RESOURCE USE AND TECHNICAL EFFICIENCY IN RICE PRODUCTION IN COLOMBIA

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CHAPTER I

INTRODUCTION

General Problem

Rice is a very important commodity in the Colombian food economy. It is one of the main staple foods for the country's population. The Departamento Nacional de Planeacion (DNP), estimated that the domestic consumption of rice increased at an average annual rate of 5.3 percent during the period 1960-1980; the consumption per capita increased from 10.8 kilograms in 1960 to 36.5 kilograms in 1980. Also, the DNP study computed that a typical Colombian consumer spends about 6 percent to 10 percent of his available income for rice.

The increase in domestic consumption of rice over time has been explained not only in terms of increased population and increased income per capita, but also in terms of the reduction in the relative price of rice with respect to potential substitute goods in consumption such as pasta, plantain, potatoes, beans, and cassava. Such a relative price decrease has been attributed to a sharp increase in the total rice supply, in response to high rates of adoption of modern output-increasing technology by rice producers.

Rice supplies the second largest proportion of the country's dietary protein after meat products (beef and poultry). Also, rice provides the main source of energy for people's diets. As pointed out by the DANE-DNP-DRI-PAN's study in 1981, rice accounted for about 14 percent of the Colombian's dietary energy as well as 12 percent of the total daily protein intake. Scobie and Posada's study showed that the social gains of improving rice production have been mostly beneficial to the poorest sectors of consumers because of the reduced relative prices of the product at the retail level, and the high income elasticity of demand (0.53 to 0.78) for rice.

Rice production represents the second largest agricultural activity in the country, after coffee production. The DNP study determined that rice contributed about 8 percent of the agricultural gross output value and used nearly 12 percent of the total cropped area. In spite of being a capital-using intensive activity, rice production and marketing systems provided about 6 percent of total labor employment opportunities available in the agricultural sector.

Colombia is now facing the task of meeting national requirements of an increasing domestic consumption of rice. According to Table I, total projected domestic demand for rough rice in the year 2,000 will be 2.6 million metric tons as a result of the population effect and the real relative price effect to consumers. This means the country will have to increase national production of rice by 44 percent over the 1985 production of 1.8 million metric tons.

To accomplish the established goal for domestic consumption, two corner solutions are depicted in Figure 1 by points A and B. Solution A implies a substantial rise in the current national average level of yields from 4.6 metric tons per hectare in 1985 to 6.8 metric tons per hectare in 2,000, holding the 1985 rice hectareage constant. On the other hand, the solution at point B indicates a significant increase of 185,000 hectares over the 1985 level of 387,300 hectares, holding the current yields of 4.6 metric tons per hectare constant.

TABLE I

PROJECTED DOMESTIC CONSUMPTION OF RICE IN COLOMBIA 1985-2000*

Year	Population (thousand)	Annual Rate of Rice Consumption (kgs/pers)	Total Annual Consumption (1,000 tons)		
			Milled Rice	Rough Rice	Index (1985=100)
1985	28,743.4	38.50	1,106.6	1,784.9	100.0
1990	30,964.8	41.34	1,280.1	2,064.7	115.7
1995	32,544.3	44.95	1,462.9	2,359.5	132.2
2000	33,366.1	48.89	1,631.3	2,631.2	147.4

*Several econometric models were inappropriate to explain rice consumption on statistical basis and, indeed, to predict future domestic demand for rice. For these reasons, a numerical approach was chosen to project future rice consumption based upon two major assumptions: (i) rice consumption is a function of the annual rate of expected growth of population of 1.5 percent (1985-1990), 1.0 percent (1990-1995), and 0.5 percent (1995-2000); and (ii) rice consumption is a function not only of the rate of population growth but of the annual rate of decrease in relative prices of rice (substitution effect) In this case, rice consumption per capita is expected to increase at an annual rate of 1.6 percent, the same as that for the period 1976-1984. No income effect is assumed.

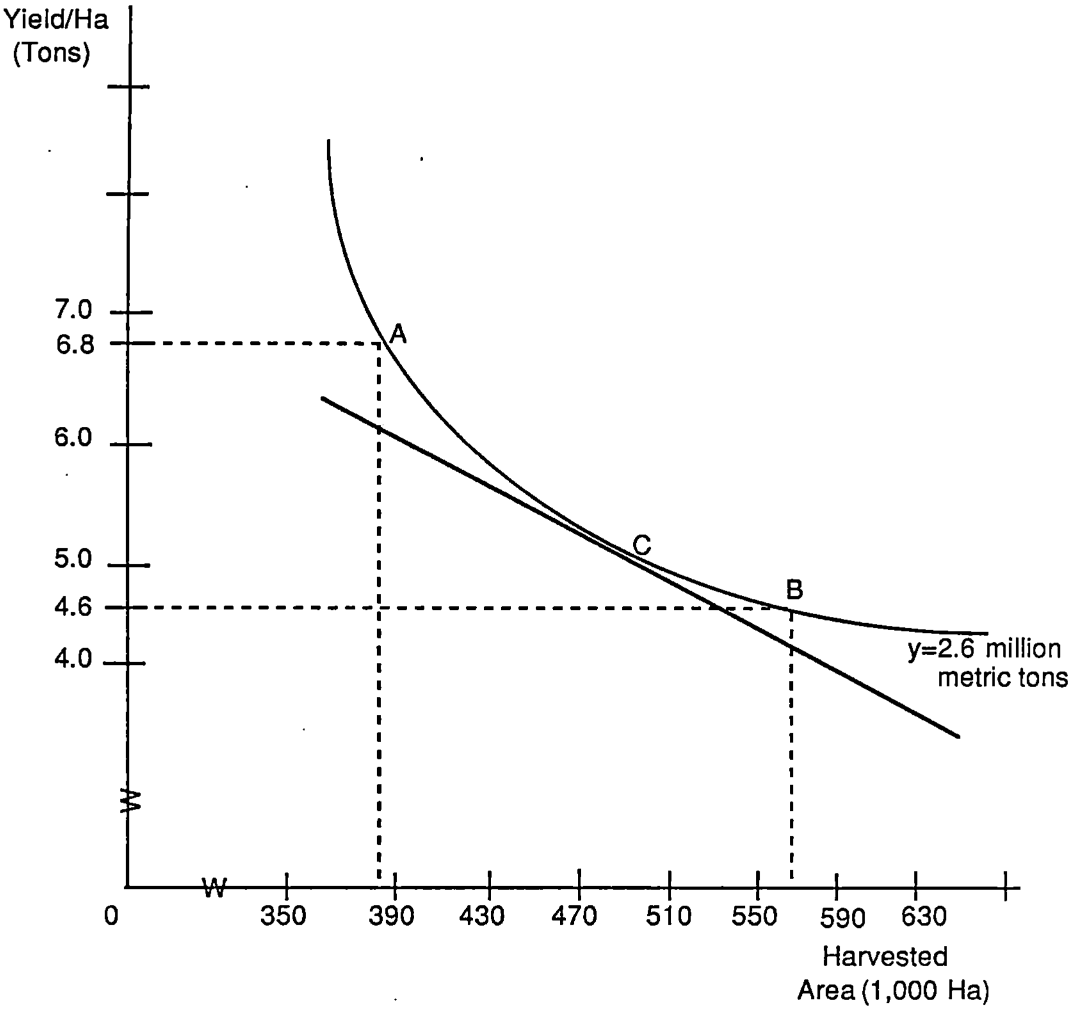

Figure 1. Trade-off Between Yields per Hectare and Harvested Area to Produce Rough Rice in Colombia by Year 2000

Conceptually, if the country is to minimize the cost of achieving the desired level of rice output, resources which should be used to expand rice production under these two alternative actions would have to be allocated in such a manner that the ratio of the marginal productivity of resources allocated in each action equals the price ratio of these resources. Assuming that yields are a proxy for research and extension resources, the optimal solution could be at point C in Figure 1, where the isocost line becomes tangent to the 2.6 million metric tons isoquant.

The solution at point C assumes that the marginal value product of resources devoted to increased yields in the older production areas of the country would be smaller than the marginal value product of the same resources used to incorporate new lands into rice production, particularly under rainfed rice systems.

Also, the solution at point C conforms to the assertion that the country's possibilities to develop new irrigated lands for rice and/or to increase yields in existing irrigated rice systems may be very limited in the future. First, current development policies preclude growing rice in future government land reclamation and irrigation programs because of its relative higher rate of water consumption than that for other cash crops (ICA-FEDEARROZ, 1985).

Second, the average yield for both irrigated rice and rainfed rice (mechanized) was estimated to be 5.4 metric tons per hectare in 1985, one of the highest in tropical countries. The average yield for irrigated rice alone was 5.7 metric tons per hectare in 1985; average yield for rainfed rice (mechanized) was 4.2 metric tons hectare. Biological researchers contend that because of the blast disease which plagues the current production regions, the development of improved varieties of rice is subject to the constraint that higher yields above present levels would imply lower resistance to blast disease, lower tolerance to hoja blanca, and would result in poorer grain quality. That is, higher yields in current regions would depend on new advances in science and technology (ICA-FEDEARROZ, 1985).

On the other hand, new locally developed varieties have shown potential comparative advantages (lower average cost per unit of output) for growing rice in new lands, especially under highly favored (high soil fertility and lack of moisture stress) rainfed cropping systems in Los Llanos (the eastern plains) and the Atlantic Coast.

However, the enlargement of the rice land frontier in these regions is at the present time subject to institutional and physical constraints due to the lack of adequate transportation, roads and bridges, and drying, milling and marketing facilities. So the average cost per unit of output at the retail level may be significantly higher due to these additional costs.

Briefly, the country has two alternatives to meet the desired goal of self-sufficiency in rice production: (i) increase the level of productive efficiency in current growing rice regions; and (ii) expand the land frontier to produce rice. Both the Colombian government and rice producers have committed to accomplish the projected goal of increased rice production by working on both issues. Most recently, the issue of increasing productive efficiency has gained public concern because a seemingly overuse of resources in rice production, as indicated in next section.

Specific Problem

Over the past 25 years, Colombia has been able to substantially increase the national production of rice, and the country has become self-sufficient in rice (Table 1). This has reduced the real price (cost) of rice to consumers and, eventually, generated some surplus of rice available for international markets.

TABLE II

RICE PRODUCTION AND PRODUCTIVITY IN COLOMBIA 1961 TO 1985

Year	Area Harvested[a] (1,000 Hectares)	Total Production Rough Rice (1,000 Metric Tons)	Average Yield (Tons/Hectare)
1961	237.1	473.6	2.00
1962	279.5	585.0	2.09
1963	254.0	550.0	2.17
1964	302.5	600.0	1.98
1965	374.5	672.0	1.79
1966	350.0	680.0	1.94
1967	290.7	661.5	2.28
1968	277.1	786.3	2.84
1969	250.4	694.5	2.77
1970	233.2	752.6	3.23
1971	253.5	904.3	3.54
1972	273.8	1,043.3	3.81
1973	290.9	1,175.8	4.04
1974	368.5	1,569.8	4.26
1975	381.4	1,622.8	4.25
1976	355.6	1,480.7	4.16
1977	337.2	1,401.6	4.16
1978	434.3	1,878.0	4.32
1979	430.6	1,829.8	4.25
1980	414.2	1,784.1	4.31
1981	439.0	1,877.7	4.28
1982	473.9	2,023.6	4.27
1983	425.4	1,813.5	4.26
1984	370.2	1,725.1	4.66
1985	387.3	1,784.9	4.60

Source: Federacion Nacional de Arroceros (FEDEARROZ). Fedearroz un Gremio al Servicio de Colombia. Bogota, D.E.: Opgraficas Ltda.,1985.

[a] These figures include two crop seasons per year. In some cases, two crops are planted on the same land each year. Also, they include two different rice cropping systems: irrigated rice and rainfed rice (mechanized rice and manual rice).

Recently, rice producers in the Central region with irrigated rice have been able to close the potential gap between the yield of their commercial fields and those from regional variety trials carried out by the cooperative research program on ICA-FEDEARROZ and the Centre Internacional de Agricultura Tropical (CIAT). Likewise, rice farmers in Los Llanos and Atlantic Coast regions have substantially increased their yields in both irrigated rice and rainfed rice cropping systems (Table III).

Conceptually, the remarkable increase in total output and the yield gap reduction are attributable to the elimination of bio-physical constraints by farmers' early adoption of capital intensive technology referred to high yielding varieties (HYV) and associated inputs such as water, fertilizers, pesticides and machinery.[1]

According to the DNP study, since 1976, 100 percent of irrigated rice and rainfed rice (mechanized) has been planted by using registered types of improved seeds. Fertilizer use in rice production accounts for about 50 percent of national usage of urea and 10 percent of total consumption of all types of fertilizers. Likewise, insecticides used in rice production amounts to 10 percent with respect to total domestic use; rice accounts for 32 percent of total herbicides' use and 17 percent of total fungicides' use. Also, rice accounts for about 20 percent of the total number of machine hours used in the agricultural sector.

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[1] For the analytical purposes of this study the inputs of production are grouped into four major classifications: land (including buildings and other structures), labor (hired and permanent labor), chemicals and seed (fertilizers, pesticides and seeds) and machinery and equipment. The last two groups are hereafter referred to as non-real capital inputs. According to Calkins and Difietre, this type of capital is called non-real capital to distinguish it from land and permanent real capital.

TABLE III

COMPARISON BETWEEN EXPERIMENTAL PLOT YIELDS AND COMMERCIAL FARM YIELDS FOR MAJOR RICE VARIETIES, REGIONS AND PRODUCTION SYSTEMS IN COLOMBIA

Regions and Varieties	Irrigated Rice (kg/ha) Plot Yields	Irrigated Rice (kg/ha) Farm Yield	Index[a]	Rainfed Rice (kg/ha) Plot Yields	Rainfed Rice (kg/ha) Farm Yield	Index[a]
Central Region						
ORYZICA-1	6,992	6,300	90	-	-	
CICA-8	7,681	6,790	88	-	-	
IR-22	6,260	6,050	97	-	-	
Los Llanos Region						
ORYZICA-1	5,328	5,100	96	4,691	4,050	86
CICA-8	5,384	5,220	97	4,948	4,325	87
Atlantic Coast Region						
ORYZICA-1	5,654	5,660	100	5,284	4,778	90
CICA-8	6,283	5,666	91	5,315	5,170	97

Source: Martinez, C.P. and M.J., Rosero. CICA-8. Bogota, D.E.: ICA, Programa de Arroz, ICA Informa. 6pp., Enero 1978.

Munoz, D., and D. Leal. Oryzica-1. Bogota, D.E.: ICA, Programa de Arroz, ICA Informa. 5pp., Enero 1983.

Federacion Nacional de Arroceros FEDEARROZ. Costos de Produccion de Arroz en Colombia. 11 Vols. Bogota, D.E.: Fedearroz, 1979-84.

[a] ICA-FEDEARROZ-CIAT Plot Yields = 100

Presently, some evidence suggests that rice farmers have been using substantially higher levels of resources than those recommended by ICA rice researchers, regardless of the production region or the cropping system. For instance, Ramirez (1979) found that fertilizer use by rice farmers in the Central region was nearly 2.2 times as much as the optimal levels derived from a production function analysis of regional variety trials data for IR-22, and CICA-4. A sample field survey, carried out by Ramirez and Badger at the Central and Los Llanos regions on 74 rice farms in 1981, revealed that farmers were using, on the average, higher levels of capital inputs than recommended by agronomists for such varieties as CICA-8, IR-22, CICA-4, and CICA-6 (Table IV). In 1984, a study conducted by Pulver, indicated that in Colombia, seed and chemical input applications in rice production reached the highest levels across Latin American countries.

Although no empirical studies exist to explain the high levels of input usage, evidence indicates that a key factor to explain this behavior by farmers is the technology itself. Typically, the rice production technology has been designed as a high input technology embodied in mechanical, biological and chemical inputs and tailored to irrigated production and to farmers who hold enough available capital and a strong cash flow. It can be postulated that early rice research policy makers and planners assumed inelastic supplies of both irrigated land and labor in the Colombian agricultural sector. Therefore, with a high elastic demand for rice output, the country could afford a yield increasing and labor-saving rice technology.

As a matter of fact, this type of technology has been successful since it seems to have properly fitted most of rice farmers resource endowments as suggested by the high rates of adoption of improved varieties (100 percent). However, available data indicates that since the middle 1970's, farmers have

TABLE IV

AVERAGE LEVEL (x), STANDARD DEVIATION (S.D.) AND COEFFICIENT OF VARIATION (C.V.) FOR RICE PURCHASED INPUT LEVELS AS USED BY FARMERS IN TWO MAJOR GROWING RICE REGIONS

		Central Region (N=44)				Los Llanos Region (N=30)			
			F Level[b]				F Level[b]		
Inputs	Units	R Level[a]	$\bar{x}$	S.D.	C.V.	R Level[a]	$\bar{x}$	S.D.	C.V.
Land Preparation	Hours machine/Ha	4.6	7.7	2.6	0.3	5.5	12.4	5.1	0.4
Seed	Kgs/Ha	100-120	200	50	0.3	100	225	75	0.3
Nitrogen	Kgs/Ha[c]	100-150	275	125	0.5	80-100	200	100	0.3
Chemical Control of Piricularia orizea	Number of applications per crop season	up to 3	5	3.2	0.64	up to 5	6	5.1	0.9
Chemical Control of Sogatodes orizicolus	Number of applications per crop season	Integrated pest control	4	3.7	0.9	Integrated pest control	3	2.7	0.9

Source: Ramirez, A. and D. Badger. Estudio Sobre Adopcion e Impacto de Nueva Tecnologia en el Cultivo de Arroz en Colombia. Stillwater: Departmento de Economia Agricola, Enero 1983, 17pp. (AE 8306)

[a] Range of level of inputs as recommended by Research and Extension Programs

[b] Level of inputs as used by rice farmers.

[c] Measured in kilograms of actual nitrogen

been cultivating rice across a wider range of environments, a large proportion of which can be classified as high stress due to the low soil fertility, drought, diseases (Piricularia orizae Cav. and "Hoja Blanca"), pests (Sogatodes oryzicolus Muir) and weeds. So to a large extent, rice farmers have been pressured to use higher levels of seeds, fertilizers, and crop protection chemicals to compensate for the higher levels of environmental stress, and maintain high yields per hectare.

From an economic point of view, a relatively high level of inputs use poses the question whether farmers are using resources efficiently, i.e. if rice producers are employing inputs in the right amounts (technical efficiency) and right proportions (allocative efficiency). Given the rice production plan (y_o, x_o), a productive efficient use of inputs implies: (i) the observed output level $y_o=f(x_o)$ the maximum output attainable from given resources x_o; (ii) the observed expenditure $w'x_o=c(w,y_o)$ the minimum expenditure to produce y_o at input prices w; and (iii) the observed profit $(py_o - w'x_o)=\pi(p,w)$, the maximum profit available at output price p and input prices w. Consequently, $f(x_o)$, $c(w, y_o)$ and $\pi(p,w)$ reflect optimizing behavior on the part of an efficient rice farmer.

The efficiency in using high input rice technology by farmers has a major short run effect on the profitability of the crop, rice producer's income and national production of rice. In the short run, the production relationships are represented by relatively fixed factor-product (y_o/x_o) and factor-factor (x_i/x_j) ratios. As indicated in Table V, the cost of seed, machinery and chemical inputs amount to about 80 percent of the total costs of production regardless of the cropping system and production region. If rice producers as a whole were overusing resources relative to an economical optimum, then farmers' income, rice profitability and domestic supply could be increased significantly, given current technology $f(x_o)$ and the input-output price ratios (w,p) by reducing the

TABLE V

COST OF RICE PRODUCTION PER HECTARE BY MAJOR REGIONS AND CROPPING SYSTEMS, 1985

	Irrigated Rice			Rainfed Rice	
Items	Central Region	Llanos Region	Atlantic Coast Region	Llanos Region	Atlantic Coast Region
	(Percentage)			(Percentage)	
Land-Bldgs. Structures	20	5	8	5	9
Chemicals-Seed	48	51	46	50	44
Machinery-Equipment	22	32	35	34	34
Labor-Overhead	10	12	11	12	12
Total	100	100	100	100	100

Source: Federacion Nacional de Arroceros FEDEARROZ. Fedearroz un Gremio al Servicio de Colombia. (Bogota, D.E.: Op Graficas Ltda,Diciembre 1985).

input usage, or eliminating factors leading to such inefficiency. Research, extension and development policy actions could be aimed at encouraging farmers to employ inputs in the most economically efficient amounts and/or proportions.

Regardless of whether farmers were making an efficient use of existing resources, the high levels of non-real capital input use is assumed to have a crucial long-run effect on the allocation of resources among regions and production systems. As a result of observed changes in factor and product prices and rice profitability, a shift of resources has been taking place from irrigated areas toward rainfed areas and other sectors of the economy for the last few years.

Capital input real prices paid by rice farmers were increasing greatly, at an annual rate of 3.5 percent during the period 1979-1984 (Table VI). Likewise, the annual rate of growth of land rental real prices and labor real wage rates were 2.6 percent and 1.4 percent respectively. In turn, rice output real prices received by farmers were declining at an annual rate of 1.7 percent.[2] Thus, the internal terms of trade for rice producers have tended to deteriorate.

If these recent price trends are to hold in the near future, since they reflect institutional and market factors outside the control of rice farmers, a decline in farmers income, total harvested area and national supply of rice could be expected to occur. For example, the higher the input-output price ratios, the

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[2] Norton (1985) found that since 1978 the rate of growth in production for 17 crops in Colombia (including rice) has been declining. This period of declining growth coincides with the period of declining internal terms of trade. This study also confirms the finding that agricultural profit margins have been reduced and Colombian agricultural supply is price responsive.

TABLE VI

RATE OF GROWTH OF INPUT REAL PRICES, AND RICE OUTPUT REAL PRICES, 1979-1984.

Inputs and Output Prices	Annual Rate of Growth (percentage)	Estimated Model[a]	R^2	F-value
Capital Inputs	3.5	$-0.27e^{3.5t}$	0.712	49.4
Land	2.6	$-0.81e^{2.6t}$	0.395	12.5
Labor	1.4	$-0.08e^{1.4t}$	0.551	49.3
Rice Output	-1.7	$-0.77e^{-1.7t}$	0.899	112.4

[a] Time series data on input real prices paid by farmers and output real prices received by farmers were fitted to the exponential model:

$P_t =$ $\alpha e^{\beta \cdot t}$ where,

$P_t =$ Input or output price at crop season t

$\beta =$ the instantaneous rate of growth of p_t is defined as the rate of change of p_t expressed as a ratio to the value of p_t itself. Thus, for a given point in time

$$[d\, p_t / d_t] / p_t = \beta\, p_t / p_t = \beta$$

t = crop season: 1979A, 1979B, . . ., 1984B

The available information on input and output prices is assembled by FEDEARROZ since 1979. Prices were deflated by the consumer price index for foods.

lower the expected profitability, and the greater the exit of rice farms of the industry. Given current productivity of resources, one hectare of irrigated rice lost in production would have to be replaced by 1.5 hectares of rainfed rice to hold total output constant. However, the greater the share of rainfed rice the lower the average yields and total supply might be assuming the same harvested area.

Thus, alternative paths of technical change in rice production would have to be chosen according to different regions and production systems. This requirement has to be met for the country to keep pace with a reasonable rate of productivity growth and to ensure the present condition of self-sufficiency in rice supply. As contended by Ruttan (1985), a requisite for agricultural productivity growth is the capacity of the agricultural sector to respond to changes in factor and product prices. Following the induced innovation hypothesis under situations of exogeneous input-output prices, a technical change bias should be associated with changing input-output prices. That is, new technology should be biased as to maximize returns to the most scarce inputs in the economy (Binswanger, 1974).

Recently, both rice farmers and biological researchers have suggested that the country should generate a cost-reducing and capital-saving technology (ICA-FEDEARROZ, 1985).[3] This technology might be mostly adapted to high stress environments such as those prevailing in rainfed areas in Los Llanos and Atlantic Coast regions.

Typically rice farmers in rainfed areas hold ample land and little labor. Consequently, rice farmers could produce with technologies that are intensive

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[3] A technology is said to be cost-reducing and capital-saving if for a constant level of output ($y_0 = y_1$) the marginal rate of substitution of capital for land and capital labor increase. Therefore, the employment of land and labor increases at a greater proportion than that for capital.

in their use of land. Because these farmers are producing with low labor/land ratios, the productivity of labor is usually higher than that for land. This, coupled with small holdings of capital, would be expected to discourage investment in certain types of capital, in particular labor-saving machinery and land-saving seeds, fertilizers and pesticides. Therefore, a technology appropriate for rice farmers in rainfed systems would be one that provides substantial employment of land, and earns high returns to labor and machinery and be not dependent on chemical inputs.

However, any expansion of the agricultural frontier would encompass large scale investments in basic infrastructure for development of the new production areas. As the inpact of such land frontier enlargement on rice supply will take place only in the long run, the government must address the issue of increased production and productivity from existing resources, regions and cropping systems. These potential developments substantiate a need for a more complete knowledge about the actual pattern of resource use and productivity, crop profitability and productive efficiency in rice production at the farm level.

At the micro level, rice production becomes a complex activity because of the several biological, socio-economic and institutional constraints faced by rice producers. Along with a relatively scarce endowment of production factors (land, labor and non-real capital), regardless of the crop variety, farm size, land tenure, production region and cropping systems, decision makers have to cope with a negative impact of exogenous factors on their crops profitability and returns to production investments. A number of farmers have gone out of business in the rice industry over the past seven years because of their failure to produce rice at the lowest cost per unit of output under an environment plagued with high incidence of pests and diseases, and the financial and tax burden imposed by ongoing domestic output-input domestic price policies, credit, and tax policies.

This thesis, therefore, aims to contribute conceptual, methodological and empirical economic information on the potentialities to improve resource use, increase productivity and increase supply of rice output from existing resources in Colombia. This study may provide agricultural planners and policy makers with empirical parameters to enable proper adjustments in the national rice commodity program and to ensure the accomplishment of the projected goals of supply and demand for rice in the year 2,000.

Objectives of the Study

The overall purpose of this study is to develop an economic analysis of rice production in Colombia and to help measure and understand the potential to increase rice farmers' income and national supply of rice from existing resources. More specifically, the study attempts to assess: a) the current levels of resource use in rice production; b) the rice crop profitability, and returns to land, labor and non-real capital inputs; and, c) the technical efficiency in rice production.

To achieve the general objective of this research, this study has the following specific objectives:

(1) estimate the resource use, cost and returns, and crop profitability in rice production using rice budget analysis from cross sectional data for five different scenarios: rice varieties, crop sizes, land tenure classes, production regions and cropping systems;

(2) evaluate the resource use, resource productivity and financial returns to individual production factors under each scenario using an average revenue function model;

(3) estimate the average technical efficiency in rice production under each scenario using a stochastic frontier total revenue function model; and,

(4) formulate agricultural policy suggestions on resource use in rice production and the national rice commodity program now in effect;

Selection of Study Area

To carry out this study, two major rice production regions of Colombia were selected: Central region (Tolima-Huila, Caldas, Cundimarca and Boyaca), and Los Llanos region (Meta and Casanare).

There are several reasons for selecting these rice production regions. These regions contributed 55 percent of the total harvested acreage and 58 percent of the total rough rice of the country in 1984. Also 47 percent of rice producers were located in these regions. The Central region has been the most important irrigated rice growing area of the country for the last 35 years. However, the harvested area has remained constant at about 110,000 hectares per year since 1970 because of the increasing deficit of water available for irrigation, increasing average total costs, high incidence of blast and hoja blanca diseases, grassy-weeds, the sogata insect and competitive products (cotton, sorghum, sesame, and livestock) for available land and water.

Similarly, the observed commercial yields of rough rice have reached 6.0 metric tons per hectare for the varieties IR-22, CICA-4, CICA-8 and ORYZICA-1. Both farmers and researchers believe that a ceiling yield has been reached under the present technology and there is no possibilities for yields to increase in the short run (ICA, FEDEARROZ 1985).

The Llanos region became a rice production area in the late 1960's. Since then, the harvested acreage has been increasing sharply, because of the introduction of CICA-8 in 1978, and ORYZICA-1 in 1983. These varieties exhibit high tolerance to blast disease, the major biological constraint to rice in this region. These varieties have become very promising to be planted under the rainfed systems in this region and the Atlantic Coast region. In 1985, the national harvested area was 387,300 hectares, of which 32 percent was rainfed rice, and the remainder was irrigated rice (FEDEARROZ 1985).

The expansion of the rainfed rice system in the Atlantic Coast and Los Llanos regions is supported by facts such as: a) the need to expand the country's agricultural frontier beyond the current areas of irrigated lands; b) the biological constraints to achieve even higher yield levels under irrigated systems via new research developments; and c) the rice profit margins in rainfed systems are higher than those for irrigated systems. Therefore, these regions in contrast to the Central region appear to offer greater opportunities for the country's investment in rice production, because of both potential increases of yields and development of new areas.

Organization of Remainder of Thesis

The remainder of this study is organized into five chapters. Chapter II presents an overview on the neoclassical theory of the firm, the duality theory in production economics, a review of the concept of productive efficiency and a survey of empirical studies on efficiency at the farm and industry levels. Several programming and econometric models to represent the production process and to study productive efficiency are examined.

Chapter III presents the analytical approaches and methodological procedures used in this thesis. Emphasis is placed on using a rice budget approach, an average revenue approach and a stochastic revenue approach. In turn, these analytical frameworks are used to model the rice production process, analyze resource use and rice crop profitability, and study technical efficiency in the context of Cobb-Douglas functional forms. The chapter includes a discussion of the sample survey to generate the cross-sectional data used in this study, and the general procedure to determine and construct the variables in the model.

Chapter IV discusses the results of the estimated rice budgets and average revenue functions for selected scenarios in rice production, the associated resource use, cost-returns, rice profitability, resource productivity and resource returns analysis. Chapter V, presents the results of the estimated stochastic frontier total revenue function and the average technical efficiency measures for each scenario. Some policy implications of the derived efficiency values are then examined. Finally, Chapter VI covers the major conclusions, recommendations and limitations of this study raising from the overall analysis.

CHAPTER II

REVIEW OF LITERATURE

The Neoclassical Theory of the Firm: An Overview

The origin of the modern theory of the firm in economics is based on the notion of the set of production possibilities of the firm. This set consists of all feasible production plans available to the producing unit and is determined by the body of technological knowledge (technology) and physical laws.

Consider a vector of inputs $x \quad R^{+}{}_{n}$ such that $x = (x_1, x_2, \ldots, x_n)$ represents a specific input combination. Also, consider a vector of outputs $y \quad R^{+}{}_{m}$ such that $y = (y_1, y_2, \ldots, y_m)$ each component of y_i representing a different output. Then the set of production possibilities of the firm can be represented by the mathematical relation or inner product $R^{+}{}_{n} * R^{+}{}_{m}$. This relation can be expressed implicitly as the transformation function $T(x,y) \geq 0$, and embodies the set of technically feasible production plans that are opened to the firm.

