farms. One further observation can be made here regarding the finding of considerably greater-variation of the frontier across Non-IRDPII farms. IRDPII's input subsidy progran led to a fair degree of st andardization of input levels among client farmers. The considerable variation in the budget constraint facing individual Non-IRDPII farmers resulted in greater random variation of their input levels[9].

So far we have reported each group's performance relative to its own frontier, a fact which constrains us from comparing absolute levels of technic al efficiency. Table 5 reports the results obtained from estimating the Stochastic Frontier for both groups combined.The frontier elasticities do not show any major divergence frac the frontier elasticities of both groups reported in Table 5. In fact most elasticities on this combined frontier lie between the corresponding elasticity estimates obtained from the separate

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[7] See Chapter 7 of the original study for an elaboration of these motivations and the role of the IRDPII in shaping them.

[8] This is, of course, equivalent to saying that the minimum cost frontier has been shifted inward.

[9] See Rawlins (1983) chapter 3 for a comparison of the standard deviation of each of the five inputs for both groups of farms. See also Table 1 of this paper.

frontiers; the one exception being fertilizer, but the magnitude of the divergence is small enough to be disregarded (.217 as against .215 for both of the separate frontiers). The "t" statistics are much higher for the pooled estimation than for the separate frontiers.

The variance of the symmetric disturbance also falls in between the corresponding estimates but the one-sided variance and hence the percentage measure of technic al inefficiency exceeds the respective estimate of either group measured separately (-.315 vs. -.294 and -.255). One possible explanation might be the fact that the non-participating farms, where modern techniques have not made as much penetration, are now being measured against a frontier that is estimated for a group that includes some IRDPII farms which are less traditional in their cropping methods and inputs employed. In other words, a few top-performing IRDPII farmers now accentuate the efficiency difference not only between themselves and the other IRDPII f armers but also the bulk of the non-IRDPII farmers.

This explanation of the average techncial efficiency realized by combining the two groups, appears reasonable in the light of the performance of the two groups in the allocative efficiency test of the earlier study. Nothing short of a firm-specific technical efficiency index can confirm or deny our interpretation[10].

[10] Not having an index we did make an effort to shed some light on the issue. Knowing that the symmetric component is random and independent of the fact of participation, we regressed the composite residual on a participation dummy; the idea being that with the symmetric component neutralized, itmight be possible to determine whether participation is indeed associated with a higher level of technical efficiency. Specifically the regression was: Reid = ao + a1Par, where Resid is a column of squared residuals obtained from the combined frontier and Part is a dummy set to 1 for IRDPII farmers and O for non-IRDPII farmers. The results are shown in Table A1. Although Part has the expected negative coefficient, the t-ratio suggests that this explanatory variable is not significant.

Table A1

Results of the Test on the Combined Frontier

Variable	Coefficient	R-ratio
ao	0.140	3.070
a1	-0.017	-2.700

R^2 = 0.00048

Table 5
Parameter Estimates for the Combined Stochastic Frontier Model

Variables	Coef.	T-Ratio
Constant	5.437	8.3
Land	0.244	4.2
Family Labor	0.256	2.1
Hired Labor	0.102	2.3
Fertilizer	0.217	4.7
Other Resources	0.163	4.5
Ancillary Parameters		
Total Variance	0.230	6.4
Symmetric Variance	0.074	3.7
One-s ided Variance	0.156	2.9
Means of one-sided variance	-0.315	-5.8

Policy Implications

IRDPII represented a quest fora replic able small f arming model for Jamaica's agricultural sector. The previous section demonstrated that the project reduced participating farmers' susceptibility to unexpected events, and increased their productive capacity.

To better interpret the implications of this finding, two relevant conclusions from the earlier work, Rawlins (1983), ought to be mentioned. First, an attempt to measure allocative efficiency revealed that while both farmer groups under-utilized purchased farming inputs, e.g., fertilizer, pesticides and hired labor, but over-utilized family labor, the pattern was more pronounced on the part of the non-participating farmers. It was argued that this probably resulted from the difference in the respective budget constraints (IRDPII farmers had generous help in buying these inputs). If this were true, it is reasonable to ponder whether the participating group's edge in allocative efficiency would outlive IRDPII itself.

Second, a qualitative analysis of IRDPII revealed many shortcomings, both at the design stage and the implementation stage. The design stage lacked the benefit of a definitive study of the area's special characteristics. One result was a tendency for individual parts of the plan to appear to fit the general situations of third-world agriculture without adequately addressing specific problems[11]. Also the preoccupation with the need to display measurable indicators of the project's success gave added

[11] See Rawlins, op.cit, chapter 7.

importance to elaborate physical works (especially in the ares of soil conservation) and poorly managed input dispensing units[12]. The result was a down-grading of the importance of the simple, time-consuming practices whieh are especially necessary for small-scale agriculture, combined with attempts on the part of some farmers to maximize present gain by perversely manipulating the various incentive schemes which were mostly concentrated on input rather than output, see Bernhart and Mann (1981), and Blustain (1981).