A production plan is any pair of observed vectors (x_0, y_0) which satisfies the transformation function if the output vector y_0 can be produced from the input vector x_0. In that case (x_0, y_0) is a feasible production plan.

The traditional neoclassical theory of the firm can be developed from different alternatives based on the notion of the set of production possibilities in the input-output space. Jorgenson and Lau (1973) illustrated that given the properties of the set of feasible production plans, the production function, the profit function, and the cost function can be derived and characterized to represent economic behavior by the firm.

Certain mathematical properties or regularity conditions are required for any of these functions to meet the basic assumptions and the optimality conditions implied by the neoclassical theory of the firm. The regularity conditions of the relevant functions are summarized in Table VII. In general, these properties are automatically enforced if the set of production possibilities is restricted to be a continuous closed, proper, and convex set.

Following Diewert (1974), for any set of production possibilities T(x,y), the production function f(x) is a real-valued function giving maximum level of output y from any given bundle of inputs x. In that case, the transformation function becomes a strict equality such that T(x,y) = 0. Then, the production function is equivalent to the set of production possibilities frontier, or:

$$f(x) = \text{Max}_y \{x{:}x \in T(x, y) = 0\}$$

In turn, the profit function $\pi(y,x)$ gives the maximum value of profit for any feasible production plan T(x,y) as a function of input and output prices. Consider a firm which employ the vector of input x available at fixed prices $w = (w_1, w_2, \ldots w_n) > 0$ to produce the vector of outputs y that can be sold at fixed prices $p=(p_1, p_2, \ldots, p_m) > 0$. Then, the set of price and profit possibilities consisting of all maximum values of the production possibilities set T(x,y) can be represented by the mathematical relation $(pR^+{}_m - wR^+{}_n)$. This relation can be implicitly expressed as:

$$\pi(y,x) = \text{Max}_{y,x} \ \{yp' - xw' \mid f(x) \geq y\}.$$

Likewise, the cost function c(w,y) shows the minimum expenditure required to produce the feasible production plan T(x,y) at input prices w. Then, the set of price and cost possibilities embodying all minimum expenditures to

TABLE VII

REGULARITY CONDITIONS OF A NEOCLASSICAL PRODUCTION POSSIBILITIES SET, PRODUCTION FUNCTION, PROFIT FUNCTION AND COST FUNCTION IN THE INPUT-OUTPUT SPACE*

Properties	Production Possibilities Set T(x,y)	Production Function y = f(x)	Profit Function π(x,y)	Cost Function c(w,y)
Continuity[1]	Continuous in y and x	Continuous in x	Continuous in x and y	Continuous in w
Homogeneity[2]	Homogeneous of degree 1 in y and x	Homogeneous of degree 1 in x	Homogeneous of degree 1 in x and y	Homogeneous of degree 1 in w
Monotonocity[3]	Increasing in y and x	Increasing in x	Increasing in y and decreasing in x	Increasing in w
Convexity[4]	Concave in y and x	Concave or quasi-concave in x	Convex in x and y	Concave in w

*For a formal derivation and discussion of these properties see MacFadden (1978) and Jorgensan and Lau (1973).

[1] The continuity property ensures the derivative property of a well-behaved function which is implied by the neoclassical marginal productivity theory. Also, this property set up the boundary of the set of production possibilities which rule out the possibility that production plans arbitrarily close to the boundary are feasible while points on the boundary itself are not. That is, the function is closed.

TABLE VII (continued)

[2] Homogeneity implies that the sets of input and output quantities or the set of input and output prices of any function are closed under any positive scalar multiplication. A number of testable consequences are derivable of these properties concerning the principles of the marginal productivity theory. In the input space homogeneity requires that returns to scale be independent of the initial level of output (or the inputs), and that marginal rates of substitution do not change as the level of output increases along a ray.

[3] Monotonocity implies that the set of production possibilities is characterized at least by free disposal of x or y. Under the conventional theory of the firm there must exist free disposal of inputs so that the law of "diminishing" marginal productivity holds.

[4] Convexity implies that returns to scale are constant or decreasing and that there are no indivisibilities in the production process. Also, that marginal rates of substitution between inputs are non-increasing and that the marginal rates of transformation between outputs are non-decreasing, basic assumptions of the neoclassical theory of the firm.

produce the feasible production plan can be formally represented by the mathematical relation:

$c(w,y) = \min_X\{w'x \mid f(x) \geq y\}$.

The traditional approaches of the theory above assert alternative ways of optimizing behavior by the firm. The firm is assumed to achieve its goals subject to the limitations of a fixed set of feasible production plans and the economic environment. The resulting events of the theory are refutable propositions concerning the properties of input demands and output supplies their elasticities as well as comparative statics theorems consistent with optimizing behaviour on the part of a firm.

MacFadden (1978) points out that the optimizing behavior by the firm with regard to choice or decision variables conforming a set of variable outputs and inputs can be tested via the general representation of the production possibilities set and the price set as the parameter or test conditions. This approach leads to the purely logical aspects of the theory assembled in the profit function model $\pi(y,x)$. In special cases this model reduces to a maximum revenue function model $\pi(w,c)$ for a non-competitive firm, and a utility function $u[\pi(w,y)]$ for a firm which considers risky choices. In the latter case, risk is modelled through an expected utility model.

The simultaneous solution of the (n) first order conditions for $\pi(y,x)$ and $\pi(w,c)$ models yields n ordinary $x^*(w,p)$ and n constant-cost $x^*(w,c)$ input demand functions, respectively. Substituting $x(w,p)$ into $f(x)$ such that $f(x) = f[x^*(w,p)]$ leads to the output supply function $y(p,w)$. The supply function indicates maximum amount of output y that the firm would be willing to supply at the market place per unit of time at output prices p, given the fixed input prices w and the set of technically feasible production plan $T(x,y)$.

As stated by Silberberg (1978), in addition, the set of production possibilities of the firm may be influenced by prior institutional arrangements and by the physical and economic environment. These effects can be summarized in the vector $z = (z_1, z_2, \ldots, z_n)$. The production possibilities set $T(x,y; z)$ then depends on the value of the vector z, the test conditions.

The theory can be tested through the comparative statics mathematical technique to determine if refutable propositions are forthcoming. Mathematically, for any function, it is the properties of the derivative of $T(x,y)$ with respect to z, $(d \mid dz)\ T(x,y;z) = f'(z)$, that represents the potentially refutable propositions from the theory.

Duality Theory in Production Economics: An Overview

Duality theory in production economics is concerned with the existence under certain regularity conditions of dual production, cost, and profit functions in the price space. Dual functions embody not only the same fundamental information on the production possibilities set of the firm, $T(x,y)$, as the corresponding neoclassical primal functions but also information on optimizing behavior by the firm[1]. By adding differentiability properties corresponding to a set of interrelated mathematical lemmas some refutable propositions usually developed via the traditional neoclassical theory, can be more easily determined and analyzed.

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[1] Commenting on Diewert (1974), Lau identified at least three approaches to dual functions: (i) the conjugacy correspondence; (ii) the symmetric duality; and, (iii) the duality between the set of production possibilities and its support function.

The dual theory is embodied in three fundamental assertions:[2]

(1) an indirect production function $y^* = y^*(w,c)$, showing the maximum level of output attainable given the production set $T(x,y)$, the input prices vector w, and the cost constraint c;

(2) an indirect profit function $\pi^* = \pi^*(p,w)$ indicating the maximum level of profits associated with the given production set $T(x,y)$ and the input and output price vectors, p and w; and,

(3) an indirect cost function $c^* = c^*(w,y)$ reflecting the minimum cost associated with the input requirement set $v(y)$ given the input price vector w.[3]

To represent the optimizing behavior of the firm implied by the neoclassical theory of the firm, the indirect or dual functions must conform to the regularity conditions depicted in Table VIII.

The differentiability condition implies two fundamental properties which are the essence of the dual analytical framework: the derivative property and the symmetry property. The derivative property gives the theory the capacity to derive directly complete systems of factor demand and output supply relationships from dual functions with all of the theoretical requirements enforced.

This property is described by three fundamental lemmas of duality theory:[4]

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[2] As far as the duality lemmas are a direct result of the envelope theorem from mathematics, the dual functions can be identified as indirect objective functions.

[3] In duality theory notation, asterisks are used to denote that the dependent variable is the result of an optimization process.

[4] The symmetry property is embedded in the corresponding Hessian matrix.

TABLE VIII

REGULARITY CONDITIONS OF INDIRECT OR DUAL PRODUCTION FUNCTION, PROFIT FUNCTION AND COST FUNCTION IN THE PRICE SPACE

Properties	Production Function $y^*(w,c)$	Profit Function $\pi^*(p,w)$	Cost Function $c^*(w,y)$
Continuity	Continuous in w and c	Continuous in p and w	Continuous in w
Homogeneity	Homogeneous of degree 0 in w and c	Homogeneous of degree 1 in p and w	Homogeneous of degree 1 in w
Monotonocity	Non-increasing in w and non-decreasing in c	Non-decreasing in p and non-increasing in w	Non-decreasing in w
Convexity	Quasi-convex in w	Convex in w and p	Concave in w
Differentiability	Twice differentiable in w	Twice differentiable in w and p	Twice differentiable in w

(1). Hotelling's lemma. If an indirect profit function $\pi^*(p,w)$ satisfies the regularity conditions and is in addition differentiable with respect to output and input prices at $p_i>0$ and $w_i>0$, then:

$(\partial/\partial w_i)\ \pi^*\ (p,w) = -x^*_i\ (p,w)$ the profit maximizing demand for factor x_i; and,

$(\partial/\partial p_i)\ \pi^*\ (p,w) = y^*_i\ (p,w)$ the profit maximizing output supply for product y_i.

Hotelling (1932) introduced the indirect profit function and stated Hotelling's lemma in the single-output case. Samuelson (1953), MacFadden (1973), and Diewert (1973) have proven different duality theorems between the production possibilities set satisfying different regularity conditions and the profit functions.

(2) Roy's identity. If an indirect production function $y^*\ (w,c)$ satisfies the regularity conditions, and is once differentiable at w with

$$(\partial/\partial wi)\ y^*\ (w,c) \neq 0$$

(which implies that $(\partial/\partial wi)\ y^*(w,c)<0$ since $y^*\ (w,c)$ is non-increasing in w) then the solution to the production maximization problem when the producer faces prices w and has an expenditure constraint c is unique and equal to:

$$x^*_i\ (w,c) = [(-\partial/\partial w,c)\ y^*\ (w,c)\ /\ (\partial/\partial c)\ y^*\ (w,c)]$$

where $x^*_i\ (w,c)$ is the constant-cost demand for input x_i. Roy's (1974) identity was primarily concerned with the utility analysis. MacFadden (1973) presented the concept of indirect production function in the context of duality of production theory, based on the theoretical duality between the utility function $u(I)$ and the indirect utility function $u(p,I)$ where I is defined as the consumers "income" constraint. MacFadden regarded $f(x)$ as a production function (in which case $f(x)$ is nonnegative) and $y^*(w,c)$ as an indirect production function in that it gives the maximum amount of output the firm can produce, given an expenditure constraint of the form:

$$\sum_{i=1}^{n} x_i w_i \geq c.$$

(3) Shephard's Lemma. If the indirect cost function $c^*(w,y)$ satisfies the regularity conditions, and is once differentiable with respect to input prices at the point $w>0$, then

$(\partial/\partial w_i)\, c^*(w,y) = x^*_i(w,y)$ the constant-output demand function.

The duality theorems between the production function and the cost function are essentially due to Samuelson (1953) and Shephard (1953). Since then, the Shephard's Lemma has been proven or stated by many authors. Macfadden and Diewert provide a complete survey on detailed proofs of duality theorems relating to cost and production functions.

Two major implications of duality theory are: first, it is possible to postulate a differentiable functional form for a production, profit or cost function meeting regularity conditions and obtain the system of derived demand functions by differentiation; second, a production technology can be described interchangeably by either a production, or a profit or a cost function. Since each of these functions express the same information, then it is theoretically possible to derive the primal production function from the dual functions or viceversa.

The derivation of a cost function from a production function is generally understood in the context of the cost minimization problem.[5] However, the derivation of a production function from a cost function is less obvious and only possible by the use of Shephard's lemma. Silberberg (1978) illustrates the

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[5] $\text{Min}_x\,(w'x)$ subject to $T(x,y) = f(x) = 0$. By postulating a functional form for $f(x)$ and using either Lagrangian or mathematical programming techniques the minimal cost function $c^*(w,y) = x^*(w,y)$ is obtained.

self-duality property of the Cobb-Douglas function. Given that the derived input demands $x^*(w,y)$ represent n equations in $n+1$ unknowns, the solution procedure for w and y can be achieved by a simultaneous equation technique. The solution for y yields an expression in terms of input quantities and parameters, namely, the production function. Nerlove (1963) made use of this duality relationship to estimate the parameters of the production function of the electric power industry from the dual Cobb-Douglas cost function.

The knowledge of the regularity conditions for the dual functions permits derivation of the restrictions implied by neoclassical theory on factor demand and output supply functions as presented on Table IX. Hanoch and Rotshmild (1972) showed that when supply and demand functions are estimated as ad hoc separate single equations these restrictions are not usually enforced.

The slopes of $y^*(w,p)$ and $x^*(w,p)$ are a result of the convexity of $\pi^*(w,p)$ and Hotelling's lemma. By convexity the second derivative:

$$(\partial^2/\partial p\, \partial p')\, \pi^*(w,p) < 0.$$

Likewise:

$$(\partial^2/\partial w\, \partial w')\, \pi^*(w,p) > 0.$$

Similarly, the slope of $x^*(w,c)$ becomes indeterminate, because by Roy's identity the partial derivative of $y^*(w,c)$ with respect to w_i has indeterminate sign. That is:

$$\partial \left[\frac{-(\partial/\partial w)\, y^*(w,c)}{(\partial/\partial c)\, y^*(w,c)} \right] / \partial w = [\, -(\partial^2/\partial w\, \partial w')\, y^*(w,c)]\, [\, (\partial/\partial c)\, y^*(w,c)\,]$$

$$-\, [\, (\partial^2/\partial w\, \partial c)\, y^*(w,c)\,]\, [\, -(\partial/\partial w)\, y^*(w,c)\,] / [\, (\partial^2/\partial c\, \partial c')\, y^*(w,c)\,] \gtreqless 0,$$

$$\text{since } [\, (\partial^2/\partial w\, \partial c)\, y^*(w,c) \gtreqless 0$$

TABLE IX

PROPERTIES OF DERIVED DEMAND FOR INPUTS AND OUTPUT SUPPLY FUNCTIONS IN THE PRICE SPACE IMPLIED BY DUALITY THEORY

Property	Output Supply y* (p,w)	Ordinary Input Demand x* (p,w)	Constant-Output Input Demand x* (w,y)	Constant-Cost Input Demand x* (w,c)[1]
Slope	Non-negative	Non-positive	Non-positive	Indeterminated
Homogeneity (r)	r = 0 w.r.t. p	r = 0 w.r.t.w	r = 0 w.r.t.w	r = 0 w.r.t.w
Symmetry	Symmetric	Symmetric	Symmetric	Assymmetric

[1] The constant cost-input demand functions resembles the ordinary consumer demands in that both functions are assymmetric and have indeterminate slopes.

The second derivative of $c^*(w,y)$ with respect to w_i becomes the slope of $x^*(w,y)$ according to Shephard's lemma. Due to the concavity of $c^*(w,y)$ it can be shown that $(\partial^2/\partial w \partial w')\ c^*\ (w,y) < 0$.

The linear homogeneity of the dual functions implies the mathematical result that first derivatives of homogeneous functions of degree r, are homogeneous of degree r-1. The homogeneity of degree zero (r=0) for all the derived demands and supply functions is consistent with the neoclassical proposition that optimal input use (and the respective output level) depends on the ratio of input and output prices. It means that the optimal level of input use and output level of the firm are invariant to a equiproportionate change of both input and output prices.

The symmetry properties of the demand and supply functions are a consequence of the continuity regularity condition of the dual functions and the Young's theorem. This theorem states that if $y=f(x)$ have second order partials derivative that exist and are continuous, then $(\partial^2/\partial x_i \partial x_j)\ f(x) =(\partial^2/\partial x_j \partial x_i)\ f(x)$.

The symmetry property was established as a theoretical restriction on any system of cross-price effects since the pioneering works by Slutsky (1915), Hotelling (1932), Hicks (1946) and Samuelson (1947). Its imposition on applied economic research leads to econometric and statistical estimation advantages by reducing the number of parameters, conserving degrees of freedom, and eliminating multicollinearity problems. Following Young's theorem, if an indirect function is twice differentiable and continuous at input prices w or output prices p, then, the second partial derivatives exist at x or p. These derivatives take the form of a Hessian matrix of the function at x_0 or p_0, which is symmetric. That is, $(\partial^2/\partial w_i \partial w_j)\ f(x) = (\partial^2/\partial w_j \partial w_i)\ f(x)$ for $_{i,j} = 1,2, \ldots,$ n. A similar remark is extended at output prices p.

Duality theory also implies technological flexibility. That is, the robustness of the technology in adapting to changing economic conditions can be investigated via parametric models which allow the identification of particular economic effects while imposing no more restrictions than necessary in other aspects of technology.

According to Diewert (1974), the use of duality theory and the concept of flexibility provide an alternative to determine factor demands and output supplies when the technology is complex[6]. Flexibility portrays no prior restrictions on the elasticities of substitution or any other parameter to be estimated. Rather, flexibility permits to test for the regularity conditions of dual functions as well as for specific economic effects of technology such as returns to scale, distributive shares and substitutability. Diewert (1971, 1973), Christensen et. al. (1971), Lau (1972, 1974), MacFadden (1978), Berndt and Khaled (1979), and Pope (1982).

Most of the latest developments in efficiency analysis using frontier functions are duality based (Forsund et. al., 1980). Lau and Yotopoulus (1971) devised a non-frontier approach for measuring economic efficiency across firms through a dual profit function expressing profit level as a function of variable input prices and fixed input quantities. This model which is known in the literature as the Lau-Yotopoulus Unit-Output-Price-Profit Function, was used by O'Connor and Hammonds (1976) in a study of efficiency in the U.S. meat retail systems. Trosper (1978) employed the model to determine the ranching efficiency of Cheyenne Indian ranchers.

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[6] The notion of flexibility is based in approximation theory, and is referred to as the ability of any functional form to approximate some unknown functions. The idea is to provide the first and second order partial derivatives of an unknown function at some point, most often with a Taylor series expansion of exact functional forms such as Cobb-Douglas and Constant Elasticities of Substitution (CES).

The Concept of Productive Efficiency

The logical starting point of efficiency analysis in the context of the neoclassical theory of the firm is the set of production possibilities.[7] According to Debreu (1951), the concept of production function assumes efficiency in the sense of a transformation of inputs into outputs and full employment of resources. In such a case, the production possibilities set becomes a strict equality $T(y,x)=0$, and the concept of production possibilities frontier can be introduced. The production possibilities frontier defines the set of maximal vectors in the output space $R^{+}{}_{m}$ which can be obtained from any specified input vector x. Thus, given any vector x, the set of maximal output vectors feasible becomes $R_x(y)=\text{Max}_y \{x{:}x\,\varepsilon T(y,x)=0\}$. This set defines the conventional isoquant relationship. Similarly, given any vector of outputs y, the set of minimal input vectors feasible to produce y becomes $R_y\,(x) = \text{Min}_x \{y{:}y\ \varepsilon T(y,x) = 0\}$. This set also defines the conventional isoquant relationship.

Following Farrell (1957), the concept of productive efficiency is made up by two components: technical efficiency and allocative efficiency.[8] Since then, these measures have played a major role in evaluating economic efficiency of productive units, by using the concept of production possibilities frontier.

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[7] Forsund and Hjalmarson (1974) pointed out that efficiency measurements must be based on well specified theoretical concepts to ensure correct interpretations for economic policy. In this study, the notion of efficiency is based on the theory of production and it is hereafter referred to as productive efficiency.

[8] In some cases the production economics literature refers price efficiency as allocative efficiency. However, for the purposes of this research, price efficiency is understood to indicate efficiency associated with the proper pricing of output rather than efficiency of factor allocation decisions.

Farrell considered the observed production plan for a firm to be (y_o, x_o). Then, Farrell contended that a scalar λ could be found such that the vector: $y^* = \text{Max}_y \{\lambda y_o \mid \lambda y_o \in R_{xo} (y), \lambda \geq 1\}$ can be obtained.

Unless y_o itself belongs to the maximal set Rx_o (y), there will exist a λ strictly greater than 1 which meets the condition above. Thus, the fraction $\theta = 1/\lambda$ is a measure of the technical efficiency of the firm. Alternatively, a scalar γ could be searched such that the vector: $x^* = \text{Min}_x \{ \gamma x_o \mid \gamma x_o \in Ry_o (x), o < \gamma \leq 1\}$ can be determined where the fraction γ is the technical efficiency of the firm.

Farrell argued that neither the maximal output set R_x (y) nor the minimal input set R_y (x) are ordered sets. Although the introduction of the frontier concept reduces the set of relevant alternatives inside the feasible production set, a criterion function is required to choose from a set of non-dominated vectors. Market prices of inputs and outputs provide the required norm. For example the output price vector $p \in R^+_m$ can be used to search for a scalar revenue function $r = p'y \in R^+_m$. Therefore, the set $r \in R^+_m$ is completely ordered and the maximum revenue can be selected. Likewise, the input price vector $w \in R^+_n$ can be used to find a scalar cost function $c = w'x \in R^+_n$ and again the set is completely ordered such that the minimum cost can be chosen. In which case, r and c are regarded as a measure of allocative efficiency.

Both technical efficiency and allocative efficiency can be examined from either the input side or the output side. However, to determine productive efficiency specific assumptions on the optimizing behavior of the firm are required. Consider the firm is cost minimizing with output exogeneous. Suppose that the optimal input vector that minimizes $c = w'x$ subject to the condition that y_o should be produced is x^{**}. Then the minimum value of c is $c^{**} = w'x^{**}$. Also as the firm achieves technical efficiency at x^* to produce y_o, then the cost there will be $c^* = w'x^*$. Hence, the technical efficiency of the firm is defined by $\gamma = (w'x^* / w'x_0)$. Alternatively, allocative efficiency of the firm may be defined by $\sigma = w'x^{**}/w'x^*$.

The overall or productive efficiency of the firm is measured as $\varepsilon = w'x^{**}/w'x_0$ as the actual cost of the firm is $c_0 = w'x_0$. But ε can be factored as $[w'x^{**}/w'x^*] \times [w'x^*/w'x_0] = \sigma \times \gamma$. Since σ and γ must lie between 0 and 1, their product can become 1 if and only if each of them equals 1. Therefore, a firm can be regarded as being efficient, if and only if, it is technically efficient as well as allocatively efficient.

Farrell also noted that the observed plan (y_0, x_0) would result in full efficiency if the following conditions are simultaneously satisfied:

(i) for the input vector x_0, y_0 is the optimal solution to the problem

$\text{Max}_y\ p'y$

Subject to: $T(y,x_0) = 0$.

(ii) for the output vector y_0, x_0 is the optimal solution to the problem

$\text{Min}_x\ w'x$

Subject to: $T(y_0,x) = 0$.

If the price vectors are given parametrically, then, maximizing the ratio $p'y_0/w'x_0$ is equivalent to maximizing the difference $(p'y_0 - w'x_0)$, which is nothing but profit maximization. Since $r_0 = p'y_0$ represents the maximum value of the output (revenue) attainable from the input cost $c_0 = w'x_0$, the ratio r_0/c_0 is directly related to efficiency. However, under this assumption productive efficiency of the firm cannot be separated into technical and allocative efficiencies.

The earliest empirical application of the concept of production possibilities frontier to study efficiency concept was done by Farrell, in 1957. Farrell applied it in measuring productive efficiency in U.S. agriculture. Farrell rejected the conventional production function approach to estimate the production frontier on the ground that its results represent only an "average" function. He contended that the method of least squares in the usual form fails to estimate a "true" frontier production function. Consider the statistical model $y_t = x_t\beta + e_t$, where e_t is identically independently distributed as N $(0,\sigma^2)$. The estimated random residual vector $e_t = y_t - x_t\beta$ must have some positive and some negative values so that they all add up to 0. But, for any observation y_t, if $e_t > 0$ means that y_t exceeds the estimated frontier level $x_t\beta$. Hence, the frontier estimated by OLS is not really a frontier production function.

The econometric literature identifies at least three directions of research to solve this problem: programming models, econometric models, and duality theory based models.

Models to Measure Productive Efficiency

Programming Models

This sort of model assumes the maximal output vector $R_x(y)$ or the minimal input vector $R_y(x)$ to be taken with respect to the firms in the sample and define a "best - practice" frontier as posed by Farrell. Consequently, these models are classified as non-statistical in that they fit a parametric or non-parametric frontier without assuming the form of the distribution of the one-sided error. All of these models use mathematical programming techniques to estimate the frontier function. Typically, these models involve a ray comparison with a point which is collinear with the vector of actual inputs (input-based index) which lies on the relevant isoquant. Also, this comparison is made in the output space (output-based index). By assuming that $T(y,x) = o$ is linearly homogeneous both measures match.

(1) Farrell's model. Farrell considered a two-inputs (x_1, x_2) and one output (y) firm. The frontier production function $y = f(x_1, x_2)$ was assumed to exhibit constant returns to scale. Thus, $1 = f(x_1/y, x_2/y)$ such that the frontier technology is defined by the unit isoquant SS' depicted in Figure 2. Then, efficiency can be measured relative to the standard set by the unit isoquant. Let PP^1 represent the isocost line. If the observed production plan for the firm is (y_o, x_{11}, x_{21}) at point R in Figure 1, Farrell's model defines the ratio OB/OR as technical efficiency, the ratio OD/OB as allocative efficiency, and the ratio OD/OR as total productive efficiency. The model also assumes fixed factor proportions, fixed factor prices among firms, and homothetic technology.

Two main criticisms apply to Farrell's approach. First, the frontier is supported entirely by a set of sample observations and is, hence, particularly susceptible to extreme observations (outliers) and measurement error. Secondly, the assumption of constant returns to scale and homotheticity are restrictive. However, this model holds the advantage that no functional form is imposed on the data set.

The concept of productive efficiency as introduced by Farrell and its implications for modeling production processes and practical economic policy have not escaped the theoretical controversy which still surrounds the notion of efficiency. Hall and Winsten (1959), Leibenstein (1966), Forsund and Hjalmarson (1974), Stigler (1976), Leibenstein (1978), Kopp (1981), and Pasour (1981) have papers illustrating this controversy. In contrast, a considerable volume of theoretical work has been undertaken to extend the concept of efficiency measures based upon the concept of the frontier unit isoquant. The ongoing discussion of theoretical models on productive efficiency support the stochastic frontier model specification chosen in the present study.

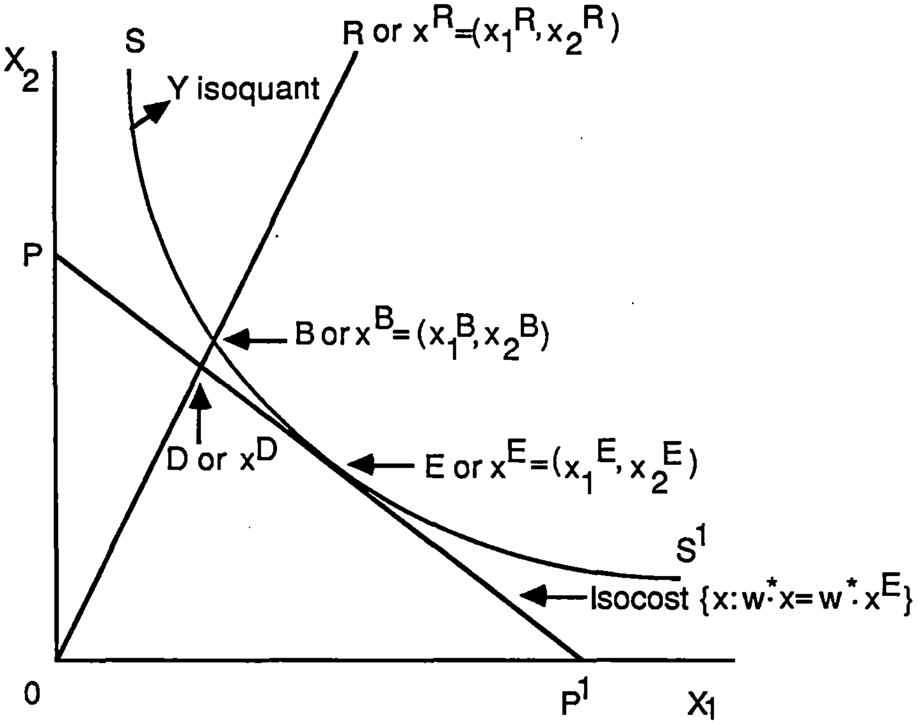

Figure 2. Farrell's Frontier Model

(2) Aigner and Chu's Model. Aigner and Chu (1968) applied the methods of linear programming LP and quadratic programming QP in an attempt to estimate a deterministic parameter frontier production function in the Cobb-Doublas form and estimate technical efficiency of production units.

Aigner and Chu considered the model: $y = f(x)e^{\mu}$ where: y is output of the firm, x are inputs, and μ is the disturbance term with $E(\mu) = 0$. This model specification implies that each residual μ should be non-positive such that the frontier restriction is satisfied as all observations require to be on or beneath the production frontier. Given a homogeneous Cobb-Douglas functional form

$$f(x) = \prod_{i=2}^{n} x_i^{a_i} e^{\mu} \tag{2.1}$$

then, the model may be rewritten in linear form as:

$$\ln y = a_1 + \sum_{i=2}^{n} a_i \ln x_i + \mu, \quad \mu \leq o \tag{2.2}$$

The random error term μ forces $y \leq f(x)$. The parameter vector a_i can be estimated by:

A linear programming approach to minimize the sum of the residuals subject to the constraint that each residual be non-negative. Hence:

$$\text{Min } (1)' (f(x) - y) \tag{2.3}$$

Subject to: $f(x) \geq y$, $a_i \geq o$, and $x_i \geq o$

A quadratic programming approach to minimize the sum of squared residuals subject to the same constraint. That is:

$$\text{Min } [y - f(x)]' [y - f(x)] \tag{2.4}$$

Subject to same constraints as (2.3) above.

The solution to (2.3) or (2.4) leads to parameter estimates a such that no observed output exceeds the frontier that is computed using these parameters.

The technical efficiency for each observation is computed directly from the vector of residuals, since μ represents technical inefficiency.

Aigner and Chu's model improved the Farrell's model in that it characterizes frontier production functions in a simple mathematical form, and does not restrict the underlying technology to constant returns to scale. That is, $\sum a_i = 1$ is not imposed a priori. This generality is achieved at the cost of specifying a functional form which imposes structure on the frontier that may be unwarranted.

To release the homogeneity, and homotheticity restrictions on the frontier as well as to deal with the problem of outliers, several methods have been developed. Seitz (1971), Timmer (1971), Forsund and Jansen (1977), Charnes, Cooper and Rhodes (1978), Forsund and Hjalmarsson (1979), Kopp (1981) and Kopp and Diewert (1982) among others have made remarkable contributions on these issues.

Seitz and Timmer focused attention on the problem of an "estimated" frontier extremely sensitive to outliers. The Seitz approach deals with grouping homogeneous observations on locational basis prior to estimation of input-based indexes of efficiency. However, while grouping observations that way may be feasible for non agricultural firms, this method would require homogeneous groups to be clustered by using multivariate statistical techniques to correct for factors completely outside the control of agricultural firms.

The Timmer approach to sensitivity to individual observations was first suggested by Aigner and Chu. Timmer estimated the frontier production function to derive output-based indices of efficiency from a LP analysis by using all observations available. Then, the approach is to discard those observations found efficient, to reestimate the frontier and so on. The process has to be repeated until convergence is obtained in the parameter values in successive estimates. Timmer called his model "probabilistic frontier" because he used a probabilistic inequality constraint p_r (f(x) > y) ≥ p, such that the observations discarded in earlier rounds would lie above the frontier. Nevertheless, the usefulness of Timmer's model will depend on the availability of adequate (large) number of observations and the rate of convergence of the parameters.

Forsund and Jansen, and Forsund and Hjalmarson focused attention on relaxing the linear homogeneity assumption and extending Farrell's approach to measure scale efficiency and technical change as well.

(3) Charnes, Cooper, and Rhodes' Model. This model extended the measurement of input-based indices of efficiency to the multiple output case. Consider a set of K firms each using the input vector x_i (i = 1, 2, . . ., n) and producing the output vector y_j (j = 1, 2, . . ., m). Therefore, for a given firm k the known production plan becomes (y_k, x_k). The model suggests the measure of efficiency for the firm k to be E_k. The LP formulation is:

$$\text{Max } Ek = (p'y_k/w'x_k)$$

Subject to: $p'y_t - w'X_t \leq 0,\quad \text{for } t = (1, 2, \ldots z)$

$$p,w \geq 0$$

The solution to the LP problem yields the values for vectors p and w, which serve as a proxy for market prices or "shadow prices". Evaluated at these prices the ratio of revenue to cost is to be the highest for the firm k, and no firm would be earning positive profits. In this sense this model becomes similar to Debreus' model which is concerned with the economy-wide problem of efficiency and general equilibrium.

Charnes, et. al. showed that the linear fractional programming model above has an equivalent LP formulation as:

$$\text{Min}_x\ C_k = w'x_k \tag{2.5}$$

$$\text{Subject to}\quad w'x_t - p'y_t \geq 0, \quad (t = 1, 2, \ldots, z)$$

$$p'y_t = 1; \qquad p,w \geq 0$$

The dual of this minimization LP is the problem:

$$\text{Max}_y\ E_k = p'y_k/w'x_k \tag{2.6}$$

$$\text{Subject to}\quad y\alpha \leq E_k \,.\, y_k,\ x\alpha \leq x_k, \text{ and } \alpha \geq 0$$

The resulting optimal E^*_k defines a feasible output vector $y^*_k = E^*_k .\ y_k$ collinear with the observed output of the firm k, y_k. The non-negative components of vector α serve as weights which are used to combine the processes of the z firms (including firm k) to produce the output vector y^*_k from the actual input of the firm k, x_k. The positive scalar E^*_k has a minimax interpretation. It is the minimum of the maximum expansion possible of the production level of m different outputs. Since E^*_k is the lowest of these growth factors over all outputs, it will be feasible for each component of the output vector. In this form $(1/E^*_k)$ is a measure of the efficiency of the firm k.

To conform to the notion of Pareto optimality, Charnes et. al. imposed the following conditions: $E^*_k = 1$; $y\partial^* = y_k$; and $x\ \partial^* = x_k$. Hence, any output or input slack should be counted in the objective function to avoid penalizing the firm in terms of the efficiency. Therefore, the problem is set up as:

$$\text{Max } F_k = E_k + \sigma \sum_j e^+_j + \sigma \sum_i e_i \tag{2.7}$$

$$\text{Subject to} \sum_t y_{jt}\,\partial_t - E_k\, x_{jk} - e^+_j = 0 \quad \text{for } (j = 1, 2, \ldots m)$$

$$\sum_t X_{it}\,\partial_t + e^-_i = 0 \quad (i = 1, 2, \ldots n)$$

$$e^-_i,\ e^+_j,\ E_k,\ \partial_t \geq 0$$

where ∂ is an arbitrary small positive real number, e^+ and e^- are the vectors of output and input slacks. The measure of efficiency in this problem is $(1/F^*_k)$.

After adjusting for slacks in the outputs and inputs a new output vector y^*_k and input vector x^*_k are obtained. In light of available processes the pair (y^*_k, x^*_k) lies on the frontier production function.

The remarkable contribution of Charnes et al model is that they visualized a possible linkage between programming methods and econometric (regression techniques) as a two-stage estimation procedure. At the first stage the corrected input and output data for all firms are obtained by LP solutions. These data can be used in a second stage to estimate the frontier production function in the usual econometric way. The linkage between the two methods has become the most striking issue in the contemporary literature of efficiency analysis, as shown by Kopp.

Overall, the programming models have several weaknesses. First, the parameters obtained by LP or QP are merely point estimates without associated statistical properties such as standard errors, t-tests, and confidence intervals. As pointed out be Afriat (1972) the fundamental problem here is one of a truncated distribution. Once an inequality constraint is imposed, the probability density function ordinarily lying in the infeasible region is now concentrated at the boundary point. According to Zellner (1963), no analytical results are derivable of the distributional properties of inequality constrained estimators without further assumptions on the regressors or the disturbance term in the frontier model.

Second, by virtue of an inherent property of the simplex LP algorithm the number of efficient firms operating on the efficient frontier cannot be more than the number of parameters to be estimated. This problem can be overcome by following a QP model which need not lie on a corner point of the feasible set.

Econometric Models

On the other hand, the econometric models assume the maximal output vector Rx(y) or the minimal input vector Ry(x) to be taken with respect to all the firms which could conceivably exist and embody current technology. Thus, these approaches define an frontier. The models are econometric approaches in what they specify the disturbance term to have an explicit distributional form. In constrast, parametric programming methods only require the disturbance to be different from 0. That is, $\mu \geq 0$. Two different formulations of the disturbance term in econometric frontier models are discernible from the literature: the deterministic approach and the stochastic approach.

The deterministic statistical approach assumes: (i) the random disturbance μ to follow a one-sided distribution (i.e. truncated normal, exponential, gamma etc.); and, (ii) the observations on μ to be independently and identically distributed with mean and variance given by the density function $f(\mu)$, and x to be independent of μ [$E(x'\mu) = 0$]. In this approach all firms share a common family of production, cost and profit frontiers and all variation in firm performance is attributable to variations in firm efficiencies with respect to the common family of frontiers. The model formulation which is known as a deterministic frontier was introduced by Afriat (1972) and extended by Richmond (1974) and Greene (1980).

The stochastic frontier approach is distinguished by a random disturbance term ($\varepsilon = \upsilon + \mu$) composed of two parts: (i) a one-sided component μ representing the degree of inefficiency; and, (ii) a symmetric component υ, representing either shocks entirely outside the control by the firm which affect the firm's performance (bad weather, input supply breakdowns, etc.) or the usual statistical "noise" that every empirical relationship contains (measurement error on the dependent variable or model misspecification with omitted variables individually unimportant). This formulation was introduced by Aigner, Lovell and Schmidt, and Meesum and Van Den Broeck in 1977.

Both approaches can be implemented to obtain frontier production functions f(x), as well as frontier cost functions c^* (w,y), and frontier profit functions π^* (w,p) using duality theory to determine both the technical parameters of the frontier functions, and the efficiency parameters simultaneously.

Forsund et al. (1980) restated the concept of productive efficiency within the framework of econometric models using duality theory. Consider a firm which is observed at production plan (y_0,x_0). This plan is said to be technically efficient if $y_0 = f(x_0)$ and technically inefficient if $y_0 < f(x_0)$ [Since $y_0 > f(x_0)$ is assumed to be impossible.] One measure of technical efficiency is given by the ratio $0 \leq y_0/f(x_0) \leq 1$. Technical inefficiency is due to excessive input usage which is costly, and so $w'x_0 \geq c^*(y_0,w)$. Since cost is not minimized, profit is not maximized and then $(py_0 - w'x_0) \leq \pi^*(p,w)$.

The plan (y_0, x_0) is said to be allocative efficient if $f_i(x_0)/f_j(x_0) = w_i/w_j$ and allocative inefficient if $f_i\,(x_0)/f_j\,(x_0) \neq w_i/w_j$.[9] Allocative inefficiency results from employing inputs in the wrong proportions which is costly, and so $w'x_0 \geq c^*(w,y_0)$. Since cost is not minimized profit is not maximized and $(py_0 - x'w_0) \leq \pi^*(p,w)$.

The firm is said to be scale efficient if $p = c^*(w,y_0)$ and scale inefficient if $p \neq c^*(w,y_0)$. It follows that $(py_0 - w'x_0) = \pi^*(p,w)$ if and only if the firm is technically, allocatively and scale efficient.

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[9] $f_i(x_0) = (\partial/\partial x_i)\, f(x_0)$ and $f_j\,(x_0) = (\partial/\partial x_j)\, f(x_0)$ correspond to marginal physical products for inputs i and j respectively. The ratio $f_i\,(x_0)\,/\,f_j\,(x_0)$ stands for the marginal rate of substitution of input i for input j.

On these theoretical grounds the following assertions can be made. Observed output supply y_0 and observed input usage coincide with profit maximizing output supply $y^*(p,w)$ and input usage $x^*(p,w)$ if and only if the firm is technically, allocatively and scale efficient. Observed expenditure $w'x_0$ coincides with minimum cost $c^*(w,y_0)$ if and only if the firm is both technically and allocatively efficient. If $w'x_0 > c^*(w,y_0)$ this difference may be due to technical inefficiency alone, allocative inefficiency alone or some combination of the two. Observed input usage x_0 matches with cost minimizing input demand $x^*(w,y_0)$ if and only if the firm is both technically and allocatively efficient. Finally, a combination of technical and allocative inefficiency may cause $x_0 > x^*(w,y_0)$ for at least some input i, but may cause $x_0 < x^*(w,y_0)$ for some other inputs j. Also, a combination of technical and allocative inefficiency is necessary but not sufficient for $(py_0 - w'x_0) = \pi^*(p,w)$.

Thus, the efficiency parameters of the econometric models are related to the assumed causes of inefficiency and are modeled by various stochastic disturbance structures.

(1) Afriat - Richmond - Schmidt Model

Afriat, Richmond and Schmidt through different papers considered the deterministic frontier model:

$$y_t = f(x_t)e^{\mu}. \tag{2.8}$$

They defined average efficiency by the expected value of the disturbance term $\mu = [\ln f(x) - \ln y]$, and assumed μ to be a one-sided disturbance having an hypothetical probability density function $f(\mu)$. Also, μ was assumed to be independent of x and non-positive for a production function or non-negative for a cost function.

Under the deterministic specification, individual (sample observations) output-based indices of efficiency can be determined by the ratio $e^{\mu} = y_t / f(x_t)$, where $f(x_t)$ is the frontier functions.

Afriat (1972) who was the first to propose this model in its general form, used a two-parameter beta distribution for μ with expected value equal to $[(\alpha / (\alpha + \beta)])$ where α is the shape parameter and β is the scale parameter. Afriat pointed out that an appropriate way of capturing the idea that f(x) represents a full frontier is to treat μ as a random variable taking values between 0 and 1. In the absence of any prior theory about the form of the distribution of μ, Afriat selected the Beta distribution. Afriat devised a maximum likelihood estimation procedure for the model.

Richmond (1974) extended the model to the Cobb-Douglas form, which under the current assumptions of decreasing and constant returns to scale implies a gamma distribution for μ with expected value (θ/λ), where θ is the shape parameter and λ the scale parameter. He noted that the choice of a distribution for μ is crucial because the maximum likelihood estimates (MLE) depend on it; that is, different assumed distributions yield different estimates. Richmond also noted that as long as $y \leq f(x)$ the MLE estimates of f(x) are not assymptotically efficient because they are not using all the available information on the range of y and suggested the corrected ordinary least squares (COLS) estimation procedure.

Schmidt (1976) explicitly added a one-sided disturbance to the statistical model and showed that if μ is exponential then Aigner and Chu's L P procedure is maximum likelihood and their QP procedure is maximum likelihood if μ is half-normal. Schmidt also showed that MLE estimates were not assymptotically efficient.

Greene (1980) reviewed the maximum likelihood properties of the estimators for this model. Greene showed that the assymptotic efficiency property of MLE still held if the distribution of μ satisfies: (i) the density of function $f(\mu) = 0$ at $\mu = 0$, and (ii) the derivative of μ with respect to its parameters approaches zero as μ approaches zero. Greene noted that the gamma distribution not only satisfies this criterion but also has a greater flexibility in the shape parameter θ. Even more Green showed that the gamma function does not violate one of the regularity conditions of the ML estimation procedures, that requires the range of the dependent variable to be independent of the parameter values. Greene also contended that a consistent though biased estimate of the intercept is generated by the COLS procedure.

However, as pointed out by Lee (1983) any specification of density functions for random distribution should be based on information about the economic mechanisms generating the inefficiencies. In spite of this, in empirical studies such information is not available and the choice of a distribution must be based on evaluation of alternative distributions by statistical means.

Overall, the deterministic frontier models are extremely sensitive to outliers and measurement errors. Also, the application of either MLE or COLS estimation procedures do not warrant estimators with all assymptotic properties unless a density function such as the gamma distribution is selected. Aigner, Amemiya and Poirier (1976) constructed a more reasonable error structure than a purely one-sided one. Specifically, they assumed

$$\mu_i = \begin{cases} \mu_i / \sqrt{1-\theta} & \text{if } \mu_i^* > 0 \quad \text{for } i = 1, \ldots, n \\ \mu_i / \sqrt{\theta} & \text{if } \mu^*_i \leq 0 \end{cases}$$

where the errors μ^*_i are iid $N(0, \sigma^2)$ for $0 \leq \theta \leq 1$; otherwise μ^*_i has the negative truncated normal distribution as $\theta = 1$ or the positive truncated nomal when $\theta = 0$.

Aigner et. al. justified their error specification assuming that firms differ in their production of y for a given set of values of x according to random variations in their ability to utilize "best practice" technology (a source of error that is one-sided ($\mu_i \leq 0$) and/or measurement error in y, a symmetric error. The parameter θ is interpreted as the measure of relative variability in these two error sources and its values bound the full frontier function for $\theta = 1$, or the average function for $\theta = 1/2$.

Even though Aigner et. al. contribution amelliorated some of the criticisms on the deterministic frontier model their model does not allow for random shocks in the production process which are outside the firm's control. As a consequence, few extreme observations determine the frontier and overstate the maximum possible output given inputs. Also, the usual large sample properties for the ML estimates can not be claimed under the usually assumed one-sided distributions, i.e., truncated normal and exponential. Therefore, a more direct approach to model the error process implied by this behavioral consideration was deemed to be required. This requirement was achieved in two simultaneous but separate contributions by Aigner, Lovell and Schmidt (1977) and Meeusen and Van Den Broeck (1977).

(2) Aigner, Lovell and Schmidt (ALS)'s Model.

Aigner et. al. considered the statistical model

$$y_t = f(x_t)\, e^{\varepsilon} \tag{2.9}$$

The model assumes the error structure to be composite as $\varepsilon = \upsilon + \mu$, where υ represents the symmetric disturbance which cause f(x) to vary across firms and μ reflects inefficiency. Inefficiency is measured through the expected value of μ. Also, the model assumes υ are iid $N(0, \sigma^2_\upsilon)$, μ to be one-sided disturbance independently distributed of υ and to satisfy $\mu \neq 0$ to ensure that all observations lie on or within the cost ($\mu \geq 0$) or production frontier ($\mu \leq 0$). ALS considered μ to have a truncated normal distribution. That is, μ is $|\,N(0, \sigma^2_\mu)|$ below zero. Therefore, the ALS's model may collapse to a deterministic frontier when $\sigma^2_\upsilon = 0$. Similarly, the stochastic model collapses to the Zellner, Kmenta and Dreze (1966) average function when $\sigma^2_\mu = 0$.

ALS contended that the economic logic behind this specification is that the production process is subject to two economically distinguishable random disturbances. First, some factors are under the firm's control, such as technical and allocative inefficiency, the will and effort of the producer, and defective and damaged products. These factors reflect the fact that each firm's output must lie on or inside its frontier $[f(x_t) + \mu]$. Second, some factors are outside the firm's control. Therefore, the frontier itself can vary randomly across firms or over time for the same firm. In this sense, the frontier is stochastic, with the random disturbance $\upsilon \geq 0$ being the result of favorable as well as unfavorable external events such as, luck, climate, topography, and machine performance. Errors of observation and measurement on y are another components of $\upsilon \geq 0$.

ALS devised a maximum likelihood estimation procedure of model (2.9). Under the assumption of independence between υ and μ the probability density function of the composed error $f(\varepsilon)$ is computed as the sum of two independent random variables with probability density functions $f(\upsilon)$ and $f(\mu)$, respectively. Because of the inclusion of the symmetric error, e^υ, all large sample properties of ML estimators are claimed from the stochastic frontier.

Meeusen and Van Der Broeck (1977) developed a similar model. They assumed a multiplicative composed disturbance ε, as that in (2.9) with an exponential distribution for μ. As ALS did, they used a MLE procedure of model (2.9).

Aside from an empirical application by ALS on the U.S. metals industry, few empirical studies on efficiency have been carried out by using the stochastic frontier model. Lee and Tyler (1978) applied the model to assess average technical efficiency of the Brazilian manufacturing industry, and the Colombian small scale manufacturing industry. Bagi (1983) studied technical efficiency in west Tennessee agriculture. Schmidt and Lovell (1979, 1980), extended the model by considering the duality between a Cobb-Douglas stochastic frontier production and cost functions in the U.S. private electric power industry. Green (1980), developed a method of estimating the stochastic frontier model by using flexible functional forms and duality theory. The method was illustrated with data on the U.S. manufacturing industry. In turn, Meeusen and Von Den Broeck applied their model to study efficiency of the French manufacturing industry. Extensions of this model are found in a study by Van Den Broeck et. al. (1980) of the Swedish milk industry.

Duality Theory Based Models

Aside from the programming frontier models and econometric frontier models already discussed to assess average and individual measures of economic efficiency, it is possible to investigate efficiency without explicit use of frontier models with one-sided error disturbance.[10] These models are based on duality theory and due to Lau and Yotopoulus (1971), Toda (1978), and Kopp and Diewert (1982).

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[10] Some other ad-hoc approaches are found in the literature. Lingard et. al. (1983) used a covariance analysis with a view of examining efficiency differences among small rice farms. Herdt and Mandac (1981), used a conventional production function approach to determine differences in technical efficiency between experimental plots and farmers' fields.

(3) Lau and Yotopoulus's Model.

The model considers a sample of n firms partitioned into two large-scale and small-scale groupings (75). The prediction model is $y_i = k_i f(x_i)$ for i = 1, 2 where $k_i > 0$ defines an index for technical efficiency. By assuming profit (gross-margin) maximizing behavior on the part of the firm subject to the prediction function, a dual profit function is set up as $\Pi^*(p,w)$. Then, the first-order conditions for a normalized $\pi^*(p,w_i, k_i, \lambda_i)$ dual profit function are $k_i (\partial/\partial x^*_{ij}) f(x^*_i) = \lambda_{ij} (w_{ij} / p_i)$ for i = 1, 2 and j = 1, . . ., n, where λ_{ij} defines an index for allocative efficiency.[11]

The model allows analysts to test equal technical efficiency ($k_1 = k_2$), equal allocative efficiency ($\lambda_{1j} = \lambda_{2j}$), equal economic efficiency ($k_1 = k_2$, and $\lambda_{1j} = \lambda_{2j}$), and absolute economic efficiency ($\lambda_{1j} = \lambda_{2j} = 1$). The major shortfalls of the model are: (i) it is unable to investigate efficiency in a firm-by-firm basis, and (ii) the functional form chosen for the prediction function must be sufficiently tractable (self-dual) to get the corresponding profit function. So the model is restricted to homogeneous and homothetic technologies.

(4) Toda's Model.

Toda (1976) investigated economic efficiency by using a generalized Leontief average cost function approach and duality theory. Toda considered the output normalized dual cost function:

$$c^*(w,y)/y = \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_{ij} [w_i w_j]^{1/2} \quad \text{where } \alpha_{ij} = \alpha_{ji} \tag{2.10}$$

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[11] The profit-maximizing ordinary demand functions $x^*_i = x^*_i (p,w_i)$ are derived from the normalized profit function by using Hotelling's lemma. The indexes k_i and λ_{ij} are incorporated into the normalized dual profit function, also known as the unit output-profit function (UOP).

By Shephards Lemma the constant-output average cost minimizing input demand functions are:

$$x^*_i\,(w,y)\,/\,y = 1/2 \sum_{j=1}^{n} \alpha_{ij}\,[\,w_j/w_i\,]^{1/2} \qquad (2.11)$$

To investigate allocative inefficiency equation (2.11) is transformed as:

$$x^*_i\,(w,y)\,/\,y = 1/2 \sum_{j=1}^{n} \alpha_{ij}\,[\,\lambda_{ij}\,(w_j/w_i)\,]^{1/2} \qquad (2.12)$$

Where λ_{ij} measures allocative inefficiency. Then, the observed average cost function can be rewritten as a generalized Leontief function:

$$w'\,[\,x^*_i\,(w,y)\,/\,y] = \sum_{i=1}^{n} \alpha_i\, w_i + 1/2 \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_{ij}\,[\,\lambda_{ij}\,(w_j/w_i)\,]^{1/2} \qquad (2.13)$$

It is clear that for any $\lambda_{ij} \neq 1$ then $w'\,(x^*|y) > c^*(w,y)\,/\,y$ which reflects that allocative inefficiency is costly.

The major advantage of Toda's model is that it can be implemented on a flexible functional form. However, the parameters λ_{ij} are not firm-specific but an average measure of inefficiency. Forsund et. al. (1980) points out that non-frontier models are more difficult to estimate and yield average measures of allocative efficiency. It does not provide information on technical efficiency as compared to frontier models.

(5) Kopp and Diewert's Model.

As pointed out by Forsund et. al. (1980), Kopp (1981) and Waldman (1984) the efficiency measures through the disturbance term specification in statistical frontiers are transformations of estimated parameters and, therefore, cannot be obtained for each observation. That is, $e^{\mu} = y_t\,/\,f(x_t)\,e^{\upsilon}$ and the output-based index cannot be estimated for each data point. In fact, to the extent that the expected value of the one-sided distribution disturbance μ is assumed to measure efficiency and υ is unobservable no measure can be obtained for each individual firm, but only an average measure of efficiency over the entire sample, given by the expectation of ε $E(\varepsilon)$.

In an attempt to rectify this shortcoming, Kopp (1981) proposed an approach which is a synthesis of Farrell's model and a deterministic frontier (Afriat-Richmond-Schmidt model). Kopp's model provides a series of efficiency indices that are available for each firm belonging to a specific peer group.[12] These indices capture the technical, allocative and productive efficiency of individual inputs at either firm level or aggregate level without imposing homogeneity and homotheticity restrictions on the technology.

Kopp and Diewert (1982) extended the model to generate Farrell indexes of productive efficiency by using a frontier cost function as efficiency standard instead of a frontier production function which is usually subject to the problem of severe multicollinearity. This model draws heavily on duality theory, requires no direct knowledge of the production frontier specification or its parameters, permits flexible functional forms, and utilizes only the information contained in the cost function to derive technical and allocative measures of efficiency.

The Kopp and Diewert's generalization of Farrell's indexes is depicted in Figure 2. This model assumes SS' is not the unit isoquant efficiency standard but the efficient isoquant associated with an efficient production surface, specifically, a deterministic frontier cost function.[13] The efficiency measures are defined as the ratio of two vector norms. The point R, B and E are now

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[12] As defined by Kopp (1981), "a peer group could be an industry if that industry shared a common technology . . ."

[13] A full frontier function is estimated by using methods which assume an explicit distributional form by the one-side disturbance term.

denoted in terms of their coordinates as: x^R, x^B and x^E. Technical efficiency (TE) is defined as: $\| x^B \| / \| x^R \|$; allocative efficiency (AE) as: $\| x^D \| / \| x^R \|$, and productive efficiency (EE) as $\| x^D \| / \| x^R \|$.

The model assumes the relative factor prices $w^* = (w^*_1, w^*_2)$ are embodied in the isocost line (PP'). Then, the equation of PP' is $\{ x: w^* \cdot x = w^* \cdot x^E \}$, and yet TE is equal to the ratio of total cost at R to total cost at B, $w^* \cdot x^R / w^* \cdot x^B$, and AE is the ratio of the cost at E to the cost at R, $w^* \cdot x^E / w^* \cdot x^R$.

Also, the model states that the frontier cost function dual to the technology is defined by $c^*(w,y)$. Let $w^* > 0$ be the price vector which corresponds to the price line PP'. Also, let y^* be the output that the inefficient point x^R produces. Then by Shephard's Lemma, the coordinates at point E, x^E, may be found by differentiating the cost function so:

$$x^E = \partial c^*(w^*, y^*) / \partial w^* = [\partial c(w^*, y^*) / \partial w_1, \ldots \partial_c(w^*, y^*) / \partial w_n], \text{ and } y^* > 0.$$

The point x^D may be found as the intersection of the line joining the origin to x^R with the isocost line PP'. Thus, $x^D = \lambda^D x^R$ where $\lambda^D = c^*(w^*, y^*) / w^* \cdot x^R$.

In turn, $x^B = (\partial / \partial w^B)\, c^*(w^B, y^*)$ (2.14) for the set of input prices $x^B > 0$. Also, since x^B lies on the line joining the origin to x^R, $x^B = \lambda^B x^R$ (2.15) where $\lambda^B > 0$ is a scalar to be determined. Equations (2.14) and (2.15) constitute a system of 2n equations and 2n+1 unknowns, x^B, w^B, and λ^B. The system is underidentified and an additional equation is required to determine x^B. To do so, the nth input price vector w^B in equation (2.14) is normalized such that $1 = x^B_n$ (2.16). Hence, the system of equations is now:

$$x^B = (\partial / \partial x^B)\, c^*(w^B, y^*) \tag{2.14}$$

$$x^B = \lambda^B x^R \tag{2.15}$$

$$1 = w^B_n \tag{2.16}$$

Since $x^B_1 = \lambda^B x^R_1$ (2.17), by dividing (2.15) into (2.17) λ^B is eliminated to get n non-linear equations of the form $x^B / x^B_1 = x^R / x^R_1$ that is:

$x^{B}_{1}/x^{B}_{1} = x^{R}_{1}/x^{R}_{1}$

$x^{B}_{2}/x^{B}_{1} = x^{R}_{2}/x^{R}_{1}$

"

" (2.18)

"

$x^{B}_{n}/x^{B}_{1} = x^{R}_{n}/x^{R}_{1}$

By substituting (2.16) into (2.14) the following system of non-linear equations is obtained.

$(\partial/\partial w^{B}_{1})\, c^{*}(w^{B}_{1}, \ldots, w^{B}_{n-1}, 1, y^{*})$

$(\partial/\partial w^{B}_{2})\, c^{*}(w^{B}_{1}, \ldots, w^{B}_{n-1}, 1, y^{*})$

"

" (2.19)

"

$(\partial/\partial w^{B}_{n})\, c^{*}(w^{B}_{1}, \ldots, w^{*}_{n-1}, 1, y^{*})$

To solve for x^{B} the system of 2n-1 non-linear simultaneous equation in (2.18) and (2.19) in the 2n-1 unknowns $x^{B}_{1}, \ldots, x^{B}_{n}, w^{B}_{1}, \ldots, w^{B}_{n-1}$, must be computed. Once the values for x^{B}, x^{D} and x^{E} are computed, the resulting generalized indexes of technical efficiency, allocative efficiency and productive efficiency can be measured.

Kopps and Diewert contended that the method is reliable and easy to use even in the case of complex representations of the technology (non-homothetic, non-neutral technological change). However, the problems of estimation of deterministic frontier functions are ignored, in such a way that the effects of outliers, choice of a distribution for the disturbance term and the associated method of estimation (MLE vs. COLS) may still remain. Moreover, the model as presented by Kopps and Diewert is a deterministic frontier function and may not be compatible with economic reasoning behind stochastic frontier functions in studying efficiency. Nevertheless, Kopp (1981) contends that composed error models of the ALS class are specifically excluded because Farrell measures assume all deviations from the efficient surface to be the result of inefficiency. Russell and Young (1983) used alternative technical efficiency measures including those of Timmer and Kopp to assess the relative performance of farmers in the Northwest of England.

A number of recent econometric studies deal with the problem of the inability of stochastic frontier models to yield individual measures of inefficiency. In an attempt to rectify this short-coming of the stochastic frontier model, Jondrow et. al. (1982), proposed estimating the firm level inefficiency with an estimate of the conditional expectation of u given ε, $E(u|\varepsilon)$. To obtain estimates of $E(u|\varepsilon)$, residuals from estimating the stochastic frontier model are used as inputs into the conditional distribution of u given ε, $f(u|\varepsilon)$.

Waldman (1984) extended the Jondrow et. al. approach by adding a linear unbiased estimator and a best linear prediction estimator. He concluded that all three estimators are slightly identical. Hence, the problem of measuring individual effects is overcome by following any of these procedures.

Lee (1983) argued that since there are no prior arguments to choose any particular one-sided distribution for μ the inefficient component in the stochastic frontier functions, and the empirical results are different for different distributional assumptions, the choice should be based on statistical means. Lee proposed a Lagrangean multiplier test which is able to test for a broad class of distributions (half-normal, truncated normal, exponential and gamma distributions). The empirical results are deemed to be successful.

Schmidt and Lin (1984) sugested to use tests of normality of the residual term ε, to determine the correct model specification. Two suggested tests are: the Jarque-Bera assymptotic Lagrange multiplier and the skewness test.