It is customary to group under three headings the factors which shift the production possibility frontier outward; they are, better technology, a sustained improvement in general education (improved human capital), and a higher level of physical inputs. Most Integrated Rural Development Projects throughout the Third World stress all three but recognize that the transformation of poor peasant farmers into modern cost efficient units, requires that the first two characteristics become permanently ingrained in this mode of f arming, while input subsidies are seen as a temporary complement to the process.

The nature of the data in this study does not permit a disentanglement of the individuel effects of these three factors either in shifting outward the production frontier of participating f armers, or in making it less subject to random shocks. However, there is ample evidence that at both the design and implementation stage, the officials developed something bordering upon a paranoia for quick visible indices of success, and thus proceeded to stress input and land improvement subsidies whi1e downplaying the time-consuming outreach and education aspects of agricultural extension work, see Bernhart and Mann, (1981); Blustain, (1981); DAI Interim Report, (1982).

Thus there is reason to believe that the improved productive capacity shown by IRDPII farmers is not unqualified support for the view that the project has bettered their lives. This observation immediately prompts one to ponder the longevity of the salutary effects. If a similar study is done in 1992, will it be able to pick up the two distinct patterns noted in the production possibility frontier of each group? In other words will the hunan capital improvements outlive the effects of the various input subsidies? This question takes us beyond the coverage of this paper but given the indications noted earlier in this section, it does appear these are short term improvements.

In spite of this observation, the results of our study of the effects of IRDPII upon the project area, carry much hope for success in the search for a replicable small farming

[12] See DAI Interim Report.

model of higher productivity. Nowever, any future project should resist the urge to achieve massive immediate increases in real output (or the illusion that such increases are feasible). We have seen that for IRDPII, this has resulted in an over-enphasis on various land improvement and other input subsidies which have tended to be capital intensive and costly; by contrast there has been a singular lack of emphasis on the time-consuoing outreach aspects of agricultural extension work. In other words there is the need to escape the illusion that it takes tractors and other modern mechanical equipment to be technically efficient.

A second lesson to be learned is the need to involve farmers in the planning stage, so that they do not become spect tors at the implementation stage (as befell IRDPII's Development Committees)[13]. The input of the participating farmers could have been significantly increased if the extension officers were freed from their burdensome clerical assignments, if the promised research into local crops and conditions had proceeded in tandem witN the project's other endeavors, and if the planned demonstration site visits had started prior to the penultimate year[14]. Thus, although some progress has been made, the search for a replicable small farming model for rural Jamaica is far from complete.

Conclusion

This paper has presented the stochastic frontier production model with its distinctive feature of decomposing the variance of the disturbance term so that the divergence from the frontier measures not only technic al inefficiency, but also luck and possible errors in the observations.

Separate estimates of the frontier for our two groups point up a smaller degree of variation of the frontier across IRDPII farms, which suggests that the latter were-better insulated fran random shocks such as drought or floods. In addition, client farmers experienced greater variation of actual output beneath their own frontier which IRDPII succeeded in shifting outward.

Based upon an examination of the problems attendant upon the design and implementation of the project, we speculated that the above beneficial effects were short term in nature. Finally, we suggested that any future program ought to work with realistic goals, and involve client farmers at the planning as wel l as the impl ementation stage.

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[13] These were groups of participating farmers, formed with a view to coordinating varoius self-help initiatives. Unfortunately, most of these groups failed to get off the ground.

[14] The idea was for groups of farmers to be taken on tour of exhibition stations and plots of farmer-owned land to be familiarized with the results of locally-tested techniques.

Appendix A

The Stochastic Frontier Production Model

Keeping in mind the criticisme of the earlier models, the stochastic version of the Cobb-Douglas production function can be summarized as:

$$Y_i = f(x_i;\beta) + E_i \qquad i = 1....n \qquad E_i \leq 0 \text{ ....A1}$$

where Y is the maximum output and Xi is a vector of inputs and ß is a vector of unknown parameters, and Ei is an error term indicating that firms differ from the frontier in their level of output for a given set of inputs. Aigner et al. specify the error term as being made up of two components:

Ei = Ui+Vi j=1 ....n..A2

Ui represents a random variation in an agent's ability to use the "best practice" technology, and is one-sided (U≤0) where U is assumed to be independent of V, and is derived from a N (O, σ_u^2) distribution truncated above at zero. Vi represents a random variation in input quantity possibly resulting from such external events as luck, climate, topography or machine performance, or a measurement error in output and is therefore a symmetrical disturbance and is assumed to be independently and identically distributed as N (O, σ_u^2) with Vi $\neq$ O .