However, both tests entail nested hypothesis which may yield type II errors in specifying the model since normality does not imply the frontier specification conforms with the data.

Most of empirical studies on efficiency using stochastic frontier functions have addressed technical efficiency issues. One major reason seems to be that technical efficiency is easier to estimate from a production function than is allocative efficiency. This is particularly true if functional relationships are expressed by flexible functional forms which are not self-dual. Estimating allocative efficiency from non-self-dual stochastic cost functions poses the problem that the disturbance term in the cost minimizing input demand functions is related to the disturbance term in the cost function but not in any obvious manner.

Greene (1980) developed an estimation procedure of a deterministic frontier production function using flexible functional forms, and one-sided disturbance specification. This method permits one to estimate average and individual levels of technical efficiency. Individual estimates of efficiency for each observation point are derived from the estimated residuals at each data point. Greene suggested that this methodology could be extended to study productive efficiency in a stochastic cost function frontier framework. However, Greene's suggestion has not been tested empirically yet.

Kopp (1981) stated that deviations from minimum cost models can result from both technical and allocative mistakes. Hence, the cost approach alone cannot identify these two sources of inefficiency, unless a self-dual functional form such as the Cobb-Douglas or the constant elasticity of substitution CES be selected. As shown by Schmidt and Lovell (1979) exact functional forms are self-dual and allow the derivation of the parameters of the underlying frontier production function from the estimated frontier cost function or vice versa. Flexible functional forms do not permit this correspondence.

In summary, the main body of the contemporary econometric literature has focused attention on three major problems of the frontier models: the measure of efficiency at individual observations in the stochastic model; the assumed distribution of ε; and, the estimation procedures. Since the stochastic frontier specification nestes both the deterministic frontier specification and the average function specification as special cases, this review of literature suggests that the stochastic frontier model should be the most appropriate model to study efficiency in rice production. Hypothesis testing on the variance of the disturbance term could then substantiate the empirical validity of this model.

CHAPTER III

ANALYTICAL FRAMEWORK AND METHODOLOGY

The Rice Production Technology Model

Theoretical Framework

This study assumes that the process of rice production can be described by a stochastic frontier production function $y = f(x)$ which is continuously twice differentiable, strictly monotone and strictly quasi-concave. Corresponding to this production function there exists a unique frontier total revenue function $r(x;p)$ giving the maximum total revenue from producing y during a given period of time, using inputs vector x at price vectors p and w.

The theory of the firm implies restrictions on the functional form of r at the total revenue function. A list of these restrictions are:

(a) positive linear homogeneity. $r(x;p)$ is a positive valued function and homogeneous of degree one in x, $\lambda r(x;p) = r(\lambda x;p)$;

(b) homothetic production technology, $r(x;p) = h(y)\, r(x;p)$;

(c) monotonocity, $(\partial/\partial p)\, r(x;p)>0$ where $i=1, . ., n$;

$(\partial/\partial x)\, r(x;p)>0$; and,

$x'(\partial/\partial x)\ r(x;p) = r(x;p)$;

(d) convexity, $(\partial^2/\partial x\, \partial x')\, r(x;p)$ is a negative semi-definite matrix of rank n-1; and,

(e) symmetry, $(\partial^2/\partial x_i \partial x_j)$ r(x;p) = $(\partial^2/\partial x_j \partial x_i)$ r(x;p) or the Hessian matrix containing the second partial derivatives of the total revenue function is symmetric.

Thus, the total revenue function is the true model if it is positive and non-decreasing in x and p, positive linearly homogeneous in x, quasi-concave and continuous in x.

If r(x;p) is the set of total revenue functions that satisfy restrictions (a) to (e) above, then, the estimated frontier total revenue function can be used as a standard of efficiency if technical, allocative and productive efficiency are to be identified.

The behavioral assumption underlying the total revenue formulation is that rice producers are profit maximizers-seekers and attempt to maximize net revenue of paddy rice subject to input and output prices and the production technology. Thus, input prices and output prices are exogenous while input demands, total output and total revenue (sales) are endogenous.

This theoretical profit-maximization approach is stated as appropriate to fit institutional realities faced with by Colombian rice farmers over the last decade. While output price is set by the government, all input prices are considered to be exogenous variables. For example, since a small proportion of total capital used in the whole economy goes into agriculture, the price of capital is determined outside this sector. In fact, interest rates are also fixed by the government as well as the rate of growth of money supply.

Similarly, it is accepted that except for coffee and cotton, the minimum wage rate corresponds to an exogenously determined base farm wage. Chemical inputs and machinery are energy intensive and prices of energy based inputs are strongly influenced by energy prices, import tariffs, exchange rate, and internal marketing margins which are exogeneous. Even though the agricultural sector is the major user of land, the rental price of land is exogenously determined by speculative forces (land ownership concentration) and inflationary effects.

To achieve the objectives of this study, the production of rice is investigated within an ex-post, static and partial equilibrium setting. The resource use, rice profitability, returns to land, labor, capital and technical efficiency issues are examined ex-post assuming that the ex-ante production decisions by farmers have been made (choice of production process technology). Thus, what is observed is the operation of the ex-post technology within a particular environment (scenario). The measures of relative performance of the rice production industry are developed assuming that all farms in each scenario were utilizing identical technology or corresponding to a peer group of farms. By selecting a peer group with like technologies, it is possible to abstract from ex-ante decisions.

The analysis is static because it describes the relative performance of peer groups of rice farms at a single point in time using cross-section production data on a survey of rice fields. A shortcoming of this approach is that rice decision-makers plan for uncertainty and insure against risk. Therefore, only in a dynamic setting where economic performance of farms is measured in several time periods would it be possible to capture the effects of dynamic decisions on economic performance of farms. However, in the present research, it is stated that dynamic decisions pertain to the ex-ante decisions of individual rice farms where all factors are variable and alternative technologies capable of producing a particular output may be freely chosen.

The ensuing analysis is carried out in a partial equilibrium setting in that all production factors are examined individually. Indeed, a major goal of this study is to evaluate the performance of individual resources rather than comparing the performance in the combination of resources within farms operated under like technologies.

In this study, rice production is defined as a typical commercial farming activity. Major links between rice farms and the rest of the economy are given in terms of outflows for the rice output sold and rice farm payments and inflows made by rice farm receipts and goods and services for farm use. Therefore, rice farms can be viewed as a business and engage its performance by well-known business criteria. Three major measures of rice farms economic performance are developed: resource use, rice profitability and technical efficiency. The analytical approaches used in this research on each one of these rice farm performance measures are discussed next.

Resource Use and Rice Profitability

A major hypothesis of this study was that rice production might not be a cost-efficient process because of a seemingly overuse of land, labor and non-real capital resources. Individual use of inputs appeared to exceed an economical optimum, reducing potential profit margins and returns to farmer's investments in production resources. To test this hypothesis, two approaches to the conventional theory of the firm: rice enterprise budgets and "average" total revenue functions were fitted to cross-section data on rice farms. Both approaches were implemented for different biological, socio-economic and institutional settings (constraints) which could affect rice profitability and, as a result, lead to different patterns of resource use by decision-makers. Rice variety type, rice crop size, land tenure classes, production regions and cropping systems were selected as possible scenarios because:

(a) rice farms planting introduced rice varieties from outside (IR-22) appeared to be less cost-efficient production units than rice farms cropping locally developed rice varieties. Because the introduced varieties were suffering higher susceptibility to the weeds-pest-diseases complex than the locally developed varieties, the level of resource use for farmer's planting introduced varieties could be expected to be very high with lower profitability and returns to inputs than farmers sowing locally developed varieties;

(b) small rice farms could be expected to be less cost-efficient than large rice farms because of potentially higher fixed costs of production with lower rates of return to inputs and lower profitability;

(c) tenant-operated rice farms might be expected to be less cost-efficient than owner-operated farms because the relatively high rental price for land would lead to higher fixed costs affecting resource use and cost-efficiency; and,

(d) rice farms in the Central region growing rice under irrigated systems could be expected to be less cost-efficient than rainfed-rice farms in the Llanos region, because of substantially higher levels of both variable and fixed costs of production. Hence, a lower relative rice profitability and returns to resources could be stated for farmers cropping irrigated rice in the Central region.

The ongoing analysis on resource use and rice profitability using conventional theory of the firm assumes that all farms in the sample are profit-maximizers, technically efficient, and produce homogeneous outputs from homogeneous inputs. Therefore, the estimated average total revenue function states the maximum total output value attainable from every possible input combination. Yet, all deviations from the revenue function are due only to random factors outside the farm's control. The major concern is, thus, with single-factor use and cost-efficiency as compared with a theoretical optimum determined where Marginal Revenue Product (MRP) equals Marginal Factor Cost (MFC).

However, it should be pointed out that the "average" revenue function approach neglects the existence of technical inefficiency and nonhomogeneous inputs. As a result it may not be an appropriate representation of the farm's production function. Zellner et al (1966) have shown that when a model ignores technical efficiency it might yield biased parameter estimates and larger standard errors than does a correctly specified model, and thus increases the probability of accepting the hypothesis that a given input does not have influence on the output (Error type II).

The Empirical Models

The rice enterprise budgets were prepared ex-post as a listing of all estimated average total revenue and expenses associated with rice production. The estimated budgets provided an estimate on actual average levels of resource use, resource price paid for by farmers, observed yields per hectare, rice output price received by farmers in the sample, and relative crop profitability. The standard procedure to organize enterprise budgets contains information on total revenue, variable costs and fixed costs, as indicated in the last section of this chapter.

The study assumes that resource use input and output prices and profits in rice production are normally distributed random variables. Therefore, the observed levels of resource use and profitability could be assessed at their statistical mean values. A t-statistic was then computed to test the hypothesis about mean differences in resource use and profitability between groups for each scenario:

Ho: $\bar{x}_A - \bar{x}_B = 0$

Ha: not the null.

The t-statistic takes on the form (Steel and Torrie):

$$t = \frac{S^2\bar{x}_A - \bar{x}_B}{S\bar{x}_A - S\bar{x}_B}$$

where:

$$S^2\bar{x}_A - \bar{x}_B = \frac{(n_1 -1)\, S^2_A + (n_B -1)\, S^2_B}{n_A + n_B - 2} \left[\frac{n_A + n_B}{n_A n_B} \right]$$

and,

$S^2\bar{x}_A - \bar{x}_B$ is the sample variance for the mean differences;

S^2_A and S^2_B are the sample variance of groupings A and B; and,

$S\bar{x}_A - \bar{x}_B$ is the standard deviation for the mean difference;

n_A and n_B are the number of observations in groupings A and B for $n_A \neq n_B$.

To determine the level of resource use as compared to an economical optimum and to state the returns on production resources, an average total revenue analysis was carried out. The empirical analysis supposes the existence of a well-behaved total revenue function for each scenario as derived from the random sample survey on rice farms. The general form of the average revenue model is:

$$TR = f[R, L, ME, SE, NE, PHE, POE, HE, INE, FUE] \qquad (3.1)$$

where:

R and L refer to total amount of land and labor usage per farm and ME, SE, NE, PHE, POE, HE, INE, and FUE refer to machinery, nitrogen, phosphate, potash, herbicide, insecticide and fungicide total expenditures on these inputs per farm.

The function f reflects the relationship between total revenue TR accruing to rice production and the services of two primary inputs (R, L) and eight non-real capital inputs (ME, SE, NE, PHE, POE, HE, INE, FUE) used in rice production.

For the purposes of empirical implementation, the explicit functional form for f is the Cobb-Douglas total revenue function. This functional form was selected on the bases of the following maintained hypothesis: (i) individual rice farmers attempt to maximize profits by maximizing total revenues; (ii) individual rice farmers are price takers for both output and input prices; (iii) the production coefficients are identical for all rice farms in a peer group (scenario) or the production function is linearly homogeneous (homogeneity restriction); (iv) the elasticity of substitution among inputs is constant along any isoquant; and, (v) the elasticity of substitution is the same at all levels of rice output (homotheticity restriction).

The individual farm's total revenue function was characterized by a homothetic formulation as:

$$TR_j = a \prod_{i=1}^{k} x_{ij}^{a_i} e^{\upsilon_j} \qquad (3.2)$$

where:

TR_j is the total revenue of farm j, for j = 1, . . ., n rice farms in the sample;

x_{ij} are the total amount and/or total expenditures on input

i by rice farm j, for i = 1, . . ., k production inputs;

a and a_i are the unknown constant term and elasticities of revenue for input i to be estimated; snf,

υ_j is a multiplicative random disturbance term that is distributed as $N(0, \sigma^2_\upsilon)$.

Because large errors are associated with large values of the dependent variable TR, then it is appropriate to treat the error term as multiplicative rather than additive. The standard log-linear model is therefore of the form:

$$\ln TR_j = \ln a + \sum_{i=1}^{k} a_i \ln x_{ij} + \upsilon_j \qquad (3.3)$$

The parameters in equation (3.2) are estimated by using ordinary least squares OLS estimation procedures. However, least-square estimation of Cobb-Douglas revenue (production) functions using cross-section data is fraught with statistical problems related to the violation of the basic assumptions of the OLS model. Four such problems are: aggregation bias, simultaneous equation bias, specification bias and multicollinearity.

To solve the problem of aggregating the various types of fertilizer inputs, these are expressed in terms of monetary values of pure nutrient (N, P_20_5 and K_20). Similarly, the herbicide, insecticide and fungicide input categories are aggregated in terms of the monetary value of active ingredient for each individual input. However, the problem of how to aggregate resources, whether complements or substitutes, is ignored in this research.

Marshak and Andrews (1944), Hoch (1958) and Zellner et al. (1966) contended that according to economic theory, output levels, resource use and profits of a firm should be determined simultaneously by the production function reflecting technical efficiency, the profit definition and the first order conditions for profit maximization. Therefore, the regressors of a single equation Cobb-Douglas production function may not be distributed independently of the error term such that $E(X'\upsilon) \neq 0$, in which case OLS estimators would be not only biased but also inconsistent.

To cope with a potential simultaneous bias within the current deterministic production and profit maximization context, this study assumes that rice producers' decisions on resource use depend on the expected level of profits rather than realized profits. In fact, in rice production inputs are chosen before actual output is known. In this case, as shown by Massell (1967), simultaneous equation bias will not result.

Griliches (1957) identified specification biases arising of omitting relevant production resources (some of which may be unobservable, i.e., managerial ability), using approximations in representing regressors, and inappropriate aggregation of outputs or inputs. Econometricians argue that the estimates of the parameters of production functions are biased because of excluding the variable which represents management. Management varies from farm to farm leading to a different production function and average physical productivities for inputs across farms.

This research omits management from the cross-section analysis because: (i) the lack of an appropriate unit for its direct measurement[1]; (ii) following Griliches (1957) and Doll (1974), by assuming constant returns to scale, the management coefficient in the Cobb-Douglas function could be omitted from the sum of factor coefficients which denotes returns to scale, since all farmers might be able to double their output with double inputs of all other resources; and, (iii) according to neoclassical theory management has two aspects: supervision and entrepreneurship. The former is rewarded by normal profits while the latter, which involves decision-making under conditions of

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[1] The use of subjective indices as a proxy for management was discarded in this study because apart from their subjective nature such indices might measure management potentiality rather than actual management input (82).

uncertainty, is rewarded by super-normal profits.[2] Since the marginal productivity of entrepreneurship has no meaning in economics because the supply is independent of the output level under its control, it should not be treated as a factor in the production function.

Multicollinearity among production resources is indeed a result of the assumptions of the economic model underlying the Cobb-Douglas production function. As shown by Doll (1974), the least-square estimated production function from cross-section data is often interpreted as the long-run production function for farms in the sample on grounds that inputs fixed on individual farms will vary among farms. For example, in the Cobb-Douglas model, the optimization conditions imply for a two-inputs one-output situation:

$$x_{i1} = \frac{a_1 w_2}{a_2 w_1} x_{i2} \text{ or } x_{i1} = kx_{i2} \text{ if } k = \frac{a_1 w_2}{a_2 w_1}$$

where: w_1 and w_2 are the input prices. The assumptions on homogeneity of degree one and competitive input-output markets insure that a_i and w_i are identical for all farms. Then, inputs are used in proportional amounts.

Nevertheless, the presence of collinear influences is theoretically justified. It is worrisome in the estimation process, especially if the model involves a large number of independent variables as in the current study. Therefore, instead of determining whether or not multicollinearity was present in the estimated model (3.3) above, this study was concerned with determining its severity to provide some insights for interpreting the reliability of the estimator coefficients and their analysis.

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[2] Normal profits are defined where all opportunity costs on resources are just covered by total revenue and therefore corresponds to a zero level of profits. In turn, super-normal profits correspond to any residual of total revenue above all opportunity costs.

The modified Klein's rule to detect multicollinearity was used. This rule compares the estimated simple correlation coefficients ($\hat{\rho}$) to $\hat{R}^2$; multicollinearity is then interpreted as harmful if $\hat{\rho} \geq \hat{R}^2$. A weakness of this approach is that pairwise correlations can give no insight into more complex interrelationships among three or more variables. A rather high level of autocorrelation between inputs was accepted on grounds that the average revenue model could under-state the influence of some inputs on outputs.

According to the theory of production economics, net returns from a single resource are at a maximum when the marginal resource cost MRC_i equals the marginal revenue product of resource i, MRP_i. Then, by examining the ratio MRP_i/MRC_i, it can be stated not only the level of resource use as compared to its optimum but also the net revenue accruing to one additional unit of resource cost.

The MRP_i was derived from the estimated elasticities of revenue (a_i's) in model (3.3). By definition:

$$a_i = \frac{\partial TR}{\partial x_i} \cdot \frac{\bar{x}_i}{\overline{TR}}$$

Therefore,

$$MRP_i = \frac{\partial TR}{\partial x_i} = \frac{\partial y_i}{\partial x_i} \cdot p = a_i \frac{\overline{TR}}{\bar{x}_i}$$

where:

TR is the average total revenue in the sample;

x_i is the average level of resource use or expenditure for factor i;

p is the rice output price; and,

$\partial y_i | \partial x_i$ is the marginal physical productivity of resource i.

The MRC_i is the additional cost farmers would have to pay for one extra unit of resource i. In this case, because rice farmers are input-price takers,

$MRC_i = w_i$, the unitary resource price at the farm-gate. That is, the price is adjusted by interest charges and transportation costs. Hence, the following statements could be made:

(i) if $MRP_i < 0$ then resource use of factor i would be found to be in stage III of production. Rice farmers could increase profit margin (net revenue) by reducing observed levels of resource i;

(ii) if $MRP_i = MRC_i$, then usage of resource i would be found at its optimum level;

(iii) if $MRP_i < MRC_i$, then rice farmers could earn a higher net revenue by reducing the level of employment of resource i;

(iv) if $MRP_i > MRC_i$, then rice producers could increase net revenue by expanding use of resource i; and,

(v) The higher the ratio MRP_i/MRC_i, the higher the financial return earned by rice farmers for investing in resource i.

Rice crop financial profitability measures were computed for each scenario as the ratio profit margin (net revenue) to total costs. The estimated profit margin is to be interpreted as a return to management, risk and overhead costs incurred by farmers involved in rice production activities. The crop enterprise budgets were also used to determine breakeven points for prices. The breakeven price is the price necessary to cover all costs except management, risk and overhead, at a given yield. In this study, it is also used as a proxy variable for cost-efficiency associated with each scenario. Indeed, it reflects the average cost per unit of rice output. In turn, the break-even yield is the yield necessary to cover total costs at a given price.

Technical Efficiency

One of the primary motivations for carrying out this research was to study technical efficiency in rice production. In Colombia, the existence of technical inefficiency in rice production may provide potential for increasing farmers' income with existing resources if factors causing technical inefficiency can be identified and if the "causes" are not due to resource constraints. As stated in Chapter I, the observed levels of resource use by rice farmers posed the question whether or not decision-makers were using resources in the right amounts and therefore producing rice at the minimum cost.

Given the observed production plan (y_0, x_0) this plan would be said to be technically efficient if it yields the maximum total physical product y_0 obtainable from a given bundle of resources x_0, that is, if $y_0 = f(x_0)$. Technical inefficiency arises from excessive resource use which is costly such that the actual observed resource expenditures $w'x_0$ are greater than the minimum expenditures of producing y_0 at resource prices w, $c^*(w, y_0)$ or $w'x_0 > c^*(w, y_0)$. Since cost is not minimized, actual profit margin $(py_0 - w'x_0)$ is not maximized and becomes less than the maximum profit $\pi^*(p,w)$ that is available at output prices p and input prices w. Therefore, as shown in Chapter II, technical efficiency is a necessary condition for productive or economic efficiency to occur.

The Empirical Model

This research used inter-farm cross sectional data on 71 Colombian rice farms to estimate a stochastic frontier Cobb-Douglas total revenue function and determine the level of average technical efficiency in rice production under different scenarios.

Following Aigner, Lovell and Schmidt, the basic Cobb-Douglas estimating model (3.2) can be respecified as:

$$TR_j = a \prod_{i=1}^{k} x_{ij}^{a_i} e^{\varepsilon_j} \tag{3.4}$$

Equation (3.4) postulates that,

$$a \prod_{i=1}^{k} x_{ij}^{a_i}$$

is the maximum revenue that can be produced technologically with inputs x_i. Also, this model states the disturbance term ε_j to be a composed error. That is, ε_j is made up of two components with the following structure:

$\varepsilon_j = \upsilon_j + \mu_j$, for $i = 1, \ldots, n$

The error component υ_j is a symmetric normal stochastic disturbance, in which $\upsilon_j \sim N(0, \sigma^2_{\upsilon})$, $-\infty < \upsilon_j < \infty$. The probability density function of υ_j, $f_{\upsilon}(\upsilon_j)$ is assumed to be independent of that for μ_j. υ_j represents not only the statistical noise due to errors of observation and measurement on TR_j and omitted x_{ij} variables, but also any random, two-sided shock in the production process which are outside the rice farmer's control and not explained by differing levels of efficiency across rice farms. Weather, topography, soil type, availability of inputs and machine and labor performance accounts for most of these random factors.

The error component μ_i is a one-sided non-positive or zero disturbance in which $\mu_j \sim | N(0, \sigma^2_{\mu})|$, $\infty < \mu_j \leq 0$. That is, μ_i is assumed to (i) be derived from a half-normal distribution truncated below at zero, (ii) distributed independently of υ_j, and (iii) to satisfy $\mu_j \leq 0$. Thus, μ_j captures the influence of technical inefficiency with respect to the stochastic frontier.

Because of the disturbance term υ_j specification, $\upsilon_j \geq 0$, the deterministic frontier:

$$TR_j = a \prod_{i=1}^{k} x_{ij}^{a_i}$$

is forced to vary randomly across farms and hence the frontier revenue function becomes stochastic as:

$$TR_j = a \prod_{i=1}^{k} x_{ij}^{a_i} e^{\upsilon_j}.$$

Also the non-positive disturbance μ_j reflects the fact that each farm's revenue must lie on or below its frontier:

$$a \prod_{i=1}^{k} x_{ij}^{a_i} e^{\upsilon_j}.$$

The economic meaning of the μ_j component in equation (3.4) above is that any downward deviation from the frontier is the result of factors under the rice producer's control. That is, μ_j measures technical inefficiency as reflected in poor managerial skills, failures to use the right resource at the right time and in the right fashion, low hired workers effort, material hindrance to progress and damaged output among others.

Along the lines first suggested by Afriat (1972), the relevant measure of technical efficiency for the Cobb-Douglas revenue function becomes the expected value of μ_j, $E(e^{\mu_j})$. Given

$$TR_j = a \prod_{i=1}^{k} x_{ij}^{a_i} e^{\upsilon_j} e^{\mu_j} \tag{3.5}$$

The appropriate technical efficiency index for rice farm j is:

$$e^{\mu_j} = TR_j / a \prod_{i=1}^{k} x_{ij}^{a_i} e^{\upsilon_j} \quad (3.6)$$

Since υ_i is unobservable an individual measure of technical efficiency, cannot be estimated for each rice farm in the sample. However, the mean efficiency of the population of farms can be stated as the expectation on (e^{μ_j}), E(e^{μ_j}). For a truncated normal distribution as assumed in this study, E(e^{μ_j}) takes on the form:

$$E(e^{\mu_j}) = 2e^{\sigma^2_\mu/2} [1 - F^* (\sigma_\mu)] \quad (3.7)$$

where $F^*(\sigma_\mu)$ is the standard normal distribution function evaluated at σ_μ, the standard deviation of μ.

Econometric Estimation of the Stochastic Frontier Model

The parameters in equation (3.4) cannot be estimated by using least squares procedures because of the nature of the composed disturbance term, such that $E(\varepsilon_i) \neq 0$. Yet as the number of parameters to be estimated is relatively large multicollinearity would be expected to be high. Thus, single OLS techniques would likely lead to biased (intercept) and inefficient frontier estimators.

Aigner, Lovell and Schmidt devised a maximum likelihood estimation technique of equation (3.4), by writing the density function of the composite residual ε_j as the sum of values from normal and truncated normal distributions. As υ_j and μ_j are assumed to be independent, the joint density function for the composed disturbance term ε_i in equation (3.4) above is:

$$f(\varepsilon_i) = (2/\sigma) f^*(\varepsilon_j/\sigma) * [1 - F^* (\varepsilon_i \lambda(1/\sigma)], -\infty \leq \varepsilon_j \leq \infty \quad (3.8)$$

where: $\sigma^2 = \sigma^2_\mu + \sigma^2_\upsilon$, $\lambda = \sigma_\mu/\sigma_\upsilon$, and $f^*(\cdot)$ and $F^*(\cdot)$ are the standard normal density and distribution functions, respectively. The joint density $f(\varepsilon_j)$ is assymmetric around zero with its mean and variance given by:

$$E(\varepsilon_i) = E(\mu_i) = -(\sqrt{2}/\sqrt{\pi}) * \sigma_\mu; \tag{3.9}$$

$$v(\varepsilon_i) = v(\upsilon_i) + v(\mu_i) = ((\pi-2)/\pi) * \sigma^2_\mu + \sigma^2_\upsilon \tag{3.10}$$

Given a random sample of n observations, the resulting log-likelihood function is:

$$\ln L\ (TR|a, \lambda, \sigma^2) = n*\ln(\sqrt{2}/\sqrt{\pi}) + n*\ln(1/\sigma) + \sum_{i=1}^{n} \ln\ [1 - F^*(\varepsilon_j\lambda(1/\sigma)]$$

$$- (1/2\sigma^2) * \sum_{i=1}^{n} \varepsilon^2_j \tag{3.11}$$

Equation (3.4) is a multivariable, unconstrained non-linear in parameters (a, λ, and σ^2) function involving a cumulative normal distribution. Hence, it must be solved in an iterative fashion. A number of optimization techniques are available for finding the optimizing values of a, λ and σ^2. In this study, the sequential application of two direct search approaches, the STEPIT package and the MINF/Powell package developed by Chandler (1973) were implemented.

STEPIT and MINF computer packages are made up by a set of compatible routines for finding a local minimum of any given smooth function of several parameters. By using STEPIT and MINF in a sequential fashion the rate of convergence could be speeded up and ensure a good fit of the function to a set of data according to the least squares criterion. Once a local optimum was deemed to be achieved, STEPIT was used again to obtain standard errors of the parameter estimates by the method of variance-covariance.

STEPIT and MINF packages were chosen because of the following reasons: (i) reduced storage memory requirement; (ii) direct search methods may be computationally easier than gradient methods requiring evaluation of first and second order derivatives; (iii) increased chances of reaching convergence and a fairly reliable solution at low rates of computer processor time; and, (iv) standard errors and correlation coefficients of the estimated parameters could be provided for.

The OLS estimator parameters a_i obtained from equation (3.3) are used as the corresponding starting points. These estimates are assymptotically consistent. Starting values for λ and σ^2 parameters are derived from the second and third moments of the residuals of the total revenue function (3.3) for each scenario.

Besides the theoretical appeal of the stochastic frontier specification, this model is selected also because of the following reasons:

(i) It is the most general of all possible theoretical specifications to study productive efficiency. From equation (3.10) above, it can be shown that the stochastic frontier function collapses to a deterministic frontier function ($\varepsilon=\mu$) if σ^2_υ --> 0. Also, the stochastic model collapses to an "average" function ($E(\varepsilon)=0$) if σ^2_υ --> 0. Therefore, test of hypothesis of the statistical significance of the variance for the error terms in equation (3.11) lead to determine which specification might be the most appropriate.

(ii) The range of the dependent variable in equation (3.11) above does not depend on the parameters a, λ, and σ^2 as $-\infty < \varepsilon < \infty$. Thus, maximum likelihood estimators are claimed to be assymptotically efficient and consistent.

(iii) The stochastic model captures the effect of nonhomogeneous input on the production function, leading to more appropriate results in productive efficiency than do average production functions. It is well known that in rice production labor is a non-homogeneous input, farmers do not use same quality of every input, farmers apply inputs at different times, using different equipment and therefore at different rate of efficiency application.

These discrepancies may account for significant yield and revenue differences.

It can be shown that leaving out the farmer's inability to use inputs effectively, and/or not accounting for the input quality differences in production function models leads to specification bias. The estimated parameters are more likely to be biased. If technical inefficiency does exist the observed input usage x_0 can be assumed to be the difference between the homogeneous input x and technical efficiency T. Thus the misspecified model can be stated as:

$$y = x\beta + \varepsilon \text{ (conceptual model)} \tag{3.12}$$

$$= (x_0 + T)\beta + \varepsilon$$

$$= x_0\beta + T\beta + \varepsilon \text{ (observed model)} \tag{3.13}$$

The OLS estimate of β, (b), in (3.13) is:

$$b = (x'_0 x_0)^{-1} x'_0 y$$

$$= (x'_0 x_0)^{-1} x'_0 (x\beta + T\beta + \varepsilon) \text{ with expected value}$$

$$E(b) = \beta + (x'_0 x_0)^{-1} x'_0 T\beta$$

Thus, b is a biased estimate of β.

Data Sources and Variable Definitions

The Sample Survey

To obtain proper and representative information on rice production, a sample field survey was designed and used to interview rice producers in the Central and Los Llanos regions of Colombia from June to September of 1981. A proportional stratified random sampling technique was used to select farmers for interviewing.

Rice production encompasses different cropping systems under different physical and socioeconomic environments. Therefore, to reduce the sample standard error ($S_{\bar{x}}$), this procedure was accomplished to minimize the variance ($S^2_{\bar{x}}$) within each stratum (production zone) and maximize the difference of the mean ($\bar{x}_i$) among strata, where $\bar{x}_i$ stands for average size of rice farm in each zone.

The sample was designed in two steps. First, the sample size (η) was computed as:

$$\eta \geq \left[\sum_{i=1}^{13} (N^2_i S^2_i) / p_i \right] \Big/ \left[N^2 (E/4) + \sum_{i=1}^{13} N_i S^2_i \right] \tag{3.14}$$

where:

N is the total number of rice farms in the regions under study (2,272)

N_i is the total number of rice farms in stratum i, for i = 1, 2, . . ., 13

$p_i = N_i/N$

E = maximum admissible error (7 hectare) around the true mean of farm size at $\alpha = 0.05$, where α = level of significance (LOS).

4 is the multiple of $S_{\bar{x}}$ to achieve a given level of $S_{\bar{x}} = E/k$, for k =4

S_i = actual variability around the observed mean of farm size in stratum i.

In the second step, the sample size (η_i) was defined for each production zone. ηi was computed as:

$$\eta_i \geq [\eta \ (N_i S_i)] / \left[\sum_{i=1}^{13} N_i S_i \right] \tag{3.15}$$

Major features of the computed sample survey by production regions, zones and cropping systems are shown in Table X. All farmers in the frame were enumerated and selected by using a table of random numbers. Farmers were involved in rice production activities under the provisions of the

TABLE X

SAMPLE SURVEY OF COLOMBIAN RICE FARMS IN THE CENTRAL REGION AND LOS LLANOS REGION

Region, Zone, and Cropping System	N_i[a/]	p_i	$\bar{x}$	S_i	Planned η_i	Completed η_i
Central Region						
Irrigated Rice						
Meseta de Ibague	59	0.026	58.0	53.7	4	3
El Espinal	405	0.178	26.5	30.6	15	10
Saldana	336	0.148	25.9	26.5	11	8
Armero	148	0.065	46.0	35.3	6	6
Campoalegre	440	0.194	48.2	42.1	22	17
Los Llanos Region						
Irrigated Rice						
Villavicencio	199	0.088	48.0	31.7	8	7
Puerto Lopez	45	0.020	95.0	57.0	3	2
Granada	54	0.023	40.5	30.2	2	4
Villanueva	57	0.025	69.2	33.4	2	1
Rainfed Rice						
Villavicencio	113	0.050	41.2	22.5	3	3
Puerto Lopez	149	0.066	38.4	27.6	5	5
Granada	186	0.081	29.4	23.6	5	7
Villanueva	81	0.036	40.8	25.8	2	1
Total	2,272	1.000			88	74

[a/] The data on total number of rice farms (frame) was provided by the Instituto Colombiano Agropecuario - Division de Produccion Agricola. The data correspond to rice farms which planted rice during the agricultural year 1980-1981.

Colombian government rice program (Ley 5a. of 1973). The government program includes: financial (credit) support through the Fondo Financiero Agropecuario, rice output price support, and private technical-consultory services.

The actual number of surveys completed was less than the number of planned surveys because some farmers were absent at the interview time. In the Espinal zone, and the Campoalegre zone it was realized that little variability would be added to the sample by additional surveys. In such a case, the marginal cost of an extra survey was assumed to exceed the marginal benefits of additional information. Overall, the actual surveys obtained are assumed to represent the population.

A structured questionnaire containing detailed information on farm resource endowments, production systems, input-output and financial markets, farmer's characteristics and attitudes was used. The survey form is in Appendix A.

To gather data on prices received by farmers on rice output and paid by farmers for inputs, and to assess the costs of real capital services (buildings, machinery, and equipment) and land, a sampling frame including all input suppliers and output buyers as reported by the respondents in the field survey was enumerated. Twenty three towns (municipios) and 254 agricultural businesses made up the frame. A stratified random sample was then used to determine the total number of surveys and the number of surveys in each town.

The average number of business firms reported in each production zone, and the variability around the mean $S^2_{\bar{x}}$ were utilized as criteria to create the sample by using formula (3.14) and (3.15) above.

The results of this sampling survey are presented in Table XI. The number of respondents is lower than the planned number because of,

TABLE XI

SAMPLE SURVEY OF COLOMBIAN AGRICULTURAL BUSINESS FIRMS IN THE CENTRAL REGION AND LOS LLANOS REGION

Region Zone and Town	N_i	p_i	$\bar{x}$a/	S_i	Planned Surveys η_i	Completed Surveys η_i
Central Region						
Ibague	28	0.110	2.7	3.0	7	7
Espinal	17	0.066	3.9	3.1	8	8
Guamo	10	0.039	4.5	3.8	2	1
Saldana	8	0.028	2.3	2.4	2	1
Purificacion	10	0.039	3.0	2.4	2	1
Armero	19	0.074	3.1	3.8	3	3
Campoalegre	10	0.039	5.1	4.1	2	2
Neiva	21	0.082	3.1	2.7	5	5
Lerida	7	0.027	1.2	1.0	2	0
Ambalema	6	0.024	0.4	0.9	2	1
Palermo	6	0.024	1.4	1.1	2	0
Los Llanos Region						
Villavicencio	33	0.129	4.1	5.7	8	11
Puerto Lopez	17	0.066	2.9	3.1	4	4
Granada	21	0.082	3.2	3.8	3	5
Acacias	13	0.051	1.7	1.8	2	1
Fuente de Oro	6	0.024	1.2	0.8	2	0
Cabuyaro	4	0.014	0.9	0.8	1	0
Restrepo	7	0.027	1.3	0.9	2	1
Cumaral	3	0.012	1.2	0.9	0	0
Castilla	4	0.014	0.1	0.1	0	0
San Carlos	4	0.014	0.1	0.1	0	0
Total	254				59	41

a/ $\bar{x}$ stands for the average number of different business firms in that location reported as input suppliers by farmers in the field survey.

particularly, private business reluctance to cooperate with the enumerator and difficulties in reaching respondents in isolated towns. The survey questionnaire is contained in Appendix B.

The procedure of using separate surveys to collect data on "physical and behavioral" characteristics of rice farms and data on "prices and costs" was due to the following reasons.

(a) With few exceptions, Colombian rice farmers do not keep record books and it is very difficult for respondents to recall price levels for individual inputs or assets, or quantities of inputs applied in a single interview.

(b) Rice farmers are reluctant to provide information on income, costs or prices as far as these data may concern income tax statements. In such a case, the information on and total revenue is usually understated. On the other hand, information on costs of production is generally overstated.

(c) A single survey form including both issues simultaneously would increase the probabilities of measurement errors and the associated costs of the information. Therefore, the surveys would be expected to yield unreliable data and be inefficient (that is, not to generate the greatest possible amount of accurate data at the lowest possible cost).

The Selection and Measurement of Variables

In this study, the selection of variables is based upon the theory underlying the short run production function, the rice enterprise budgets, the econometric model specification and policy implications to be derived from the results of this analysis. Based on these considerations, total physical amounts of labor (L), land (R) and total expenditures on nitrogen (NE), phosphate (PHE), potash (POE), machinery (ME), insecticides (INE), herbicides (HE) fungicides (FUE) and seed (SE) were chosen as independent variables of the total revenue function as stated in equation (3.1) above.

The method of measuring and constructing each variable follows budgeting principles. The selected variables in this study are:

Total Revenue. Total revenue relates to the estimated output value to the farmer of rough rice produced and sold at the market price by farm and crop season.

Land. It refers to the total amount of cropped rice in hectares by farm in the crop season. Expenditures per hectare on land consist of the estimated value for repairs, maintenance depreciation of service buildings and structures, property and income tax payments, and interest payments. This is the corresponding rental rate for owner-operated rice land. Otherwise, the rental rate is computed by the reported rent paid by hectare in tenant-operated rice land.

Labor. It includes the total number of hours of hired labor by farm (permanent labor and temporal labor) reported to be used in rice production during the crop season. In some cases, it includes family labor and operator's labor. It excludes management hours and machinery labor. Total labor expenditures per hectare were computed by multiplying the number of hours of labor per hectare for different cropping activities times the reported wage rate.

Machinery and Equipment. Machinery and equipment expenditures encompass the estimated variable costs (value of repairs, maintenance operation, and labor) and estimated fixed costs (depreciation, insurances, taxes and interest) on all machinery and equipment used up in rice production by farm and crop season. The machinery and equipment expenditures per hectare are constructed by: (i) multiplying total computed expenditures by hour-machinery by the total number of hours of machinery and equipment used per hectare in owner-operated machinery cases; or, (ii) the reported expenditures per hectare on hired machinery and equipment.

Intermediate Inputs. (fertilizer, pesticides and seeds). This involves the estimated expenditures on these inputs per farm and crop season including: the interest charges on operating capital, and the transportation costs of inputs from the purchase place to the farm. The corresponding expenditures per hectare are computed by dividing total farm expenditures on each category of inputs by the total number of cropped hectares in rice.

Components of Rice Production Expenses[3]

To identify the rice budgets and estimate the parameters of the model (3.2) above, the following variables were identified, defined and constructed:

Total Revenue. Total revenue was computed by multiplying the reported yield per hectare (kg of rough-rice) times the estimated price per kg at the sale place.

Variable Costs. These costs encompass all expenditures on seeds, labor, chemicals, machinery and equipment, transportation, and operating capital services which were assumed to vary with the level of output over the production period.

Seed expenditures were computed as the total amount of planted seed times the estimated unitary price. Similarly, expenditures on fertilizers, herbicides, insecticides and fungicides were computed by multiplying the physical units of inputs times the corresponding prices. Physical amounts are

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[3] All expenditures are expressed in Colombian pesos (Col. $) of 1981. The rate of currency exchange was, roughly, 40 Colombian pesos per dollar in July, 1981.

expressed in terms of kilograms of N, P_20_5 and K_20 (fertilizers) and kilograms of active ingredient for the other chemicals.

Expenditures on labor were computed as the total number of man-hours employed times the computed wage rate. Machinery and equipment variables costs were estimated as follows. The repairs costs were computed as a percentage of the replacement cost. A reported charge of 2 to 12 percent of new cost was used as annual charge for repairs. Maintenance costs were estimated according to the reported consumption of fuel per hour times the number of hours-machine. Lubrication was estimated as a reported percentage (between 8 and 24 percent) of fuel costs.

Fixed Costs. Fixed costs refer to expenditures on land charges and machinery and equipment costs which cannot be varied during the production period. Machinery and fixed costs included the expenditures accruing to depreciation, interest paid and taxes. To compute depreciation costs the straight line method was used. Individual farmers in the survey reported parameter values for useful life, estimated use in rice, salvage value, and interest paid. Tax charges on machinery were computed according to the enforced tax rates for depreciable farm assets.

Land fixed charges for owner-operated rice farms involved estimated repairs, maintenance and depreciation of service buildings, irrigation and drainage facilities and other farm structures. Also, estimated taxes paid on land, and expected income, and interest charges on land loans if any. Repairs and maintenance costs were computed as a reported percentage (between 4 and 16 percent) on estimated initial investments. Depreciation on physical farm structures was computed by using the straight line procedure. Land values were approximated by the income capitalization method by assuming that the long run plan is to be the current rice crop and total revenue. Tax charges were estimated according to the regulated land property tax rates and income tax rates.

CHAPTER IV

RESOURCE USE, RETURNS TO LAND, LABOR AND CAPITAL IN RICE PRODUCTION

The level of employment of land, labor and non-real capital inputs in rice production are discussed in this chapter. Also, financial returns to rice production and to each of these resources under different scenarios are analyzed.

The theory of production economics asserts that several biological, socio-economic and institutional factors may influence farmer's decisions on use of production resources. A central hypothesis in this study was that rice variety type, rice crop size, rice crop tenure classes, production regions and rice cropping systems constituted a different population or scenario. Each of these scenarios might have a different pattern of resource allocation affecting rice crop profitability and thus, influencing farmer's decision on employment of resources. In the rice production industry, unprofitable use of resources to the farm could be threatening its survival. Therefore, only farm decision makers who operate the most efficiently, i.e. produce the largest output at the lowest per unit cost, can gain control of production resources over time.

The analysis was carried out in a static partial equilibrium setting in that it considered the use of all resources individually at a single period of time using cross-sectional data. All measures on resource use and rice enterprise performance are presented on their average values (statistical mean), under the assumption that product-input prices, yields per hectare, and levels of employment of inputs are random variables and follow a normal distribution. The coefficient of variation was then used to measure variability of estimated parameters across farms.

Two measures of financial returns for each scenario were estimated: relative profitability and returns to one-Colombian peso investment on inputs. Crop profitability estimates were derived from budget enterprise analysis. Returns on inputs were stated based on an average revenue function analysis. The first section includes a brief discussion on results of estimating the average revenue function.

The second section deals with the rice variety scenario, the third with the farm size scenario, and so on. The cropping system scenario is the objective of the last section. For each scenario three major elements were considered: resource use, crop profitability and return to inputs.

Estimation of Average Revenue Functions

The average cross-sectional revenue functions estimated for each of eleven scenarios and the total sample farms are presented in Table XII. The explanatory power of all functions is deemed as appropriate with more than 90 percent of revenue variation being explained by the specified equation. Given the model specification in (3.2) most inputs turned out to be collinear with land input being the dominant factor. The presence of multicollinearity was disturbing in the estimation process because the individual effects of some inputs are difficult to isolate from the cropland effect given the sample data.

The estimated simple correlation coefficients (ρ) for land-labor, land-machinery, land-seed, land-nitrogen and land-herbicides were high and significant, and ranged between 0.60 and 0.80 for most scenarios. In turn,

TABLE XII

PARAMETER ESTIMATES AND RELATED STATISTICS OF AVERAGE COBB-DOUGLAS REVENUE FUNCTIONS FOR EACH SCENARIO

Scenario	Intercept	Land	Labor	Machinery	Seed	Nitrogen	Phosphate	Potash	Herbicides	Insecticides	Fungicides	Returns to Scale	R^2	F-value
CICA-8	6.097 (3.71)	0.641 (3.40)	0.089 (0.85)	-0.076 (-0.70)	0.512 (3.23)	0.036 (1.33)	0.008 (0.59)	-0.034 (-1.65)	0.003 (0.99)	0.016 (0.87)	0.020 (1.16)	1.221	0.974	86.09
IR-22	12.288 (15.12)	0.992 (10.90)	-0.257 (-5.36)	0.08 (2.71)	-0.097 (-1.23)	0.063 (0.89)	-0.044 (-1.32)	0.122 (3.58)	-0.028 (-1.60)	-0.062 (-3.23)	-0.003 (-0.87)	0.757	0.999	612.53
SMALL CROPS	11.593 (7.15)	0.769 (4.86)	-0.062 (-1.39)	-0.033 (-0.61)	0.103 (0.69)	0.021 (1.74)	-0.077 (-1.89)	0.073 (1.74)	0.028 (1.38)	-0.017 (-2.94)	-0.062 (-2.42)	0.753	0.931	18.45
MEDIUM CROPS	8.064 (6.02)	0.547 (2.80)	-0.095 (-0.95)	0.072 (0.81)	0.020 (0.72)	0.319 (2.44)	0.079 (3.15)	-0.051 (-2.07)	-0.014 (-0.84)	0.004 (0.78)	0.017 (1.28)	0.894	0.969	37.69
LARGE CROPS	8.916 (5.43)	0.738 (3.62)	-0.027 (-0.20)	-0.218 (-2.00)	0.3298 (1.84)	0.276 (2.38)	0.003 (0.22)	-0.017 (-0.56)	-0.027 (-0.47)	-0.048 (-1.10)	0.017 (1.02)	0.993	0.901	14.62
OWNER-OPERATED	7.465 (6.73)	0.573 (4.89)	-0.031 (-0.42)	0.010 (0.16)	0.383 (3.13)	0.027 (1.05)	0.014 (1.28)	-0.018 (-0.70)	-0.008 (-1.25)	0.031 (2.23)	0.005 (0.71)	0.985	0.977	185.46
CASH-RENTED	8.977 (2.58)	0.945 (2.77)	0.085 (0.53)	-0.183 (-0.99)	0.358 (0.88)	-0.103 (-0.86)	0.075 (0.64)	-0.081 (-0.74)	-0.010 (-0.77)	0.094 (1.29)	0.035 (1.32)	1.23	0.990	38.87

TABLE XII (continued)

Scenario	Intercept	Land	Labor	Machinery	Seed	Nitrogen	Phosphate	Potash	Herbicides	Insecticides	Fungicides	Returns to Scale	R^2	F-value
LOS LLANOS	8.836	1.200	0.086	0.045	0.082	-0.044	0.001	-0.032	0.008	0.008	0.002	1.359	0.976	64.78
	(4.60)	(4.24)	(0.87)	(0.59)	(0.40)	(-0.38)	(0.70)	(-1.74)	(0.75)	(0.44)	(1.11)			
CENTRAL REGION	11.066	0.966	-0.098	0.043	0.044	0.016	-0.022	0.017	-0.011	-0.021	0.001	0.951	0.991	365.02
	(11.95)	(9.24)	(-2.40)	(1.17)	(0.96)	(1.08)	(-0.73)	(0.54)	(-0.74)	(-1.27)	(0.88)			
IRRIGATED	9.055	0.697	-0.085	0.039	0.239	0.005	0.028	-0.006	-0.001	0.005	0.002	0.915	0.991	393.96
	(10.98)	(8.08)	(-1.94)	(0.95)	(2.71)	(0.1)	(1.82)	(-0.87)	(-0.84)	(0.88)	(0.21)			
RAINFED	10.076	1.529	0.225	-0.135	-0.032	-0.011	-0.003	-0.042	0.07	-0.02	-0.007	1.58	0.978	35.89
	(3.47)	(3.35)	(1.37)	(-0.77)	(-0.71)	(-0.87)	(-0.73)	(-1.58)	(0.96)	(-0.78)	(-0.85)			
TOTAL SAMPLE	7.665	0.593	-0.028	-0.002	0.359	0.024	0.014	-0.012	0.001	0.029	0.012			
	(8.39)	(6.28)	(-0.85)	(-0.83)	(3.64)	(1.26)	(1.40)	(-0.93)	(0.64)	(2.43)	(1.25)	1.216	0.977	260.1

t-statistic values are in parenthesis

labor-machinery, labor-seed, labor-nitrogen, and labor-herbicides were also found highly and significantly correlated. Likewise, machinery-seed, machinery-nitrogen and machinery-herbicides appeared to be highly significantly collinear. Overall, however, the estimated ρ values were less than R^2. Therefore, the hypothesis of severe multicollinearity was rejected based on Klein's test.

The estimated elasticities of revenue for labor, machinery, insecticides and fungicides were negative, and statistically significantly different from zero, for some scenarios. Specifically, the negative sign of labor was significant for rice farms planting the IR-22 variety, for rice farms in the Central reigon, and for irrigated crop systems. Also, the negative sign for machinery was significant in the case of large rice farms. Similarly, the coefficient for insecticides was negative for small rice crops and for IR-22 planted farms. The elasticity estimate for fungicides was negative in the case of small rice farms.

These findings confirm that the marginal physical productivity (MPP) for those inputs under particular scenarios was less than zero. According to the theory of production economics, if MPP < 0, the employment of that resource is in a stage III of production, and a higher level of revenue could be attained by reducing the use of that particular input.

Several possible reasons may help explain why the MPP of those inputs was negative: (i) free inputs with zero cost to producers; (ii) input prices to producers highly subsidized; (iii) non-enforcement by the goernment for farmers to pay off agricultural loans used to purchase inputs and finance field labor; (iv) rice farmers' valuation of input shares at their average revenue product rather than at their marginal value product; (v) data inaccuracies; and, (vi) incorrect model specification to represent rice crop responses to resource use, among others.

In this case, the first three reasons are deemed as non-applicable. Indeed, input prices are exogenously determined to the farm and provided for without subsidy. The rate of default reported by the Fondo Financiero Agropecuario on credit allocated to rice production has been less than two percent in the last five years.

It can be postulated that rice farmers value the contribution of resources in different ways based on their contribution to the production process. Resources which are essential in maintaining rice fields such as labor, machinery, water and chemicals (used to ocntrol weeds, pests and diseases) seem to be valued at their average value product rather at their marginal value product. The level of use of these resources depends on exogenous factors such as weather and type of rice planted. Therefore, these resources can be used more intensively than the profit maximizing levels.

On the other hand, resources which are fundamental in increasing yields, such as new seed varieties, fertilizers, labor and machinery, appear to be assessed at their marginal value product. Therefore, the level of employment of these resources depend on the economic environment and actual cost to farmers. This analysis suggests that input overuse can be the result of farmers behavior in response to factors outside the decision-maker's control. In this sense, rice farmers' behavior would resemble that of small scale farmers who overuse some inputs to minimize the probability of losses subject to a minimum level of expected profits or utility (such as food self-sufficiency, full employment of family labor and to fulfill financial commitments).

The above elasticity estimates may still include possible biased effects of measurement errors. Also, it can be contended that the model (3.2) may mislead the true input-output relationships. An alternative specification to postulate the relationship between yields and major resources could be a linear response and plateau function (Ackello-Ogutu et al. 1985). A formal test on measurement errors and model misspecification is postponed to Chapter V.

The relative small size of the estimated elasticities of revenue for most inputs and scenarios (except for land, nitrogen and sed) supports the statement that rice producers use some resources at such an intensive level that the marginal value product approaches zero and/or is negative. Overall, these findings suggest the need to review the profit maximization behavioral assumption in rice production and to analyze resource use in the context of expected profits or utility related criteria.

For the remainder of this study, the average revenue functions are used to determine the marginal revenue product and returns of individual inputs as shown in next sections of this chapter, and provide starting values for econometric estimation of the stochastic frontier revenue function in Chapter V. The first analysis was carried out under the maintained hypothesis of profit maximization. Also, the analysis ignored the effect of multicollinearity on the estimated parameters.[1] The average revenue model as specified in equation (3.2) was considered to be appropriate to develop the ongoing analysis for several reasons.

The model specification was found to be more appropriate than alternative specifications of a production function in terms of goodness of fit for most scenarios. Alternative models included those studied by Baghi (1982),

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[1] The marginal revenue product values were derived from the estimated elasticities of revenue presented in Table XII. Because of the general problem of multicollinearity that plagues regression models of this kind, the ensuing analysis based on these parameter estimates needs to be made with certain caution, as pointed out in Chapter III. However, these results confirm the existence of a pattern of resource use and financial profitability in rice production which deserves further attention.

Schmidt and Lovell (1979), Kopps (1981), Lingard et. al. (1983), and the Conventional Yield per hectare model.

To ameliorate the collinearity problem, a stepwise technique was used for selecting variables to be included in the revenue model. Nevertheless, at the 5 percent level of significance criteria, it was found that only land input met the requirement for most scenarios, leading to a too short model.

The computed low t-values for the parameters in model (3.2) may be due to not only the multicollinearity problem but also to omitting the effect of technical inefficiency and input quality discrepancies. Thus, by assuming that the observed input level and technical efficiency are either uncorrelated or positively correlated, the estimated standard error in the average function are expected to be biased upwards. The effect of individual inputs on output is then understated, and the probability of Type II error increased.

Given the conceptual model (3.12) and the average estimated model (3.13), the variances of the estimated parameters β and b, are respectively:

$\text{Var}(\hat{\beta}) = \sigma^2 \mid \Sigma (x_i - \bar{x})^2$, (variance for the frontier model)

$\text{Var}(\hat{b}) = \sigma^2 \mid \Sigma (x_{0i} - \bar{x}_0)^2$ (variance for the average model)

Since $x = x_0 + T$, by expanding $\Sigma (x - \bar{x})^2$ in Var (β):

$$\Sigma (x_i - \bar{x}) = (x_{0i} + T_i) - (x_{0i} + T) = (x_{0i} - \bar{x}_0) + (T_i - \bar{T})$$

Therefore:

$$\Sigma (x_i - \bar{x})^2 = \Sigma (x_{0i} - \bar{x}_0)^2 + 2\,\Sigma (x_{0i} - \bar{x}_0)(T_i - \bar{T}) + \Sigma (T_i - \bar{T})^2$$

If x and T are not correlated or positively correlated then:

$\Sigma (x_i - \bar{x})^2 > \Sigma (x_{0i} - \bar{x}_0)^2$ and hence:

$\text{Var}(\beta) > \text{Var}(b)$

Thus, the average model is more likely to lead to larger variances (standard errors) than the conceptual model. In this research the conceptual model is postulated as the stochastic revenue function (3.4) mentioned previously. Should $\bar{x}$ and T be negatively correlated then $\Sigma (x_i - \bar{x})^2 < \Sigma (x_{oi} - \bar{x}_o)^2$ and, consequently Var (β) < Var (b).

Rice Variety Type

Since the late 1960's more than 90 percent of Colombian rice farms in irrigated and rainfed (mechanized) production systems have been growing improved high yielding semi-dwarf varieties. Two major groups of improved seeds can be identified: introduced varieties and locally created varieties. The former rice varieties were developed by the International Rice Research Institute IRRI in the early 1960's and brought in to Colombia since 1968. IR-8 and IR-22, two introductions from Asia, became the most important varieties grown in irrigated systems in Colombia from 1969 through 1976. Because these seeds became susceptible to local biological constraints or suffered loss of grain quality their production share has been declining over time relative to new locally developed semi-dwarf varieties.

The latter varieties have been created under a cooperative rice research program between the Centro Internacional de Agricultura Tropical (CIAT), the Instituto Colombiano Agropecuario (ICA), and the Federacion Nacional de Arroceros (FEDEARROZ). Rice varieties such as: CICA-4, CICA-6, CICA-8 and CICA-9 have been rapidly and widely adopted as they are better adapted at local constraints not only in Colombia but also throughout Latin America in irrigated and rainfed cropping systems.

Typically, both introduced and locally developed rice varieties have been created to achieve higher yields and better grain quality, and to be better adapted to tropical ecologies. To attain these goals, improved varieties must be cropped with a high input technology embodied in mechanical and chemical inputs. Thus, the improved varieties of rice represent a technology biased towards using non-real capital inputs and saving land and labor. Therefore, economic profitability to farmers depends heavily on the non-real capital input-output price ratio. However, as shown in an earlier section of this chapter, the rice farmer's decision on employment of resources may be influenced by both biological factors affecting the variety yield potential as well as by socio-economic and institutional factors being faced by individual farmers.

Biological constraints to grow a given rice variety determine the marginal productivity of allocated resources to produce such a variety of rice. In turn, the socioeconomic and institutional setting determines the farmer's resource endowment and the input-output price relationships.

In this study, CICA-8 and IR-22 were found to be the most common planted varieties; 62 percent of the farms included in the survey were totally planted with CICA-8. Also, 27 percent of the sample fields were fully cropped with IR-22. At the survey time both varieties were facing important production constraints. IR-22 was suffering high susceptibility to hoja blanca disease, lodging, and grassy-weeds. However, farmers were still growing this variety because of its high grain quality, higher yields, and higher output price than any other improved variety in irrigated systems.

Similarly, CICA-8 was losing tolerance to blast disease and facing susceptibility to leaf scald and grain spotting diseases. Consequently, lower yields and lower output prices were expected by farmers. Because these ecological and institutional constraints vary between varieties, both use of resources and returns to production factors probably differ from one variety to another.

Resource Use

As indicated in Table XIII, except for phosphate and machinery inputs, the level of employment of inputs was found to differ significantly between IR-22 and CICA-8. On the average the use of seed, nitrogen, pesticides and labor was substantially higher for IR-22 than for CICA-8.

Farmers in the survey sample argued that major constraints to grow IR-22 in the Central Region (irrigated system) were high infestations by grassy-weeds, and lack of enough water supply to get rid of the problem by flooding.

To fight weeds, farmers were planting higher levels of rice seed per hectare (257 kilograms per hectare). By expanding plant population farmers were increasing the marginal productivity of land, fertilizers, machinery and labor for given outlays of these inputs, and decreasing the productivity of herbicides. Thus, due to the increase of seed in the very short run an increase in the use of inputs with increased productivies (fertilizers, labor and machinery), and a decline in the use of herbicides could be expected. However, since IR-22 was a susceptible variety to insects and diseases, the employment of insecticides and fungicides should be increased as well to maintain grain quality or raise yields to such level as 6331 kilograms per hectare.

On the other side, CICA-8 was released as a variety with high tolerance to blast and hoja blanca diseases, sogata insect and particularly adapted to local constraints prevailing in Los Llanos region. Following a similar reasoning as before, by introducing CICA-8 a variety resistant to pest-diseases, a decrease in the use of fungicides and insecticides, and increase in the use of fertilizers, machinery and labor should be expected. Since this variety was more resistant to blast disease and other pests, more output could be produced with

TABLE XIII

RESOURCE USE PER HECTARE, COSTS OF PRODUCTION, TOTAL REVENUE, NET REVENUE AND RELATIVE PROFITABILITY FOR TWO VARIETIES OF RICE: CICA-8 AND IR-22

		CICA-8 (N=34)			IR-22 (N=19)			
	Per hectare Units	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	t-value[a]
Yields	Kg/Ha	5208	1059	20.3	6331	964	15.2	-19.9*
Seed	Kg/Ha	195	54	27.4	257	54	29.9	-47.3*
Nitrogen	Kg/Ha	118	60	51.1	215	69	32.6	-26.8*
Phosphate	Kg/Ha	38	28	73.5	39	18	46.7	-0.7
Potash	Kg/Ha	44	40	89.9	34	19	56.0	5.7
Machinery	Hr/Ha	13.07	3.8	29.2	13.46	4.3	31.8	-1.7
Herbicides	Kg/Ha	6.61	4.9	73.9	7.82	5.3	68.1	-4.8*
Insecticides	Kg/Ha	2.27	2.1	93.9	4.68	3.8	80.6	-14.3*
Fungicides	Kg/Ha	2.94	2.1	71.1	4.04	5.5	137.0	-4.7*
Labor	Hr/Ha	88.42	39.1	44.2	125.1	43.4	33.8	-16.8*
Total Cost	$	52045.00	14088.00	27.1	75516.00	15668.60	20.7	-28.7*
Total Revenue	$	69280.00	14704.00	21.2	84779.00	12237.70	14.4	-20.6
Net Revenue	$	17235.00	11448.00	66.4	9163.00	12101.90	132.1	12.3*
Breakeven Price	$	10.05	1.90	19.0	11.94	2.10	17.3	-17.2*
Breakeven Yield	Kg	3915	1048	26.8	5551	1196	21.2	-26.2*
Relative Profitability	%	37.4	30.6	81.9	15.6	20.9	134.4	15.1*

[a] The tabular t-value = 3.596 at $\alpha = 0.0005$ and 71 d.o.f.

a certain amount of inputs than before. Thus, the marginal productivity of land, labor, machinery, seeds and fertilizers could be raised, while the marginal productivity of insecticides and fungicides would be reduced.