When $\sigma_v^2 = 0$, the model collapses to a deterministic frontier model, and when $\sigma_u^2 = 0$ it collages to a stochastic production function model. In addition to the usual measure of productive efficiency derived fran the earl ier models:

$$Y_i / \left[f(X_i;\beta) \right] \text{..A3}$$

we have another suggested measure:

$$Y_i / \left[f(X_i;\beta) + V_i \right] \text{..A4}$$

It is equation 4 that is used in the empirical test in the main body of the p aper .

Appendix B

The Decomposition of the Error Term

M.A. Weinstein (1964) derived the distribution function of the sum of a truncated normal and symmetric normal random variable. The density function for E is:

$$f(E) = \frac{2}{\sigma}\, f^* \frac{(E)}{(\sigma)} 1 - F^* \left(E\sigma^{-1}\right) \text{...B1}$$

where $-\infty < E < +\infty, \quad \sigma^2 = \sigma_u^2 + \sigma_v^2 \lambda = \sigma_u / \sigma_v$

f* is the standard normal density function
F* is the cumulative distribution function of the standard normal distribution.

Weinstein found this density to be asymmetric around zero with mean:

$$E(e) = E(u) = -\frac{\sqrt{2}}{\sqrt{\pi}}\, \sigma_u \text{ ....B2}$$

and variance :

$$V(e) = V(u) = V(v) = \frac{\pi - 2}{\pi}\, \sigma_u^2 + \sigma_v^2$$

Note that as λ^2 approaches zero, the symmetric error dominates in determining E.

Assume that there exists a random sample of N observations. The log likelihood function may be written as:

$$Ln\left[L\left(Y/\beta,\lambda,\sigma^2\right)\right] = N\left[\ln\left(\frac{\sqrt{2}}{\sqrt{\pi}}\right)\right] + \ln\left(\sigma^{-1}\right) + \sum_{i=1}^{N} \ln\left[\left(1 - F^*\right)\left(E_i \lambda \sigma^{-1}\right)\right] - \frac{1}{2\sigma^2} \sum_{i=1}^{N} E_i^2 \text{ . . . . . .B3}$$

Taking partial derivatives of equation A3:

$$\frac{\partial \ln(L)}{\partial \sigma^2} = -\frac{-N}{2\sigma^2} + \frac{1}{2\sigma^4} = \left(Y_i - 3X_i\right)^2 + \frac{\lambda}{2\sigma^3} \sum_{i=1}^{N} \frac{f_i^*}{\left(1 - F_1\right)} \left(Y_1 - \beta' X_i\right) \text{..........................B4}$$

$$\frac{\partial \ln(L)}{\partial \lambda} = -\frac{1}{\sigma} \sum_{i=1}^{N} \frac{f_i *}{(1-F_1 *)} (Y_i - \beta' X_i) \text{ .... B5}$$

$$\frac{\partial \ln(L)}{\partial \beta} = \frac{1}{\sigma^2} \sum_{i=1}^{N} (Y_i - \beta') X_i + \frac{\lambda}{\sigma} \sum_{i=1}^{N} \frac{f_i *}{(1-F_i *)} X_i \text{ .... B6}$$

where Xi is a (KX1) vector of the ith row of X, and Fi* and Fi* are evaluated at $(Y_i - \beta' X_i)\lambda\sigma^{-1}$

At the optimum,

$\sum_{i=1}^{N} \frac{f_i *}{(1-F_i *)}(Y - \beta' X_i) = 0$. Substituting this value into equation A1 and solving for an

estimate of σ^2 :

$$\hat{\sigma}^2 = \frac{1}{N} \sum_{i=1}^{N} (Y_i - \beta' X_i)^2 \text{ .... B7}$$

An estimate of β can be arrived at by premultiplying β' into equation 10 and adding the result to $-\lambda$ times equation A5. This yields :

$$\frac{1}{\sigma^2} \sum_{i=1}^{N} (Y - \beta' X_i) \beta' X_i + \frac{\lambda}{\sigma} \sum_{i=1}^{N} \frac{f_i *}{(1-F_i *)} Y_i = 0 \text{ .... B8}$$

$\hat{\beta}$ (as determined from Eq. A8) is independent of $\hat{\sigma}^2$ from other equations but forms, together with equation 11, the basis of an iterative solution scheme. The next step is to find solution algorithms which optimize the parameter values β, λ, σ^2. In turn, the average technical efficiency for the sample can be calculated using $\sigma_u \sqrt{\frac{2}{\pi}}$

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