Nevertheless, back to 1981, as the field survey was implemented, blast disease was causing widespread damage in farms planted with CICA-8. Also, CICA-8 fields in rainfed areas were being affected by high incidence of weeds at earlier stages of crop season. Biological researchers have persistently contended that because large areas are sown with a single variety, the genetic resistance of new germplasm to pests and diseases is broken down and the variety collapses in a relatively short period of time (3-4 years). In fact, nearly 52 percent of national rice acreage in 1981 corresponded to CICA-8.[2]

As the probability of yields reductions due to diseases increases for a given level of output and particular amount of resources, the marginal productivity of pesticides is increased. With high incidence of weeds and a disease susceptible variety, the returns to seed, fertilizers, labor and machinery become lower because the weeds-diseases complex prevents a higher response of rice output to these inputs. Thus, to preserve a certain level of output, usage of all resources has to be expanded. The impact of higher levels of inputs usage on rice costs and returns by type of seeds is examined in the following section.

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[2] CICA-8 was mostly substituted in 1982 by ORYZICA-1, a new locally developed variety. In 1985, the distribution of area by rice variety type was: CICA-8 (10.7 percent), ORYZICA-1 (55.4 percent), IR-22 (14.5 percent), and other vars (19.5 percent). However, ORYZICA-1 was already suffering loss of tolerance to the pest-diseases complex.

Crop Profitability and Returns to Inputs

Rice costs and returns are a function not only of levels of input use but of levels of yields, inputs and output prices. As illustrated on Table XIV, excluding seed, nitrogen, phosphate and herbicides, prices paid by farmers for other inputs were significantly higher for IR-22 than for CICA-8. Also, prices received by farmers for IR-22 paddy were slightly higher than those for CICA-8. Consequently, because of higher input levels and higher input prices, IR-22 turned to be a substantially more expensive variety to be grown by farmers than CICA-8.

In spite of IR-22 higher yields (1100 kg more output per hectare than CICA-8) and higher output prices, the returns above variable costs (operating costs) were similar between the two varieties. However, the net revenue was significantly higher for CICA-8 than for IR-22 (Appendix C). The average cost of producing 1 kilogram of paddy was Col. $11.94 for IR-22 and Col. $10.05 for CICA-8. Hence, the computed relative profitability of CICA-8 (37.4%) was twice as high as that for IR-22 (15%). These findings confirm the statement that higher physical productivity of land (yields/ha) do not, necessarily lead to higher benefits to decision makers.

One major objective of this chapter is to shed light on whether or not rice farmers were using inputs efficiently. After examining the resource use issue, it was hypothetized that rice farmers cropping CICA-8 and IR-22 could be earning higher profit margins and returns to inputs by either reducing the observed levels of some inputs or expanding their usage for some other inputs.

The marginal revenue product estimates and returns to each Colombian peso investment on inputs by rice variety type are presented in Table XIV. As suggested in Chapter I, the level of input usage for several production factors

TABLE XIV

INPUT AND OUTPUT PRICES, MARGINAL REVENUE PRODUCT AND RETURNS TO LAND, LABOR AND NON-REAL CAPITAL INPUTS FOR TWO VARIETIES OF RICE: CICA-8 AND IR-22

	Output Kg	Land Ha	Labor Hr	Machinery Hr	Seed Kg	Nitrogen Kg	Phosphate Kg	Potash Kg	Herbicides Kg	Insecticides Kg	Fungicides Kg
						Prices ($)					
CICA-8											
$\bar{x}$	13.27	8125.00	36.15	824.36	33.21	22.88	17.88	19.64	354.99	336.20	614.20
SD	0.4	7809.0	6.8	410.0	3.1	2.0	9.4	7.7	210.3	199.8	386.5
CV	2.7	96.1	18.8	49.7	9.4	8.7	52.6	39.3	59.2	59.4	62.9
IR-22											
$\bar{x}$	13.42	15250.00	52.69	986.87	34.34	21.99	21.05	21.22	376.16	478.55	786.40
SD	0.6	7588.0	7.9	657.5	2.7	1.1	5.3	5.5	194.7	169.8	539.0
CV	4.2	49.8	14.9	66.6	7.9	5.0	25.2	26.1	51.8	35.5	68.5
t-value[a/]	-4.91*	-7.86*	-12.83*	-4.45*	-1.13	-0.80	-2.93	-6.26*	1.52	-16.52*	-5.67*
						Marginal Revenue Product ($)					
CICA-8		1902.70	88.20	-438.75	190.20	26.10	37.14	-255.04	80.10	2228.30	1729.60
IR-22		7101.20	-191.00	551.10	-32.80	26.33	-141.70	672.10	-857.60	-3261.90	-94.60
						Returns ($)					
CICA-8		0.24	2.43	III SP[b/]	5.72	1.14	2.07	III SP	0.22	6.62	2.81
IR-22		0.47	III SP	0.56	III SP	1.15	III SP	31.67	III SP	III SP	III SP

[a] The tabular t-value = 3.596 at a = 0.0005 and 71 d.o.f.

[b] III SP = third stage of production

seemed to exceed the profit maximizing levels. Rice farmers growing CICA-8 would be using too much machinery and potash inputs. Likewise, IR-22 croppers could be deemed to be using too much labor, seeds, phosphate, herbicides, insecticides and fungicides. That is, a higher revenue could be achieved by reducing the level of expenditures on these inputs.

Farmers who were planting CICA-8 could also increase expected profits by expanding seed, insecticides, labor, and phosphate employment and using lower rates of machinery and potash. In turn, rice producers who were growing IR-22 could increase net revenue by employing potash more intennsively or reducing current rates of herbicides, insecticides, labor, phosphate, fungicides and seed. Individual inputs yielding the highest net revenues were insecticides (Col. $6.62) and seed ($5.72) in CICA-8 production and potash (Col. $31.67) in IR-22 production.

Rice Crop Size

In Colombia no research has been done on economies of size to determine the relationshp between rice crop size, resource use and financial profitability. However, this issue has gained public interest since the average farm incomes have been declining, prompting exit of farms from the industry and stagnating the rate of growth of rice supply.

Following the traditional definition of small, medium and large farms, rice crops can be grouped into small, medium and large categories according to their endowment of the most scarce resource to produce rice: land. Although rice farmers hold little labor and capital (operating capital) resources, the most strigent resource to grow rice is deemed to be land. Regardless of what the production region or cropping systems are, the opportunity cost of land is the highest among all inputs, reflecting its relative scarcity.

Consequently, for the purposes of this analysis, the rice crops in the survey were classified into three size groups according to harvested land as: (i) small crop size - less than 10 ha; (ii) medium crop size - greater than 10 ha and less than 50 ha; and, (iii) large crop size - greater than 50 ha and less than 300 ha[3].

In agreement with economic theory, each group of crop sizes can be assumed to follow a different short-run average cost curve representing minimum average costs per unit of output or "plant sizes" matching on different amounts of fixed resources, given the set of prices and technology. Similarly, the long-run average cost curve for the farms in the sample can be visualized as the envelope curve tangent to the family of short-run average cost curves.

By assuming diminishing marginal productivity to resources the short-run average cost curves should be typically U-shaped. The downward sloping part represents a fuller utilization of the fixed resource and spreading of the fixed costs over more output. The rising portion of the curve results from having to apply larger proportions of the variable inputs to the fixed resources to achieve additional units of output.

Given the long-run average cost curve, the most efficient rice crop size would be that one at which its minimum short run average cost curve is tangent to the lowest point on the long-run average cost curve. This crop size would correspond to the most cost efficient size.

In rice production, the most cost efficient crop size is unknown. Uncertain input-output prices, uncertain yields, resource constraints, high cost of capital, taxation on land and investments, indivisibility of land and machinery, and

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[3] Crop sizes above 300 ha were deemed to be not typical observations of the rest of the sample farm. So three rice farms were discarded from the total sample. Because "outliers" minimize the residual sum of squares, the OLS fitted equation become biased toward those observations.

managerial ability differences among other factors can be assumed to determine the most cost efficient rice crop size. However, some preliminary insights on this issue can be drawn of the ensuing analysis.

About 30 percent of the rice fields in the survey sample were found to be in the small size category (average size = 7 ha), 33 percent of medium size (average size = 23 ha), and 37 percent large size (average size = 94 ha). The impact of rice crop size on resource use is examined next.

Resource Use

1. Small vs. Medium Size Farms.

For seed and herbicides there was no significant difference in resource use among small and medium size crops (Table XV). Most of small and medium size rice crops in the sample, were located in the Central region. As already discussed above, irrigated fields in this production region were plagued of problems such as grassy weeds and high incidence of insects and diseases (sogata, hoja blanca, and blast disease).

One hundred percent of small and medium rice farmers were planting varieties suffering high susceptibility to the sogata insect (plant hopper) and hoja blanca associated disease. Therefore, the combined effect of weeds and diseases attack were forcing farmers to plant high levels of seed to fight weeds and consequently increased levels of chemicals to maintain, and/or raise yields and profits.

The weed problem in small rice crops had become so critical because these farms were lacking production alternatives to rotate rice crops over time in the same fields.

TABLE XV

RESOURCE USE PER HECTARE, TOTAL REVENUE, NET REVENUE AND RELATIVE PROFITABILITY FOR THREE FARM SIZES OF RICE

		Rice Farm Size < 10 He (N=21)			10 He < Rice Farm Size < 50 He (N=23)			Rice Farm Size > 50 He (N=27)			t-values[a]		
	Per Hectare Units	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	t(1,2)	t(1,3)	t(2,3)
Yields	kg	6229.00	630.5	10.1	5647.80	1365.4	24.2	5555.00	1014.3	18.2	8.5*	9.9*	1.4
Seed	kg	270.00	21.7	8.0	237.00	68.2	28.8	195.00	47.3	24.3	10.1*	34.2*	12.6*
Nitrogen	kg	192.00	46.0	24.0	184.00	85.6	46.6	124.00	72.5	58.3	1.8	18.9*	13.4*
Phosphate	kg	38.00	20.0	54.6	39.00	24.8	64.2	39.00	24.1	21.9	-0.7	-0.7*	0.0
Potash	kg	41.00	22.4	54.6	41.00	32.4	78.6	47.00	41.4	89.2	0.0	-3.1	-2.9
Machinery	Hr	12.35	3.8	31.5	13.20	93.8	29.1	14.11	3.6	26.9	-3.3	-7.6*	-4.3*
Herbicides	kg	4.39	4.1	92.2	8.27	5.7	68.8	6.51	3.6	65.7	-12.0*	-9.8*	6.7*
Insecticides	kg	3.96	4.3	107.3	3.04	3.0	100.9	2.98	2.2	72.9	4.0*	5.1*	0.4
Fungicides	kg	3.35	1.9	59.4	4.02	5.2	128.8	2.95	2.4	80.8	-0.6	3.0	4.5*
Labor	Hr	99.76	41.2	41.2	109.80	51.8	47.2	92.71	42.4	45.7	-3.3	2.8	6.3*
Total Cost	$	64398.07	6433.4	9.9	66953.60	21234.6	31.7	57369.81	17748.2	30.9	-2.5	7.1*	7.7*
Total Revenue	$	85300.37	7953.4	9.3	75936.30	18778.9	24.7	73761.92	14399.5	19.5	10.1*	16.7*	2.3
Net Revenue	$	20902.30	2741.3	3.5	8982.07	10252.5	114.4	16392.11	3835.7	23.4	34.9*	10.7*	-16.9*
Breakeven Price	$/kg	10.47	0.9	8.8	11.68	2.0	17.1	10.32	2.3	22.6	10.9*	-1.3	-9.7*
Breakeven Yield	kg/$	4762.53	631.8	13.3	4983.00	1583.1	31.7	4318.00	1285.0	29.7	-2.7	13.1*	-11.4*
Relative Profitability	%	33.20	13.7	42.9	18.20	21.4	117.8	35.50	31.1	98.7	13.9*	-2.1	-10.4*

[a] The tabular and t-value = 3.596 at a = 0.0005 and 71 d.o.f.

2. Small vs. Large Farms

Except for seeds, nitrogen, machinery, herbicides and insecticides, resource use by small rice farmers did not differ from that by large rice farmers (Table XV). Small rice farmers were using larger amounts of seed, nitrogen and insecticides as it was expected. On the other hand, large size rice farms, most of them located in the Llanos region, were using more machinery and herbicide inputs. This later could be attributable to a higher productivity of machinery and herbicides under rainfed conditions.

3. Medium vs. Large Farms

As suggested in Table XV, resource use by medium rice farms substantially differed from that by large rice farms with few exceptions: phosphate, potash and insecticides. As before, resource use appeared to be intimately linked to farm location. Accordingly, medium size farms which predominate in the Central region were suffering the complex weeds-pests problem, whereas large farms mostly located in Los Llanos region were facing the weed problem under rainfed conditions.

The impact of the aforementioned differences in resource use on costs and returns is discussed below.

Crop Profitability and Returns to Inputs

As illustrated on Table XVI, small rice farmers were paying significantly higher prices for land, seeds, phosphate and potash compared as medium size rice farmers. When contrasted to large rice farmers, small farmers were incurring higher input expenditures for land, labor, seeds, and herbicides. On the other hand, small farmers were paying lower prices for labor, machinery, nitrogen and pesticides compared to medium farms. In turn, medium farmers

TABLE XVI

INPUT AND OUTPUT PRICES, MARGINAL REVENUE PRODUCT, RETURNS TO LAND, LABOR AND NON-REAL CAPITAL INPUTS FOR THREE FARM SIZES OF RICE

	Output Kg	Land He	Labor Hr	Machinery Kg	Seed Kg	Nitrogen Kg	Phosphate Kg	Potash Kg	Herbicides Kg	Insecticides Kg	Fungicides Kg
						Prices ($)					
Small Farm Size											
$\bar{x}$	13.70	23673.80	43.12	503.61	34.62	20.95	20.50	20.33	393.89	389.12	543.00
SD	0.5	4109.7	8.7	151.0	3.4	1.1	5.0	5.3	222.1	231.1	527.4
CV	3.9	17.4	20.3	29.9	9.8	5.4	24.6	26.2	56.4	59.4	82.0
Medium Farm Size											
$\bar{x}$	13.42	19535.30	46.75	861.20	32.90	22.00	17.71	18.12	407.81	562.58	705.62
SD	0.6	9128.0	13.0	503.5	3.2	1.6	8.6	7.8	216.6	427.0	457.6
CV	4.3	46.7	27.9	58.5	9.7	6.9	48.2	43.1	153.1	75.9	64.9
Large Farm Size											
$\bar{x}$	13.26	14463.20	40.10	985.87	32.31	23.18	19.50	20.96	305.21	382.63	709.40
SD	0.4	10903.2	9.5	521.0	1.6	1.7	8.3	6.3	146.2	219.1	434.4
CV	2.9	75.3	23.9	52.8	5.1	7.4	42.3	29.8	47.9	57.3	61.2
t(1,2)[a]	9.3*	4.3*	-5.1*	-14.9*	8.1*	-11.6*	6.1*	5.1*	-0.9	-7.6*	-5.1*
t(1,3)	15.1*	10.9*	5.5*	-36.7*	15.5*	-25.6*	2.5	-1.8	7.9*	0.5	-5.7*
t(2,3)	5.6*	8.9*	10.2*	-4.3*	3.9*	-13.4*	-3.7	-7.1*	9.8*	9.0*	-0.1
						Marginal Revenue Product ($)					
Small		9437.1	-66.7	-247.9	31.7	9.4	-286.5	461.7	1134.5	-1385.5	-2422.4
Medium		2245.9	-76.7	436.7	6.7	150.7	347.0	-438.2	-309.4	695.4	1752.8
Large		681.7	-25.2	-1226.4	117.9	218.7	14.35	-67.0	-408.8	-5782.5	818.9
						Returns ($)					
Small		0.40	III SP[b]	III SP	0.92	0.45	III SP	22.71	2.88	III SP	III SP
Medium		0.11	III SP	0.87	0.19	6.85	19.59	III SP	III SP	1.23	2.48
Large		0.05	III SP	III SP	3.65	9.43	0.70	III SP	III SP	III SP	1.15

[a] The tabular t-value = 3.596 at a = 0.0005 and 71 d.o.f.

[b] III SP = third stage of production

were paying higher prices for land, labor, herbicides and insecticides than large farms, but lower prices on machinery, nitrogen and potash.

Most of these input price differences were due to differences in input quality as well as on interest charges and transportation costs, with higher interest costs being accounted for by small and medium size farmers and higher hauling costs by large farmers.

In all cases, the prices received by farmers were statistically different among rice crop sizes. The higher output prices were received by small farmers cropping the IR-22 rice varieties while the lower prices corresponded to large farms cropping CICA-8 and other varieties with lower grain quality than IR-22. Although the process of both input and output price formation at the rice farm gate has not been studied yet, this study suggests several findings.

Output prices were mostly influenced by the level of carryover at hand of the mill industry and the Instituto Colombiano de Mercadeo Agropecuario IDEMA at the harvest season. The higher the carryover was the greater the surplus of paddy became in terms of physical capabilities of the public and private sector to purchase and store rice. Therefore, real prices received by farmers were forced down to levels substantially below the government advertised price "floor" or price support. In such an event, farmers were not being paid by cash right after delivering the paddy rice, but 2 or 3 months later with no interest charges.

With few exceptions, rice farmers in the survey were undergoing severe cash flow problems during the planting and harvesting season. According to farmers the cash flow problem was exacerbated not only by the input-output marketing systems but also by the inadequacy of the credit system. In fact, rice production uses techniques which involve greater cash outlays for non-real capital inputs and hence greater demand for credit. For the sample as a whole the total credit needs of rice producers were being met by institutional credit (23 percent), informal credit (46 percent), and own-farmer cash resources (31 percent). Typically, the interest rates were twice or three times as high for informal credit as compared to institutional credit.

Thus, with informal credit meeting about half of the farmer's credit requirements, sale of paddy was done to write off cash debts mostly concerning agrochemical dealers and bank lenders as well. Consequently, the potential earnings of the harvest were highly spent before crops had matured and farmers were in a precarious situation before the next cropping season.

Regardless of the rice crop size, the capacity of savings and investments seemed to be quite limited in most cases. This lack of capacity of investment can be examined through the current stock of physical assets. On the average the stock of machinery and equipment owned by farmers was 6 years old, that for buildings 11 years old and that for primary structures of irrigation and drainage 23 years old (Central region) and 5.5 years (Los Llanos region).

Small farms were found to achieve the highest yields per hectare among three sizes. This result was expected since small rice farms typically produce with high labor - land ratios and therefore, the productivity of their labor is usually low and the productivity of land is quite high. Small rice farms also turned out to have the highest returns above variable costs and estimated profit margin as compared to medium and large farmers (See Appendix C).

However, as shown in Table XVI, overall, large size farms were slightly more cost-efficient production units, than small size farms. The computed breakeven prices ranged from Col. $10.47 for small farmers to Col. $10.42 for large ones. The resulting total cost to total revenue ratios varied between 0.74 and 0.70 respectively. Consequently, the relative profitability of rice crop was largest for large size farms (35.5 percent), preceding that for small size farms (33.2 percent) and medium size farms (18.2 percent).

Little evidence was found of decreasing costs with initial increase in rice crop size. Perhaps, due to the fact that the sample survey was not stratified by crop sizes within each stratum (production zone), the current data set might obscure potential findings on this issue. As already discussed large farms corresponded the most to the Llanos region, small farms predominated in the Central region while medium size farms were located in both regions. As long as rice producers were faced with different types of constraints within each production zone, the farm size issue could be separated out by cropping regions. In spite of that, it could be observed that small and large rice crops were more cost efficient than medium size units. Also, it could be hypothetized that in the Central region there may exist increasing costs as farm sizes get large (larger proportions of variable costs to fixed costs are needed to increase output) while in the Llanos region production costs decline with increase in size (a fuller utilization of fixed resources is attained).

The marginal revenue product and returns to investment on individual inputs under each rice crop size group are presented in Table XVI. Labor appeared to be used in stage III of production for all crop sizes. Machinery and insecticides were being used in excess to achieve maximum revenues in both small and large farmers. Medium size and large size farmers were using too much potash and herbicides. In addition, small farmers were employing too high levels of phosphate and fungicides.

These findings suggest that small farmers could increase net revenue by reducing the level of usage of all inputs except for potash and herbicides. Similarly, medium farmers could arise profit margins by expanding the level of nitrogen and phosphate and large farmers by using higher levels of seed and nitrogen. Fertilizers were found to yield the highest returns to farmers: nitrogen (Col. \$9.43 in large size crops), phosphate (Col. \$19.59 in medium size crops) and potash (Col. \$22.71 in small size crops).

These results also confirm the hypothesis that rice farmers, regardless of their crop size, were using too high levels of several inputs, reducing their opportunities to earn higher levels of profits.

Land Tenure Classes

As is the case on rice crop size, the potential effects of land tenure arrangements on the economics of resource use in rice production are unknown. Economic theory suggests that under conditions of competitive farms, the resources owned and managed by a single decision-maker whose objective is to maximize profits, are allocated in agricultural production in a cost-efficient fashion. For cash and share rented farms become as efficient as owner-operated ones, several conditions must be met: (i) variable costs must be shared in the same proportion as production; (ii) the shares in all crops must be the same; (iii) expected returns on investments over time must be the same under the share lease as in ownership; and, (iv) value of the output received by each party must be the marginal value product of resources contributed by each.

Besides the owner-operators land tenure class, rice production was taking place through different forms of crop share and leasing arrangements. The most comon ones were cash renters and the "compania" or 50-50 share lease. Sixty five percent of the farms enumerated in the sample corresponded to owner-operated, 21 percent to cash-rented, and 14 percent to "50-50" crop leased.

The owner-operator paid all costs and realized all crop output value. The cash renters paid all costs including a fixed per hectare cash rent and received the full crop output value. Under the 50-50 lease, some of the variable input costs were shared between landlord and tenant. Most often, under these lease arrangement the tenant contributed 50 percent of costs of chemical inputs and seed, all labor, and all machinery costs. The tenant also received 50 percent of the paddy value as return on his capital, labor and managerial abilities.

It is stated that because the cash rent represents a fixed outlay, the cash renter might allocate resources in the same way as the owner-operator provided total revenue exceeds total cost by an amount greater than the opportunity cost of his labor and management. In turn, because the 50-50 tenant allocates resources so as to maximize his net revenue (his share of revenues minus his share of costs) he might choose a different resource mix than that selected by an owner-operator or a cash-tenant.

The impact of owner-operated farms and cash-rented farms on resource use, costs and returns is examined next.

Resource Use

As was expected, owner-operators and cash-renters rice farmers do follow a similar pattern of resource use except for seed, nitrogen, labor and herbicides (Table XVII). In the sample, 32 farms out of the 46 owner-operated farms were located in the Central region, cropping rice under an irrigated system. Hence, the observed high levels of seed usage to control weeds has been shown to enhance the marginal productivity of chemicals and labor, stimulating its usage by farmers. On the other hand, 9 out of 15 cash-renters were planting CICA-8 in the Llanos region under rainfed cropping system. Thus, as it has been pointed out, under such circumstances the marginal

TABLE XVII

RESOURCE USE PER HECTARE, TOTAL REVENUE, NET REVENUE AND RELATIVE PROFITABILITY FOR TWO LAND TENURE CLASSES (ARRANGEMENTS) IN RICE PRODUCTION

		Owner-Operator (N=46)			Cash-Renter (N=15)			
	Per Hectare Units	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	t-value[a]
Yields	Kg	5869	1111.5	18.9	5468	920.3	16.9	8.1*
Labor	Hr	97.9	43.0	43.9	109.2	53.4	49.0	4.8*
Machinery	Hr	13.2	4.0	30.2	13.7	3.5	25.3	-2.9
Seed	Kg	236.6	56.9	24.0	208.9	60.7	29.0	9.7*
Nitrogen	Kg	167.4	77.3	46.1	149.1	73.2	49.1	5.0*
Phosphate	Kg	39.6	21.6	54.8	35.0	28.4	81.2	3.7
Potash	Kg	43.0	30.0	69.0	43.6	46.2	105.9	-0.3
Herbicide	Kg	6.1	4.5	74.0	7.8	5.3	68.1	-7.1*
Insecticide	Kg	3.3	3.2	97.0	3.3	3.2	97.3	0.0
Fungicide	Kg	3.5	3.7	106.5	3.1	2.2	71.3	2.6
Total Cost	$	64295.00	15715.00	24.4	56049	20340	36.8	9.43*
Total Revenue	$	78980.00	15704.00	19.9	73765	12618	17.1	7.5*
Net Revenue	$	14686.00	10779.00	73.4	17716	15137	85.4	-4.8*
Breakeven Price	$	10.95	1.70	15.6	10.12	2.8	26.9	7.8*
Breakeven Yield	Kg	4785	1171	24.4	4150	1487	35.8	9.8*
Relative Profitability	%	25.5	19.9	77.9	43.0	41.7	97.1	-11.2*

[a] The tabular t = 3.460 at $\alpha = 0.0005$ and 61 d.o.f.

productivity of herbicides and labor to control weeds is increased prompting farmers to expand their usage.

Crop Profitability and Returns to Inputs

There were no statistical differences among prices paid by farmers for machinery, seed, nitrogen, herbicides and insecticides in both scenarios (Table XVIII). On the average, opportunity costs of land and phosphate, potash and fungicide prices were substantially higher for owner-operators than for cash-renters. The sample survey data revealed that owner-operators were using mostly composite type of fertilizers and selective or specific type of fungicides which carry higher retail price levels than simple types of fertilizers and multiple action type of fungicides.

Land charges (cost of repairs, buildings and structure depreciation, interest and taxes paid) for owner-operators turned out to be 57 percent higher than the fixed cash-rent paid by tenants. Lower prices of machinery and land charges for tenants had major implication on the costs of production structure. Although the variable costs were equivalent for both tenure classes (Appendix C), the fixed costs for land owners were 47 percent higher than for tenants. Fixed costs made up 41 percent of total cost of rice production for land-owners.

Two additional findings can be remarked. First there existed a high correlation between land and machinery ownership. In fact, 82 percent of land owner-operators were also machinery owners. On the other hand, only 21 percent of land tenants held own-machinery and equipment assets.

Second, a high correlation was found between land tenure and cropping systems. For example, 74 percent of land owner-operators were growing rice under irrigated conditions. In turn, 67 percent of tenants cropped rice under rainfed systems. Because of the potential impact of these issues on rice

TABLE XVIII

INPUT AND OUTPUT PRICES, MARGINAL REVENUE PRODUCT, RETURNS TO LAND, LABOR, AND NON-REAL CAPITAL INPUTS FOR TWO LAND TENURE CLASSES (ARRANGEMENTS) IN RICE PRODUCTION

	Output Kg	Land Ha	Labor Hr	Machinery Hr	Seed Kg	Nitrogen Kg	Phosphate Kg	Potash Kg	Herbicides Kg	Insecticides Kg	Fungicides Kg
						Prices ($)					
Owner											
X̄	13.44	20395.00	42.66	809.72	33.11	22.18	20.20	21.14	361.40	445.70	725.29
SD	0.6	9036.0	11.1	448.5	2.9	1.8	6.5	4.7	189.5	324.9	488.5
CV	4.1	44.3	26.0	55.4	8.6	8.0	32.3	22.1	52.4	72.9	67.4
Renter											
X̄	13.49	12933.00	44.97	777.20	33.41	22.15	15.60	15.10	376.90	416.50	542.80
SD	0.4	8955.0	9.9	590.1	3.2	1.7	10.0	10.1	232.9	241.7	340.9
CV	3.1	69.4	22.0	75.9	9.5	7.7	64.2	66.4	61.6	58.0	62.8
t-value[a]	-1.7	17.1*	-4.9*	1.3	-2.0	-0.4	11.4*	16.3*	-1.5	2.1	8.7*
						Marginal Revenue Product ($)					
Owner	-	3034.10	026.94	64.94	132.93	15.59	49.95	-58.70	-231.82	4887.91	375.79
Renter	-	4954.60	81.12	-1040.60	134.20	-57.10	547.23	-1549.50	-159.70	5861.14	1420.48
						Returns ($)					
Owner	-	0.15	III SP[b]	0.08	4.01	0.70	2.47	III SP	III SP	10.96	0.51
Renter	-	0.38	1.90	III SP	4.05	III SP	27.09	III SP	III SP	13.15	1.96

[a] The tabular t-value = 3.460 at $\alpha = 0.0005$ and 61 d.o.f.

[b] III SP = third stage of production

profitability a more extensive discussion of them is postponed to the last section of this chapter.

As a result, although owner operated farms were attaining higher yields per hectare, returns above variable costs and profit margins were lower than those corresponding to cash-rented farms, as indicated in Table XVIII. Tenants appeared to be more cost-efficient than land owners and relative profitability to be 69 percent higher than that for owners.

The total revenue function analysis suggested that owner-operators used too many labor, potash and herbicide inputs. Likewise, tenants applied too intensively machinery, nitrogen, potash and herbicides. Consequently, owners could increase net revenue by cutting down excessive levels of input usage and expanding the use of nitrogen and insecticides. The latter inputs were found to be yielding the highest returns per peso invested on inputs for owner-operated farms.

Similarly, tenants could raise their net revenue by eliminating excessive input usage and increasing the employment of those inputs with highest returns such as phosphate (Col. $27.09), insecticides (Col. $13.15), and nitrogen (Col. $4.91).

The results above suggest once again that rice producers on the average were using too high levels of inputs relatively to those levels required to maximize profits given the biological, socio-economic and institutional constraints.

Production Regions

The study was carried out on two major rice cropping regions of Colombia: the Central region and the Llanos region. Both regions contributed 55 percent of the total harvested acreage and 60 percent of the total paddy rice of the country in 1981. About 47 percent of rice producers were located in these regions.

Either the resource endowment or the constraints to produce rice differ substantially between regions. The Central region is characterized by small holdings of land, water, labor and capital in the form of operating capital. Because the increasing incidence of grassy weeds, sogata - hoja blanca complex, high costs of production and water scarcities, rice production has been declining over the last seven years. A number of production activities compete for scarce resources in this region. Cotton, sorghum, livestock and sesame are the most important ones. It has been stated that lower input-output price ratios to the latter production activities would severely threaten rice production. Farmers would be expected to shift easily to more profitable activities.

The region as a whole is characterized by a suitable physical and institutional infrastructure to produce and distribute rice output in terms of roads, transportation, drying and milling facilities, provision of cash inputs, machinery services, financing, research and extension (private technical consultory) services.

In turn, the Llanos (eastern plains) region has ample land and water but little machinery, labor and capital (operating capital and investment capital). Because of lower unitary total costs of production in the Central region, rice production has been growing over the last 15 years. Most inflows of resources have come from the Central region. However, this region is suffering from several biological constraints among which natural infestations of weeds, blast disease, low soil fertility and water stress have become increasingly important for the last few years. Furthermore, the region is losing potential for further expansion of the agricultural frontier because of the lack of adequate transportation, irrigation and drainage, roads and bridges, drying, milling and marketing facilities which increase costs to producers and marketing margins to consumers. Also, infrastructure problems limit the application of existing technology. Hence, given those constraints a different pattern of resource use and crop profitability would be expected between these two regions.

Resource Use

As depicted in Table XIX the employment of production factors differed substantially between Los Llanos and Central regions. Rice producers at the Central region used greater amounts of labor, seed, nitrogen, phosphate, insecticides, and fungicides than farmers in the Llanos region. No statistical differences were found among usage of machinery, potash and herbicides between regions.

The higher resource use found in the Central region could be associated with the irrigated cropping system and type of seeds planted. As was discussed in earlier sections of this chapter, because of the high incidence of the grassy weeds - hoja blanca complex, and the high susceptibility of planted varieties to diseases, farmers were "forced" to expand their level of usage of seeds, fertilizers and chemicals. In turn, the incidence of the weeds-blast disease complex was found to be an important biological constraint in the Llanos. Therefore, farmers were required to use intensive mechanical and chemical actions to control weeds and still maintain high marginal productivities for seeds, fertilizers and fungicides. The impact of observed production resources use on rice costs and returns in both regions is considered in the next section.

TABLE XIX

RESOURCE USE PER HECTARE, TOTAL REVENUE, NET REVENUE, AND RELATIVE PROFITABILITY FOR TWO RICE PRODUCTION REGIONS

		Los Llanos Region (N=27)			Central Region (N=44)			
	Per Hectare Units	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	t-value[a]
Yields	Kg	4901	1062	21.7	6325	655	10.3	-39.2*
Labor	Hr	81.12	32.2	39.7	112.13	48.3	43.0	-18.5*
Machinery	Hr	13.45	3.8	27.8	13.19	3.96	30.0	1.7
Seed	Kg	173.5	43.4	25.0	266	33.1	12.5	-58.3*
Nitrogen	Kg	95.6	41.8	43.8	205.1	61.2	29.8	-50.9*
Phosphate	Kg	33.3	27.1	81.5	41.9	19.9	47.5	-8.9*
Potash	Kg	44.2	44.6	100.9	42.4	24.8	58.4	1.2
Herbicide	Kg	6.3	4.1	64.7	6.6	5.1	77.6	-1.5
Insecticide	Kg	2.0	1.6	77.8	4.1	3.7	89.8	-19.7*
Fungicide	Kg	2.6	2.1	82.4	4.0	4.0	100.0	-10.7*
Total Cost	$	46861.00	12052.00	21.8	72182	14034	20.0	-42.7*
Total Revenue	$	64663.00	14116.00	21.9	85988	8793	10.2	-44.3*
Net Reveneu	$	17802.00	19633.00	11052	13806	11309	76.6	6.7*
Breakeven Price	$	9.69	1.93	19.9	11.12	1.8	16.4	-20.4*
Breakeven Yield	Kg	3556	924	25.9	5083	1075	21.1	-38.9*
Relative Profit	%	42.1	53.0	125.8	19.1	20.3	106.3	15.9*

[a] The tabular t-value = 3.596 at $\alpha = 0.0005$ and 71 d.o.f.

Crop Profitability and Returns to Inputs

Except for seed and machinery, prices paid for all other inputs by rice farmers in the Central region were considerably higher than those paid for by farmers in the Llanos region (Table XX). Land charges per hectare turned out to be 2.5 times as high in the Central region as in the Llanos region, reflecting its relative scarcity. However, the price of land in both regions was equivalent to 7 times the value of its marginal product, suggesting that land prices were overvalued.

The average wage found in the Central region was 35 percent higher than that in the Llanos region, 53 percent higher than the minimum rural wage (Col. $38.25), and 9.4 percent above the minimum urban wage (Col. $43.75) set up by the government. However, its marginal value product was found to be negative. This fact sharply contrasts with labor pricing in Los Llanos region, where a surplus value was found for labor. The value of the marginal physical product of labor was about 2.5 times as high as the current wage.

In spite of the fact that farmers in the Central region were producing substantially higher paddy output per hectare and having higher returns above variable costs than farmer in Los Llanos region, their profit margin was lower (Appendix C). Consequently as depicted in Table XX, the relative profitability in Los Llanos region (42.1 percent) was twice as high as in the Central region (19.1 percent).

The coefficient of variation for the computed profitability parameters were 126 percent (Llanos region) and 106 percent (Central region). These results underline the high variability in expected profitability in rice production in both regions and point out a need for a better knowledge on the sources of such a profit variability. In years to come, because rice profitability is expected to be

TABLE XX

INPUT AND OUTPUT PRICES, MARGINAL REVENUE PRODUCT, RETURNS TO LAND, LABOR AND NON-REAL CAPITAL INPUTS FOR TWO RICE PRODUCTION REGIONS

	Output Kg	Land Ha	Labor Hr	Machinery Hr	Seed Kg	Nitrogen Kg	Phosphate Kg	Potash Kg	Herbicides Kg	Insecticides Kg	Fungicides Kg
						Prices ($)					
Los Llanos											
x	13.19	10073.00	35.45	899.60	32.20	23.49	16.14	18.22	331.13	334.50	643.78
SD	0.3	5731.0	5.4	416.0	1.9	1.6	10.6	9.2	172.1	186.9	414.5
CV	2.3	56.9	15.3	46.2	5.6	6.9	65.9	50.3	51.9	55.9	64.4
Central											
x	13.60	24184.00	47.87	743.50	33.77	21.34	21.12	20.88	385.20	498.96	714.93
SD	0.6	6966.6	10.6	506.8	3.3	1.3	3.7	4.1	210.9	346.1	497.7
CV	4.2	28.8	22.2	68.2	9.7	5.9	17.7	19.8	54.7	67.4	69.6
t-value[a]	16.1*	-53.9*	-36.2*	8.2*	-13.8*	36.4*	-14.8*	-9.1*	-6.8*	-14.96*	-3.7*
						Marginal Revenue Product ($)					
Los llanos		1491.10	87.48	229.5	32.19	-36.18	8.67	-340.60	133.93	1116.34	186.19
Central		7539.50	-92.34	303.10	14.51	7.23	-64.99	71.47	-365.47	-2673.20	21.52
						Returns ($)					
Los Llanos		0.15	2.46	0.26	1.00	III SP	0.54	III SP	0.40	3.33	0.29
Central		0.31	III SP[b]	0.41	0.45	0.34	III SP	3.42	III SP	III SP	0.03

[a] The tabular t-value = 3.596 at α = 0.0005 and 71 d.o.f.

[b] III SP = third stage of production

quite similar to that in other sectors of the economy and the domestic market requirements will have to be met, policies aimed at reducing variability of net income should be implemented to ensure and maintain the desired rate of growth of the rice industry.

It should be noted that rice profitability was found to be affected by factors such as input-output price variability, yield and acreage variability as suggested by the coefficient of variation corresponding to these parameters under each scenario. All of these factors are deemed to be random factors outside the farmers' control. Also, it should be remarked that rice profits variability have not remained constant over time and was found to vary unevenly across each rice production scenario.

As was expected, output prices received by farmers in the Llanos region were statistically different (lower) from those received by producers in the Central region. Rice croppers in the Llanos complained about facing high probabilities of output losses at the harvest and post-harvest time, because of a shortage of combines, lack of drying, storaging, transportation and milling facilities. As a result of the different marketing constraints actually faced by farmers, 85 percent of the rice producers in the survey sold their paddy output at local mills and received on the average output prices up to 37 percent below the floor price advertised by the government.

Only 12 farms in the survey were determined to be combine-owner operated farms. In turn, only 23 farmers owned a truck to transport rice, and three farms had drying facilities at the farm level. As a result, a major constraint to cope with most by farmers was a shortage in drying, processing, and hauling facilities to minimize potential losses at the harvest and post-harvest periods. Such a loss was rising out from reductions of grain quality and physical output losses. A recent study by FEDEARROZ and ICA indicated that total post-harvest losses could amount to 12 percent of total expected output value or equivalently to Col. $8.7 billions (1986 prices) per year.

Rice producers in Los Llanos region were using nitrogen and potash at levels beyond the requirements to attain maximum revenues (Table XX). Therefore, rice farmers could increase profits by reducing the actual level of employment of all inputs except for labor and insecticides. The former inputs were reducing profit margins and even yielding net economic losses. The latter inputs would yield higher net revenue by increasing its usage.

Likewise, rice producers in the Central region were found to be using levels of labor, phosphate, herbicides and insecticides yielding negative returns. Farmers were also employing input levels for land, machinery, seeds, nitrogen and fungicides beyond an economic optimum. For this region potash was the only input found to yield positive returns to farmers.

Cropping Systems

In Colombia, rice production takes place under two well-defined cropping systems: irrigated rice production system and rainfed rice production system. Most of the differences in rice production between and within production regions can be traced directly to the type of production system. Irrigated rice represented 68 percent of total rice area in Colombia and 71 percent of the total production in 1985. Irrigated rice is found in lowland flat fields across the country with moderate to high fertile soils. One hundred percent of the system is cropped with modern semi-dwarf varieties. Typically, the system is highly biased to using machinery and other non-real capital inputs and saving land and labor.

Similarly, rainfed rice is found mostly in highly favored upland fields. Typically, this system is highly favored because there is no water stress due to a good rainfall distribution through the crop season. Also because of relatively high soil fertility.

However, both systems were suffering major biological constraints. Irrigated rice was being limited, mainly due to high fields infestations by grassy-weeds, high incidence of blast disease, hoja blanca virus, lodging and plant hopper (sogatodes); also the vector of the hoja blanca disease. In turn, rainfed rice was produced under conditions of severe pressures by weeds, acid soils, increased incidence of rice blast - hoja blanca complex, lack of suitable grain quality and infraestructure problems. The impact of these constraints on resource use costs and returns in rice production are looked into next.

Resource Use

The average levels of production factors used as reported by rice farmers in the sample survey (Table XXI). As expected, farmers cropping rice under irrigated systems used in much more intensive way all inputs (except for land and herbicides), than farmers growing rice in highly favored upland ecologies. These results confirm once again the statement made by farmers that the major biological constraint to crop rice in both production systems was the weed-pest-diseases complex. The rationale supporting farmer's use of resources has been discussed throughout all this chapter so it not to be repeated in this section. Briefly, farmers in irrigated systems found it more profitable to fight weeds by increasing plant population and spreading over higher levels of chemicals to offset the susceptibility of rice varieties to diseases. By such a means, the marginal physical productivity of all inputs was raised. On the other hand, farmers in rainfed systems found it more profitable to control weeds by mechanical or chemical means as pre-planting cultural practices.

TABLE XXI

RESOURCE USE PER HECTARE, TOTAL REVENUE, NET REVENUE AND RELATIVE PROFITABILITY FOR TWO CROPPING SYSTEMS IN RICE PRODUCTION

		Irrigated Rice (N=52)			Rainfed Rice (N=19)			
	Per Hectare Units	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	t-value[a]
Yields	Kg	6164	775.2	12.6	4744	1130	23.8	32.8*
Labor	Hr	108.7	46.6	42.9	77.5	32.6	42.0	17.2*
Machinery	Hr	13.36	4.0	29.7	13.12	3.61	27.6	1.4
Seed	Kg	251.5	49.0	19.5	173.8	42.1	24.2	27.3*
Nitrogen	Kg	187.7	70.4	37.5	97.2	3.61	49.0	3.4*
Phosphate	Kg	41.3	22.1	53.4	31.2	24.9	79.7	9.6*
Potash	Kg	48.2	34.4	71.4	29.3	26.7	91.3	13.6*
Herbicide	Kg	6.22	4.86	78.0	7.10	4.3	60.9	-4.2*
Insecticide	Kg	3.61	3.53	98.0	2.41	1.6	67.1	8.9*
Fungicide	Kg	3.81	3.74	98.2	2.33	2.2	94.9	11.0*
Total Cost	$	68703.00	14034.00	20.4	45720	12438	27.2	38.6*
Total Revenue	$	83470.00	10735.00	12.8	62576	15207	24.3	35.5*
Net Revenue	$	14767.00	11309.00	76.6	16856	13171	78.1	-3.8*
Breakeven Price	$	11.12	1.79	16.1	9.83	2.17	22.1	15.6*
Breakeven Yield	Kg	5083	1075	21.1	3469	940	27.0	35.6*
Relative Profitability	%	24.8	28.3	114.7	41.3	27.3	66.2	-12.4*

[a] The tabular t-value = 3.596 at α = 0.0005 and 71 d.o.f.

Rice Profitability and Returns to Inputs

As indicated in Table XXII, output prices received by farmers in irrigated areas differed statistically from those obtained by producers in rainfed areas. As pointed out in the latter section, a shortage was reported by farmers on harvesting and post-harvesting services (mainly combines, transportation and drying facilities) in rainfed areas. So farmers were receiving lower output prices because a lower grain quality brought about by lack of timeliness in harvesting and poorer processing activities.

Excluding potash and fungicide input prices substantial differences were found among prices paid for all other inputs, by farmers in both cropping systems. Land prices in irrigated areas were twice as high as those in rainfed areas. However, in both cases there was an indication that land prices were overstated relative to the value of its marginal physical product.

While wages received by rural workers in irrigated areas were significantly higher that those earned by workers in rainfed areas, the marginal physical productivity of labor in the former system was negative. A case of surplus value was realized for labor in rainfed systems. That is, the marginal value product for labor was significantly above the actual wage rate.

As stated in Appendix C, the structure of costs of production for both cropping systems was quite different. The relative relationships between variable costs and fixed costs was equivalent to about 65 percent and 35 percent of total costs, respectively, in both production systems. However, in absolute values, the costs composition varied markedly. While variable costs turned out to be 37 percent higher for irrigated systems than for rainfed ones, the fixed costs were 57 percent higher for the former system than for the latter one.

TABLE XXII

INPUT AND OUTPUT PRICES, MARGINAL REVENUE PRODUCT, RETURNS TO LAND, LABOR, AND NON-REAL CAPITAL INPUTS FOR TWO CROPPING SYSTEMS IN RICE PRODUCTION

	Output Kg	Land Ha	Labor Hr	Machinery Hr	Seed Kg	Nitrogen Kg	Phosphate Kg	Potash Kg	Herbicides Kg	Insecticides Kg	Fungicides Kg
						Prices ($)					
Irrigated											
$\bar{x}$	13.55	21982.00	46.34	774.48	33.72	21.70	19.85	20.03	373.81	485.03	708.09
SD	0.6	8535.0	10.6	488.4	3.1	1.5	5.9	5.0	209.3	327.1	479.4
CV	4.2	38.8	22.8	63.1	9.2	6.7	29.7	25.0	56.0	67.4	67.7
Rainfed											
$\bar{x}$	13.17	10162.0	34.42	880.50	31.67	23.39	17.40	19.40	339.60	299.70	631.15
SD	0.3	5835.0	5.5	449.3	1.5	1.9	10.8	9.9	183.4	181.1	433.2
CV	1.9	57.4	15.9	51.0	4.6	8.1	62.4	50.9	48.1	60.4	68.6
t-value[a]	14.3*	35.9*	31.3*	-5.0*	20.3*	-23.6*	6.3*	1.8	4.0*	1538*	3.66
						Marginal Revenue Product ($)					
Irrigated	-	4720.00	-79.41	262.72	82.24	22.73	62.01	-24.86	-24.11	945.81	70.46
Rainfed	-	1982.50	243.11	-702.35	-12.18	-8.79	-19.46	-499.58	1139.00	-1135.69	-986.04
						Returns ($)					
Irrigated	-	0.21	III SP[b]	0.34	2.43	1.05	3.13	III SP	III SP	1.95	0.10
Rainfed	-	0.20	7.06	III SP	III SP	III SP	III SP	III SP	3.04	III SP	III SP

[a] The tabular t-value = 3.596 at $\alpha = 0.0005$ and 71 d.o.f.

[b] III SP = third stage of production

Owner-operators in irrigated systems contended that the ongoing policies on land taxation (expected income tax and land value taxes) were not only discriminating against the most productive farms (those generating the highest income levels) but also even importance discouraging reinvestments in land, buildings, machinery, and equipment improvements. As long as income and land taxes were levied on a progressive bases, the larger the fixed assets values owned by a farmer became or the higher his income earned was, the higher the rate of taxes. That is, the tax policy discriminated against the irrigated cropping system which typically requires larger capital assets holdings and furnishes a higher total revenue than rainfed system does.

Moreover, the cost composition between irrigated and rainfed rice farms could be stated to play a major role in determining both level of profits and its variability. As shown in Table XXII, while relative rice profitability for rainfed rice was 67 percent higher than that for irrigated rice, its variability was substantially lower. The coefficient of variation of rice profitability was 66 percent for rainfed rice compared to 115 percent for irrigated rice. Owner-operators in irrigated systems, who held high capital assests (fixed costs), might be assumed to make decisions on rice production based on maximizing the net present value of their investment in land, machinery and physical structures. Therefore, these farmers should crop rice to minimize potential losses on their fixed resources regardless of what the economic environment was (input-output prices relationship). In contrast, producers in rainfed areas whose capital holdings were relatively low (most of them were tenants) could more easily take advantage of any outlooked or foregone economic situation by entering or leaving the rice industry at their best convenience.

The marginal revenue product and returns to investment on inputs are presented in Table XXII. It can be observed that rice farmers under irrigated conditions were found to be using too much labor, herbicides and insecticides and greater amounts of land, machinery and fungicides that needed to achieve maximum net revenues. In turn, farmers in rainfed systems were found to be in stage III of production for machinery, seed, fertilizers, insecticides and fungicides. The usage of land could be deemed to be beyond the optimal level.

Farmers in irrigated areas should not only eliminate the excessive use of inputs but also expand the employment of nitrogen and phosphate to increase net revenue. Similarly, rice croppers in rainfed areas could increase profit margins by using more intensively labor and herbicides and reducing the use of all other inputs.

The analysis on resource use and returns to rice investments indicates that regardless of the biological, economic and institutional setting, rice producers were overusing resources in production, mainly, machinery, labor and chemicals to control pests and diseases. Overuse of resources leads to productive inefficiencies and rice producers could earn higher net revenues by reducing their use. In light of the present data and economic analysis it can be hypothesized that because farmers were allocating resources in excess to the optimum a problem of technical inefficiency in rice production could be arising. Since an excessive use of resources is costly, an analysis on technical efficiency in rice production and its associated costs to farmers is in order. These are major objectives of Chapter V.

CHAPTER V

TECHNICAL EFFICIENCY IN RICE PRODUCTION

This chapter presents the results of estimating a stochastic frontier total revenue function to derive average levels of technical efficiency in rice production under different scenarios.

Given a Cobb-Douglas revenue function, the stochastic frontier model is:

$$TR_i = a \prod_{j=1}^{k} x_{ji}^{aj} \cdot e^{\varepsilon i} \qquad (5.1)$$

where TR_i is total revenue function for rice farm i, x_{ji} is a vector of j production factors for rice farm i, a_j is a vector of parameters and ε_i is a composite error term for rice farm i. The error term ε_i is a non-normal error made up of two components, υ_i and μ_i. It is assumed that the υ_i and μ_i are mutually independent, that the υ_i are identically-independently distributed as $N(0, \sigma^2_\upsilon)$ and the μ_i are identically-independently distributed as the absolute value of a $N(0, \sigma^2_\mu)$. The symmetric error υ_i represents the usual statistical noise compounding any relationship and the $\mu_i \leq 0$ is a one-sided error term representing technical inefficiency. μ_i measures technical inefficiency in the sense that it determines the shortfall of total revenue (TR_i) from its maximum possible value given by the stochastic frontier:

$$a \prod_{j=1}^{k} x_{ji}^{aj} e^{\varepsilon i} \qquad (5.2)$$

The average technical efficiency is estimated as the mean of the distribution of μ_i, $E(e^{\mu i})$. It has been shown that in the half-normal case (μ_i is distributed as the absolute value of a $N(0, \sigma^2\mu)$ variable), the mean technical efficiency equals $2e^{\sigma 2\mu/2}[1\text{-}F^*(\sigma\mu)]$, where $F^*(\sigma_\mu)$ is the standard normal cumulative distribution function (cdf) evaluated at σ_μ.

The first section discusses the empirical estimation of the stochastic frontier function for each scenario. The second section computes the average levels of technical inefficiency and interprets the resulting estimates for each scenario.

Estimation of Stochastic Frontier Revenue Functions

The empirical analysis involved fitting ten-factor stochastic frontier Cobb-Douglas functions to data for 71 Colombian rice farms. Twelve different scenarios were analyzed. The data used were from a 1981 survey of farm and rice crop management information for farms operating in two major regions of rice production: the Llanos region and the Central region. The log-likelihood function of the sample took the following form:

$$L\,(TR \mid a, \lambda, \sigma^2) = n \ln (\sqrt{2} \mid \sqrt{\pi}) + n \ln (\sigma^{-1}) + \sum_{i=1}^{n} \ln [(1\text{-}F^*(TR_i - x_i a)(\lambda\sigma^{-1})]$$

$$- (1/2\sigma^2) \sum_{i=1}^{n} (TR_i - x_i a) \tag{5.3}$$

The parameters of the model (5.3) were estimated by applying the STEPIT computer package. The optimization technique STEPIT is an accelerated version of the one "variable-at-a-time" method from the set of several direct search methods available to minimize a non-linear in parameters multiple-variable single equation as (5.3). In some cases, a combination of the STEPIT and MINF/POWELL package was required to speed up convergence, improve the process of fitting and attain an optimal solution.

The estimated maximum likelihood parameters for six scenarios (whole sample farms, IR-22, small and medium crop sizes, owner-operated farms and irrigated cropping systems) are presented in Table XXIII. For the rest of the scenarios, excluding the large crop size scenario, a stochastic frontier specification could not be fitted given the sample data.

First of all, the initial estimate of σ^2_υ for the large crop size scenario turned out to be less than zero. As pointed out by Schmidt and Lovell, there is no guarantee that the OLS/Moments estimates of σ^2_μ and σ^2_υ would be non-negative. In this case it is possible to find $\hat{\mu}_2$ and $\hat{\mu}_3$ such that $\sigma^2_\upsilon < 0$. This result causes concern because it precludes the computation of the estimates for the parameter $\lambda = \sigma_\mu/\sigma_\upsilon$ in equation (5.3) for that particular scenario.

As indicated in Table XXIV, for the remaining five scenarios, the computed λ parameter value became too large before a local optimum point could be approached. That is, in all cases λ tended to $+ \infty$. Therefore, the resulting fit was deemed unusable. By computing separate estimates for σ^2_μ and σ^2_υ it was possible to state that σ^2_υ tended to 0, and as a result λ tended to $+ \infty$ at the abnormal termination point. As long as σ^2_υ tends to 0, according to equation (3.10), an appropriate model specification would be a deterministic frontier rather than the stochastic frontier. However, in this study no attempt was made to estimate a deterministic frontier for those scenarios for several reasons.

The maximum likelihood estimation of the deterministic frontier poses the problem of choosing a distribution function that does not violate the regularity conditions of the MLE technique. As shown by Schmidt (1976) and Greene (1980), in the deterministic frontier approach the range of the dependent variable should be independent of the value of the parameters, if properties of

TABLE XXIII

MAXIMUM LIKELIHOOD ESTIMATES OF STOCHASTIC FRONTIER REVENUE FUNCTIONS UNDER DIFFERENT SCENARIOS*

Scenario	Number of Farms (n)	Intercept	Land	Labor	Machinery	Seed	Nitrogen	Phosphate	Potash	Insecticides	Herbicides	Fungicides	λ	σ^2	r[a/]
Whole Sample	71	7.723	0.596	-0.036	-0.003	0.367	0.021	0.016	-0.013	0.007	0.030	0.013	2.878	0.056	0.998
		(6.590)	(4.785)	(-0.761)	(-0.456)	(3.026)	(1.378)	(1.420)	(-0.888)	(0.243)	(1.977)	(1.255)	(2.246)	(3.12)	
IR-22	19	11.981	1.260	-0.256	0.081	-0.107	0.038	-0.044	0.123	-0.026	-0.061	-0.003	3.125	0.071	1.025
		(13.012)	(16.868)	(-5.825)	(3.001)	(-1.496)	(1.055)	(-1.447)	(3.929)	(-1.701)	(-3.505)	(-1.453)	(1.633)	(1.619)	
Small Size	21	11.592	0.823	-0.059	-0.031	0.105	0.021	-0.077	0.073	0.025	-0.017	-0.061	4.953	0.0025	0.801
		(7.254)	(5.309)	(-1.311)	(-0.574)	(0.896)	(1.75)	(-2.019)	(1.78)	(1.487)	(-1.007)	(-2.542)	(3.540)	(1.19)	
Medium Size	23	8.030	0.586	-0.089	0.077	0.022	0.329	0.078	-0.048	-0.011	0.004	0.019	2.989	0.0281	0.959
		(4.103	(2.362)	(-1.977)	(0.802)	(0.856)	(2.384)	(2.689)	(-1.846)	(-0.87)	(2.22)	(1.583)	(3.178)	(23.54)	
Owner-Operated	56	7.511	0.598	-0.017	0.004	0.387	0.017	0.017	-0.091	-0.042	0.030	0.009	3.049	0.062	0.912
		(5.267)	(4.160)	(-2.09)	(0.611)	(2.546)	(1.214)	(1.545)	(-0.029)	(-3.137)	(1.764)	(0.75)	(1.882)	(2.81)	
Irrigated Rice	52	9.041	0.781	-0.086	0.035	0.246	0.051	0.018	-0.015	-0.002	0.006	0.002	0.322	0.011	1.032
		(8.189)	(7.165)	(-1.563)	(0.67)	(2.120)	(2.684)	(1.500)	(-0.88)	(-0.88)	(0.89)	(0.018)	(0.75)	(1.931)	

* The t-statistics are included in parenthesis.

[a/] Returns to scale.

TABLE XXIV

ESTIMATES OF THE VARIANCE OF THE NORMAL DISTURBANCE TERM ($\sigma^2\upsilon$) AND THE HALF-NORMAL DISTURBANCE TERM ($\sigma^2\mu$) FOR SEVERAL SCENARIOS

Scenario	$\sigma^2\mu$	$\sigma^2\upsilon$	λ Value
CICA-8	0.97123	1.0 E-20	$+\infty$
Cash-Rented	8.36275	1.0 E-20	$+\infty$
Los Llanos Region	2.471514	1.0 E-20	$+\infty$
Central Region	0.16632	1.0 E-20	$+\infty$
Rainfed Rice	15.80849	1.0 E-20	$+\infty$

assymptotic consistency and efficiency are to be claimed for the resulting estimates. The half-normal and exponential distributions do not satisfy this criteria.

Given the deterministic frontier revenue function:

$$TR_j = a \sum_{j=1}^{k} x_{ji}^{aj} e^{\mu i}, \text{ for } 0 < e^{\mu i} < 1 \qquad (5.4)$$

it can be seen that the range of TR_j is between 0 and,

$$a \sum_{j=1}^{k} x_{ji}^{aj}$$

which depends on the value of the parameters a_j, because $0 < e^{\mu i} < 1$. Greene (1980) showed that maximum likelihood estimators of the gamma distribution do not violate the regularity condition needed to invoke the large sample properties, if the shape parameters is greater than two.

Also, the financial and time resources required to accomplish the additional task of estimating a deterministic frontier for five scenarios exceeded the limits imposed by resources available. In fact, the deterministic frontier gamma model appeared to be more complicated and expensive to estimate than the stochastic frontier half-normal model.

The failure to estimate a stochastic frontier function for several scenarios prompted tests to determine whether or not a frontier function would exist for such scenarios. Following Schmidt and Lin (1984), the existence of a frontier can be tested through tests for departure of normality of the residual terms in (5.1). The test implies testing the null hypothesis Ho: $\sigma^2\mu = 0$. If $\sigma^2\mu = 0$ then $\mu_i = 0$ for every i, and technical inefficiency does not exist. In such a case the average revenue function would be a valid specification given the assumptions of the conventional theory of the firm.

A test for the existence of a frontier can be carried out ex-ante based on the OLS residuals by noting that the null hypothesis above is really just that the errors ($\upsilon_i + \mu_i$) in (5.1) are identically-independently distributed (iid) normal. Given that the most obvious difference between a normal and the sum of a normal and a half-normal (or other one-sided error) is the skewness of the latter, the test can be based on the sample skewness coefficient of the residuals.

The coefficient of skewness of the OLS residuals is defined as:

$$\sqrt{b_1} = \hat{\mu}_3/(\hat{\mu}_2)^{3/2}$$

where, $\hat{\mu}_2$ and $\hat{\mu}_3$ are the estimated OLS second and third moments respectively, from the residuals. As noted in Table XXV, the results of the skewness tests indicate that the computed values exceed the critical values for the whole sample, CICA-8, large crop size, owner-operated and Central region scenarios. Hence, the null hypothesis of a normal error was rejected and it can be claimed that the frontier specification can be used for these scenarios.

On the other hand, the alternate hypothesis of a log-normal error was, convincingly, rejected for the rest of scenarios. However, the latter findings must be interpreted with caution. As contended by Pierce and Gray, the skewness test is reliable for samples of moderate size such as 30 or 40. Therefore, for such scenarios as IR-22, crop sizes, cash-rented farms, Los Llanos region and rainfed rice, the estimated results may be inconclusive.

Although a number of alternative tests for normality are available (Lagrangian multiplier test, Kolgomorov-Smirnov test, Shapiro-Wilk test, etc.), the skewness test is deemed to be more appropriate because it supports the intuitive notion to test normality against skewed alternatives. In the present case, the one-sided test was appropriate and the computed negative skewness values confirmed the idea behind a production frontier. Therefore,

TABLE XXV

TESTS FOR LOG-NORMALITY (SKEWNESS) FOR SEVERAL SCENARIOS

Scenario	N	$\hat{\mu}_2$	$\hat{\mu}_3$	$\sqrt{b_1}$	$\sqrt{b_1}$*
Whole Sample	71	0.02527	-0.00408	-1.006	-0.669
CICA-8	34	0.03003	-0.00586	-1.126	-0.931
IR-22	21	0.03882	-0.00824	-1.077	-1.136
Small Size	21	0.00216	0.00006	0.598	1.136
Medium Size	23	0.00743	-0.00046	-0.718	-1.118
Large Size	27	0.01564	-0.00333	-1.704	-1.089
Owner-Operated	56	0.02815	-0.00488	-1.033	-0.748
Cash-Rented	15	0.03395	-0.00753	-1.203	-1.211
Los Llanos Region	27	0.02156	-0.00143	-0.451	-1.089
Central Region	44	0.02912	-0.00459	-0.920	-0.829
Irrigated Rice	52	0.01051	0.00011	0.106	0.799
Rainfed Rice	19	0.01194	-0.00016	-0.123	-1.151

* One percent critical value of $\sqrt{b_1}$. From: Pearson E.S., and H.O., Hartley (Eds.). Biometrika Tables for Statisticians, Vol. I. Cambridge University Press, 1970.

what is advisable in future empirical studies of efficiency might be avoiding use of small sample sizes (N<30).

These results above also provided information to contend that even though the stochastic frontier approach was, theoretically, the most appealing framework to efficiency analysis, for some scenarios (except for irrigated rice) a deterministic frontier approach could be more adequate. As noted in Table XXIII, the maximum likelihood estimate of λ ranged from 8 (for the whole sample) through 24 (for the small crops size). So the variance of μ was substantially larger than the variance ov υ. Thus, the technical inefficiency error dominated the random error, and a deterministic framework to study efficiency could have been a more appropriate approach to study efficiency than a stochastic approach for such scenarios as CICA-8, the Llanos region and rainfed rice.

A further look into the stochastic frontier estimates in Table XXIII revealed that as expected, the resulting parameters were slightly similar to the OLS parameter estimates. On the average, the elasticity of revenue for land and labor inputs for most scenarios is higher in the stochastic frontier than in the OLS average function. In turn, the elasticity of revenue for non-real capital inputs is lower in the frontier function than that for the OLS estimated functions. This suggests that most efficient rice farms were more land and labor intensive users than less efficient farms.

The intercept term is usually interpreted as a rough measure of the level of technical efficiency in average production function models. Theoretically, the constant term for the frontier function model should be greater than that for the OLS function if technical inefficiency is included. In the present case, there was no major differences between the two intercepts, providing evidence that the level of technical efficiency in the estimated average functions must be relatively high with respect to that in the estimated frontier functions.

In general, the statistical significance of the estimated parameters for the frontier turned out to be lower than that for the average function. This result suggested that there was a strong negative correlation between the observed levels of resource use and technical efficiency. As was shown in Chapter IV, if Xo (observed input) and technical efficiency (T) are negatively associated, then the estimated standard errors for the average function may be lower than those for the frontier function. This finding prompted a test to determine whether or not the error components of the stochastic frontier functions were equal to zero (Ho: $\sigma^2\mu = \sigma^2\upsilon = 0$). By such a means, it could be established whether the stochastic frontier specification or the average function specification were appropriate. This test is left out to the next section.

Average Technical Efficiency

The maximum likelihood estimates of the stochastic revenue function were used to compute the mean efficiency [$E(e^{\mu})$] of all rice farms in each scenario. These estimates are presented in Table XXVI. As expected, relatively low levels of technical inefficiency were observed for all scenarios. The mean efficiency estimates for the whole sample, IR-22, small crop size, medium crop size, owner-operated rice farms and irrigated cropping system scenarios were 0.84, 0.83, 0.96, 0.88, 0.84 and 0.97, respectively. That is, the observed total revenue (output) was 16%, 17%, 4%, 12%, 16% and 3%, below the frontier. If factors leading to such inefficiency were to be eliminated, rice farmers could increase total revenue (output) by an equivalent percentage.

The empirical validity of the estimated parameters on efficiency was supported by two different hypothesis testing. As indicated in Table XXVI,

TABLE XXVI

AVERAGE LEVELS OF TECHNICAL EFFICIENCY FOR SEVERAL SCENARIOS*

Scenario	$\sigma^2\mu$	$\sigma^2\upsilon$	Technical Efficiency $E(e^{\mu})$	Cost of Technical Inefficiency $(1/r)\mu$	Mean of Residuals $E(\varepsilon_i)$
Whole Sample	0.04996	0.00603	0.842	0.158	-0.1733
	(1.713)	(3.012)			(-1.138)
IR-22	0.06449	0.00650	0.826	0.169	-0.2026
	(2.472)	(1.811)			(-2.321)
Small Crops	0.00240	0.00010	0.962	0.047	-0.0391
	(1.873)	(2.787)			(-1.248)
Medium Crops	0.02527	0.00282	0.885	0.152	-0.1268
	(1.547)	(2.727)			(-1.157)
Owner-Operated	0.05597	0.00602	0.845	0.170	-0.1887
	(2.014)	(1.977)			(-1.162)
Irrigated Rice	0.00103	0.00966	0.974	0.025	-0.0256
	(1.413)	(0.985)			(-0.255)

* The t-statistics are included in parenthesis.

under the null hypothesis Ho: $\sigma^2\mu = \sigma^2\upsilon = 0$, the finding that the technical efficiency error outweighed the random error was validated for all scenarios at reasonable levels of statistical significance.

The tests of significance of the mean of the residuals of the stochastic frontiers [Ho: $E(\varepsilon_i) = 0$] also confirmed the appropriateness of the frontier specification and, consequently, of the estimated parameters on efficiency. The null hypothesis that the mean of the residual equals zero was only accepted for the irrigated rice senario, meaning that an average function assuming 100 percent technical efficiency could be an adequate specification for this scenario. Overall, this result suggests that a deterministic frontier could have been as good specification as the stochastic frontier to analyze technical efficiency.

Both of these test results match in general those findings concerning the assumption of non-normally distributed errors for the frontier specification. Therefore, the computed values on technical efficiency can be deemed as reliable and accurate as possible given the sample data.

Interpretation of Results

Major implications of the findings are presented and discussed below.

Given the levels of resource use and current technology, the potential to increase rice total output (revenue) would vary between about 3 percent and 17 percent, from the existing levels of resource use. Thus, there are possibilities for increased profits to farmers by reducing the observed level of resource use. Also the potential to increase domestic supply would amount to about 14.2% above the current level of production.

However, to achieve the supply requirement by year 2000, an extra 30 percent increase in domestic supply would be needed. This result would imply that the country needs to expand the agricultural frontier to maintain its present position of self-sufficiency in rice. Even though recent advances in rice varietal improvement are promising for increasing the current productivity of resources in irrigated lands above the actual average yields of 5.7 metric tons per hectare, this alternative would not suffice to meet the supply requirements. New lands and investments would have to be allocated in rice production. Most of this expansion should take place in rainfed rice systems because rice has been excluded from the government land recovery and irrigation programs. Also, farmers in current irrigated rice were found as technically efficient as possible (97.8 percent), but rice crop profitability for rainfed systems was twice that for irrigated rice, so farmers may be expected to allocate more resources for rainfed rice than for irrigated rice.

As indicated in Table XXIII, except for the irrigated rice scenario, all λ values were greater than one, indicating that the variance of the technical efficiency error (μ_i) dominated the symmetric error (υ_i) in all cases. That is, the discrepancy between observed revenue and the frontier reflects basically factors that were within the control of rice farmers. Although this research was not aimed at identifying variables constraining technical efficiency in rice production, this result provides evidence to support the statement that the most important factor causing technical inefficiency (over-utilization of resources) was the weed-pest-diseases complex as discussed in Chapter IV.

First, rice farmers appear to allocate resources such as machinery, labor, insecticides, fungicides and herbicides based on average revenue product criteria rather than marginal revenue product criteria, to maintain productivity of resources and ensure a minimum level of expected output. Second, farmers appear to use resources at levels beyond recommended levels or even above an economical optimum to compensate for potential losses due to higher environmental stress.

However, this study revealed that some other factors outside the farmer's control could influence their decisions on resource use, such as high obsolecense in stock of physical assets (machinery and equipment, buildings and physical structure). Similarly, the potential profits to farmers are decreased by lack of processing facilities at the farm level (storage, drying and milling facilities).

Overcoming these biological and institutional constraints would allow farmers to increase the marginal productivity of those resources exhibiting high revenue shares, reduce the excessive use of labor, machinery, and chemicals and reduce the actual costs to farmers associated with technical efficiency. Assuming allocative efficiency, the costs of technical inefficiency would vary between about 2.5 percent and 17 percent. This implies that the percentage increase in costs of rice production is caused by a 2.5 to 17 percent over-utilization of available resources. If there was any allocative inefficiency the costs of technical and allocative efficiency would be expected to be substantially higher.

The potential to increase total output or total revenue for irrigated rice farms and small crop size farms appeared to be too low. Seemingly, rice farms in these scenarios were better able to produce rice than other farms because they had better endowments to cope with the underlying biological constraints. However, the most technically efficient farmers were not, necessarily, the most cost efficient rice producers as shown in Chapter IV. Rice farms in irrigated lands and small holdings of rice crop land could increase net revenue by reducing the observed high levels of resource use.

The possibilities to increase total physical product, total revenues and net revenues for all remaining scenarios turned out to be relatively substantial. Eliminating biological constraints would increase average rice productivity by 14.2 percent above the observed levels of 5784 kilograms per hectare (or 821 kilograms per hectare) and Col. $77,879 (or Col. $11,060 per hectare).

Assuming allocative efficiency in rice production, the impact on average costs of production would amount to a reduction of at least 14.2 percent on the observed level of costs of production of Col. $74,740 per hectare (or Col. $10,469 per hectare) to produce the same level of output. The latter figure would just be equivalent to the potential net revenue earnings accruing to eliminating the weed-pest-diseases complex. For the country as a whole it would mean a potential increase in farmers' earnings of about Col. $4200 Million (prices of 1985). This figure could also be interpreted as the opportunity cost of resources allocated to carry out research and extension activities to eliminate the above mentioned constraints.

To remove the biological constraints faced by rice farmers, enhance technical efficiency in rice production, and increase profit margins to rice producers in Colombia, policy makers should promote proper advances in agricultural science and technology. New technological developments in the future are required to be more compatible with the factor endowments of the rice producers' economy. As suggested by this study, most efficient farmers were land and labor intensive users. So technical progress should be focused to increase substantially the marginal productivity of these two resources, enhancing their employment and substitution possibilities for non-real capital inputs.

Also, rice technology in the future should address not only the pest-diseases complex but even importance the weeds problem. This study suggests that rice farmers are consciously over-utilizing some inputs mainly because a need to cope with an overwhelming grassy-weeds problem. A major reason to neglect the weed constraint in rice production at the local agricultural research agencies seems to be that the social benefits of investments in breeding programs have been, traditionally, deemed to be higher than in any other branches of agricultural research (e.g. soil sciences, plant pathology, plant physiology, agricultural economics).

Yet, a larger proportion of human and financial resources are allocated to breeding and variety improvement research programs as compared to any other academic disciplines. An immediate consequence of this assertion is that the supply of new technology may be out of focus with regard to the demand of technology as can be determined from looking into rice farmers' constraints and resource endowments.

Although the current administrative organization of rice research in local institutions should be revised and adjusted accordingly, a major constraint to develop new technology is lacking social and political support to agricultural research activities as sources of economic growth and development.

Agricultural research in Colombia is a publicly supported activity. However, at real prices of 1970, the actual budget of the Instituto Colombiano Agropecuario (ICA) in 1985 amounted to nearly the same amount as that available in 1968. Thus, the rate of growth of government expenditures for research needed to meet the rate of growth of demand for new technology in rice and all other agricultural commodities has not been rapid enough to keep up with the rate of growth of the economy as a whole. In consequence, the set of technological possibilities available to rice farmers have lagged behind farmers' actual requirements and that for most progressive producers.

Sources of the observed deterioration in rice technological progress during the last decade have risen out from outside the agricultural sector itself. In fact, the ongoing general monetary and fiscal policies since the late 1960's have been focused on reducing the rate of inflation, reducing the government budget deficit, and promoting public peace and safety. The achievement of these goals has, seemingly, precluded a stronger public support to new advances in agricultural science and technology through increased financial resources. For 1985, the cost of the agricultural research program was about 9 percent of the government budget for the agricultural sector.

If the general policies are to hold in the future, a continued decline in publicly supported research actions would be expected to take place. As a result, rice profitability and profit margins to farmers would be expected to continue to deteriorate. In such an event, rice farmers would have to react against the deterioration in their economic position by taking group action to stimulate government support for either higher prices for rice output, higher financial resources for research and extension activities, or both. The former action, already in effect, would be expected to yield even greater losses in production efficiency. With high output prices, and relatively low input prices, there would be an incentive to increase input use to produce, proportionally, high levels of output. However, without removing the current biological constraints and given current technology increasing input usage may result in substantial technical and allocative inefficiencies.

As far as rice research may be considered to be a public good and net social benefits be positive, it should be the government's responsibility to increase agricultural productivity by promoting new technological developments. But a greater participation of the private sector in research tasks would be appropriate to ensure that rice productivity can be raised sufficiently to prevent the farmers' income from continuing to deteriorate.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

Colombia is facing the task of increasing national production of rice to meet domestic demand requirements of an increasing population with higher levels of income and changing preferences in food consumption. Looking only over the population and substitution effects on rice demand, the expected national demand of rough rice by the year 2000 will be 2.6 million metric tons, a 44 percent increase above the current demand of 1.8 million metric tons in 1985.

To accomplish such a goal, both the Colombian government and rice producers must expand rice production by enhancing productive efficiency in current rice cropping regions and by enlarging the agricultural frontier, particularly under highly favored upland as well as in less favored environments.

This study examined in depth the potential to increase rice production efficiency from the existing resources and technology and the observed input-output price ratios. More specifically, the objectives of the study were to determine whether rice producers were using resources in the right amounts (technical efficiency) and to determine the gap between observed revenue levels and maximum revenue attainable from the current mix of resources.

Both issues were framed within typical scenarios of rice production (rice variety types, crop sizes, land tenure classes, production regions, and cropping systems) to examine the impact of each scenario on efficiency, and to analyze factors constraining or contributing technical efficiency for rice. The technical efficiency issue in the rice production industry has gained public interest because of possible overutilization of resources by farmers to maintain or increase expected yields and revenues.

The theoretical framework undertaken in this study to assess resource use and technical efficiency was that of a well-behaved production function, implying differentiability, monotonicity, concavity, homogeneity and homotheticity properties as stated by the neoclassical theory of the firm. Corresponding to such a production function, average revenue function models for each scenario were specified and estimated by using least square techniques.

The estimated average functions were used along with rice enterprise budgets primarily to evaluate the level of resource use, rice profitability and returns to land, labor and non-real capital inputs under each scenario. Also, the functions were used to provide for incidental and consistent parameters to specify and estimate stochastic frontier revenue functions by using the maximum likelihood techniques. The stochastic frontier functions were used in turn to determine the average level of efficiency $E(e^{\mu})$ for each scenario.

The empirical analysis involved fitting enterprise budgets, ten factor Cobb-Douglas average revenue functions, and ten factor stochastic frontier Cobb-Douglas functions to a cross-section of data from 71 Colombian rice farms and data from 41 agricultural business firms for each scenario. The data used were collected from a 1981 random farm survey involving the interviewing respondents method. Twelve different scenarios were considered in the analysis.

The economic literature recognizes two major approaches to study productive efficiency at the micro level: the average production function and the frontier production function. The frontier concept was introduced by Farrell in 1957. Farrell contended that the average production function assumes that all firms in a given industry are technically efficient. Such assumption is made explicitly in the ordinary least square (OLS) technique, which assumes that the mean of the disturbance term is equal to zero. Farrell showed that the frontier esitmated by OLS is not really a frontier function but only an "average" function. Hence, it is not a valid construct to study productive efficiency if technical inefficiency does exist.

Moreover, the conventional theory of the firm assumes homogeneous output, homogeneous inputs and maximality in the production relationship. As shown by Zellner et. al. (1966), neglecting nonhomogeneous relationships and technical inefficiency in modeling the production process not only leads to biased estimates but also to waste of valuable information concerning the efficiency in resource use.

Following Zellner et. al. 's assertion, economists have attempted to model the production function by explicitly incorporating a disturbance term accounting for technical efficiency in the estimation process. Three major directions of research are discernible in the economic literature: programming approaches; econometric approaches; and, dual approaches.

Programming methods are used to estimate deterministic functions which express the maximum output obtainable from a given input combination by using mathematical programming rechniques. The objective function is to minimize the sum of (square) residuals as a linear loss function subject to the constraint that all residuals be greater than or equal to zero. Sensitivity to outliers, number of efficient firms restricted to be equal to the number of factors of production, and lack of statistical properties of the estimated parameters are major criticisms to the programming approach. Yet, an important feature of the programming approach is an inherent flexibility in estimating individual measures of efficiency (both input based or output based) either at the firm level or the factor of production level.

Frontier models are specified as both deterministic functions and stochastic functions, depending on the form taken by the non-normal disturbance term. Given the average production function:

$$y = f(x;\beta)\, e^{\varepsilon} \qquad (6.1)$$

where ε is assumed to be identically-independently distributed $N(0,\sigma^2)$ and $E(\varepsilon) = 0$. The deterministic specification implies that $E(\varepsilon) < 0$ (one-sided error). In turn, the stochastic specification portrays $\varepsilon = \upsilon + \mu$, where υ is the symmetric random shock and μ is one-sided technical efficiency error. Both models exhibit great potential to estimate technical inefficiency whenever it does exist. Theoretically, the stochastic approach is more appealing than the deterministic approach because of its ability to handle one-sided and non-zero mean disturbances. It means stochastic frontiers sort out random shocks and statistical noise from technical efficiency in the production process. On the other hand, deterministic frontiers lump those random factors in a single error term.

It was noted in this study that the average function and the deterministic frontier are nested in the stochastic frontier function. If $E(\upsilon) = 0$ in (6.1) above, the stochastic model becomes a deterministic frontier. Likewise, if $E(\mu) = E(\upsilon) = 0$ in (6.1), then the stochastic specification is bounded by the average function. So in empirical research, well-known tests of normality can be carried out to determine the best theoretical specification.

Dual approaches are theory based and as such do not require the estimation of a frontier function. Dual methods are devised to estimate both components of productive efficiency in simultaneous fashion: technical efficiency and allocative efficiency. However, these methods' success in studying efficiency could be restricted to functional forms which are self-dual (Cobb-Douglas and CES). Use of flexible functional forms to estimate frontier functions may be impractical in empirical work because the disturbance term in the derived input demand relationships enter the error term in the primal function (cost function or profit function) in a rather complex manner when technical inefficiency is present.

The economic literature on technical efficiency had mostly a theoretical focus. Only a few empirical applications were found. Most of them were carried out to support theoretical frameworks and assertions. The major thrust of contemporary research in the field is used to (i) devise methods to estimate specific efficiency measurements from stochastic approaches; (ii) develop analytical frameworks to select ex-ante the one-sided error distribution for both stochastic and deterministic frontiers; and, (iii) use statistical inference to determine ex-post the appropriate model specification.

Using the average revenue function and rice enterprise budgets, the results of this study provided empirical evidence that rice farmers in the Central region and Los Llanos region of Colombia were overutilizing labor and non-real capital inputs (seeds, machinery and chemicals) at different levels for each scenario. Therefore, there are possibilities for increased profits to farmers by reducing the observed level of resource use. According to farmers in the sample, the most important constraint in the production of rice was the weed-pest-disease complex. This biological constraint was pushing rice producers to use higher levels of inputs than expected under the rationale that by planting higher levels of seed per hectare the marginal productivity of all remaining resources could be increased or maintained at steady levels. As a result, the employment of these resources was enhanced. These findings can also be supported by the assertion that resources which are essential to maintain high rice productivity are allocated based on average revenue product criteria rather than marginal value product criteria.

The rice crop profitability for rainfed rice was twice as much as that for irrigated rice for similar net revenues. Also, the breakeven price analysis revealed that rainfed rice was the most cost-efficient scenario. In turn, irrigated rice was found to be the least cost-efficient scenario. Similarly, the rice crop profitability for cash-rent operated farms was twice that for owner-operated farms. These findings support the observed pattern of reallocation of resources from irrigated crop systems to rainfed systems and other sectors of the economy. Also, they explain the presence of increasing proportions of tenant-operated farms in rice production.

Seed and fertilizer investments were yielding the highest financial returns to producers for most scenarios. Consequently, rice producers could earn higher profits by expanding their use under those particular conditions.

The variability of rice crop profitability was quite high, above 100 percent for most scenarios. The higher variability of rice profits in irrigated rice as compared to rainfed rice, support the statement that sources of variability stem mainly from input-output price changes rather than random yield variations.

Land rental prices were found to be overstated relative to its marginal revenue product. On the other hand, the marginal revenue product of labor was substantially understated with respect to the wage rate. Several factors outside the farmers' control could be deemed to reduce profit margins to producers. A severe cash flow problem exacerbated by inefficiencies in the input-output marketing system and inadequacy of the institutional credit system was pointed out by farmers. More specifically, net income to producers were decreased by lack of processing (drying, transportation, storaging and milling facilities) at the farm and local levels. A low capacity of savings and reinvestments was supported by high evidences of obsolecense in the stock of physical assets (machinery, buidings and structures). Owner-operators in irrigated farms contended that current taxation policies were discriminating against irrigated production systems and reinvestments to improve or up-to-date capital assets.

According to the estimated stochastic frontier functions, the impact of overutilization of inputs on average technical efficiency ranged from 2.2 percent for irrigated farms and small crop sizes (most efficient scenarios) through 17 percent for land-owner rice producers, IR-22 croppers, and medium size crops (the least efficient scenarios). The maximum likelihood estimate of average technical inefficiency was 14.2 percent over the whole sample. It means that on the average, given the current technology and existing resources, total revenue (output) could be increased by 14.2 percent if the biological factors causing technical inefficiency were to be removed and price of rice remained the same when production increased. At the mean net revenue value over the sample, by eliminating such biological constraints, rice producers could increase profit margins by Col. $4,200 millions at 1985 prices.

This study failed to estimate stochastic frontier functions for 6 out of 12 scenarios, because σ^2_υ tended to zero. For these scenarios a deterministic frontier specification could have been a better specification. A test of significance of σ^2_υ and σ^2_μ in model (6.1) revealed that the technical efficiency error (υ) outweighted substantially the random error (μ), for the estimated stochastic frontier models. Also, the existence of a frontier function was not supported by a test for departure of normality of the disturbance term ($\upsilon + \mu$) for several scenarios. Thus, an average revenue function would be appropriate to study technical efficiency in such scenarios. Overall, a test of significance of the residuals confirmed the appropriateness of the estimated parameters on average technical efficiency.

Conclusions

Several conclusions can be drawn from these results. First, the potential to increase rice productivity, farmers' net income and productive efficiency from existing resources depends heavily on the country's ability to remove biological constraints actually faced by farmers and adjust current resource use. The impact of overcoming the ongoing weeds-hoja blanca-blast disease complex on total output or total revenue was estimated to be 14.2 percent above the observed average levels of 5784 kilograms per hectare and Col. $77,879 per hectare for the sample as a whole. However, by eliminating technical inefficiency, the problem of meeting domestic supply in the future would be amelliorated but would still not be solved. Therefore, complementary policy actions to expand the agricultural frontier (particularly under rainfed systems) and develop new technology to improve current productivity (in both rainfed and irrigated rice areas) would be required.

Second, the failure of the country to cope successfully with biological constraint has resulted in a decline in the rate of growth of the national supply for rough rice since 1978. The problem has been exacerbated as a result of the observed increase in input-output price ratios as shown in Chapter I. Should the observed trends in costs and returns continue in the future, an increased exit of farmers from the rice industry (mostly from irrigated rice) and a greater inflow of resources in rainfed areas would be expected to take place. Indeed, rice profitability has been declining, leading to different patterns of resource use in irrigated rice areas and reallocation of resources towards rainfed areas and other sectors of the economy. In all situations, a decrease in technical efficiency would be expected to occur, and a sharper shortfall in total supply of rice to take place.

Third, a necessary condition to remove biological constraints and increase technical efficiency involves promoting the advances in science and technology in the rice production sector. A sufficient condition is that new technology should be biased toward land and labor. That is, technological change in the future should increase the marginal productivity of land and labor in such a manner that the marginal rate of substitution of capital for land and labor would increase, and the employment of these resources would go up at a greater proportion than that for non-real capital inputs. This study showed that most efficient farms are land and labor intensive users.

In addition, a necessary condition to maintain profit margins to farmers and reduce its variability involves providing fiscal and monetary policies for farmers to renew and up-to-date their physical assets (machinery, buildings and structures) and have access to processing facilities (drying, transportation and storage) at the farm level.

Such a strategy may also reduce the observed social divergence between private benefits and social benefits brought about by environmental pollution, soil depletion and food contamination by chemicals accruing to the excessive level of usage of machinery and chemical inputs. These issues remain to be a subject of future research on sustainable agriculture.

Limitations of Study and Need for Future Research

The theoretical framework and methodological approaches followed in this study were stimulated by recent developments in the econometric literature on stochastic frontier production functions. This study failed to estimate stochastic frontier models for six out of twelve selected scenarios. In particular, no inferences could be drawn concerning the technical efficiency in rainfed rice cropping systems, Los Llanos region, CICA-8 type of rice, and cash-rented farms.

It was found that for such scenarios, the variance of the random error in equation (5.1) $\sigma^2 \upsilon$ approaches 0. Therefore, the deterministic frontier function should be the appropriate specification rather than the stochastic specification.

Similarly, a test for normality of the disturbance terms in equation (5.1) revealed that for all but six scenarios the stochastic frontier specification could be appropriate. However, it was also found that for five of these scenarios the variance of the technical efficiency error, $\sigma^2 \mu$, was strongly influencing the disturbance term specification ε_i. Therefore, it can be contended that the stochastic frontier under the half-normal distribution assumption became a deterministic frontier. However, as shown by Greene (1980), the half-normal assumption in deterministic approaches turns out inadequate because it violates the assumption of independence of the dependent variable in the maximum likelihood estimation procedure. These results call for more empirical applications of the stochastic frontier, relative to the deterministic frontier.

This study was carried out under a static, partial equilibrium and ex-post framework given the cross-section sample data. This scheme is deemed to be theoretically restrictive and empirically weak. It is restrictive because it neglects the effect of time and risk attitudes on farmer's ability to allocate and use existing resources. So a dynamic setting should be tried in future research. That setting could likely lead to more accurate inferences on technical efficiency in case of rice production (i.e. as fixed assets represent a high proportion of total farm (cost) assets, rice producers in owner-operated farms would be more likely concerned with maximizing the net present value of the expected stream of net revenues, accruing to those assets).

This study confirmed that the economic rational for farmers to over-use those inputs which are essential to maintain high rice productivity appeared to be based more on average revenue product criteria rather than on marginal revenue product criteria. This statement suggests the need to review the profit maximization behavioral assumption in rice production and to analyze resource use in the context of expected profits or utility related criteria. Cross-section data on farm surveys collected in a single visit to respondents can provide strongly biased information. To minimize measurement errors, this method requires particular skillfulness and expertise on the field on the part of researchers. More research is needed to compare estimated efficiency measures using primary sources of data versus secondary sources of data. At least in Colombia, reliable information on time series data at the farm level is still lacking, so much of future research on the field would hinge on cross-section data. In such an event, multiple interviewing methods instead of single interviewing methods are strongly recommended to ensure data as relevant and accurate as economically possible.

Insufficient resources in terms of funding and time were major factors limiting the planning process and scope of this research. The field survey was restricted to a single shot because of the financial resources available. In the study, the deterministic frontier could not be estimated due to same constraints.

However, the overall approach undertaken in this study is deemed to yield valuable information on resource use and technical efficiency issues at reasonable financial and time costs. Computational costs and burden can be reduced significantly in future research by compiling the existing computer algorithms on optimization techniques as required to maximize likelihood functions and make them accessible through microcomputers. This contribution would be especially useful in research agencies where acess to mainframe computer is strongly restricted.

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APPENDIXES

APPENDIX A

RICE FARMERS SURVEY FORM

MINISTERIO DE AGRICULTURA
INSTITUTO COLOMBIANO AGROPECUARIO, ICA
ESTUDIO ADOPCION DE TECNOLOGIA EN ARROZ

Información Confidencial

1. PROPIETARIO: ______________________
2. PRODUCTOR: ______________________
3. ADMINISTRADOR: ______________________
4. FINCA: ______________________
5. VEREDA: ____________ 6. MUNICIPIO: ____________
7. DISTANCIA DE LA FINCA AL MUNICIPIO (Km) ________ TIEMPO ________
8. ACTIVIDADES DE PRODUCCION DE LA FINCA (en Has).

ACTIVIDADES	SEMESTRE A/81	SEMESTRE B/80
Ajonjolí ________		
Algodón ________		
Arroz Riego ________		
Arroz Secano ________		
Avicultura: ________		
Huevos ________		
Carne ________		
Ganadería: ________		
Cría ________		

ACTIVIDADES	SEMESTRE A/81	SEMESTRE B/80
Levante ________		
Ceba ________		
Maíz ________		
Maní ________		
Pastos nativos ________		
Pastos introducidos ________		
Plátano ________		
Porcicultura: ________		
Cría ________		
Levante ________		
Sorgo ________		
Soya ________		
Tabaco negro ________		
Tabaco rubio ________		
Yuca ________		
Otros ________		
________		
________		
________		

9. MERCADO DEL PRODUCTO (Ha).

ACTIVIDAD	RECOLECCION			EMPAQUE				SECAMIENTO				ALMACENAM.		TRANSPORTE			VENTA			
	Horas maq.	Jornales.	Riesgo	Clase	Tipo	Nº de Jornales.	Riesgo	Tipo	Nº de Jornales.	Kw. hora Ton.	Riesgo	Tiempo	Riesgo	Tipo	Kms.	Riesgo	Lugar	Comprador.	Modalidad	Riesgo

OBSERVACIONES:

10. MERCADO DE INSUMOS (Ha).

ACTIVIDAD	COMPRA			TRANSPORTE			ALMACENAMIEN.	
	Vendedor	Modalidad	Riesgo	Tipo	Kms.	Riesgo	Tiempo	Riesgo
Semillas								
Pesticidas								
Fertilizantes								
Correctivas								
Drogas y biológicos								
Concentrados								

OBSERVACIONES: ______________________________

11. MERCADO DE CAPITAL

ACTIVIDAD	RECURSO PROPIO		CREDITO BANCARIO			CREDITO EXBANCARIO.			TIEMPO
	%	Riesgo	%	Modalidad	Riesgo	%	i	Riesgo	días/año

OBSERVACIONES:

12. USO DE LA TIERRA

USO	AREA	
	SEMESTRE A/81	SEMESTRE B/80
TRANSITORIOS:		
PERMANENTES:		
PASTOS NATURALES		
PASTOS INTRODUCIDOS		
TIERRA EN DESCANSO		
BOSQUES		
NO UTILIZABLE		
TOTAL		

% TRACTORABLE ______________________________

OBSERVACIONES: ______________________________

13. INVERSIONES

	AREA	AÑO	OBSERVACIONES
OBRAS DE CIVILIZACION:			
Destronconada			
Drenajes			Longitud ____ Ancho____ Profund.____
Canales de riego			Longitud ____ Ancho____ Profund.____
Caballones permanentes			
nivelación			
____________________			
____________________			
CONSTRUCCIONES:			
Criadoras			
Casas			
Campamentos			
Bodegas			
Galpones			
Establos			
Porquerizas			
Corrales			
Tanques			
Pozos			
Plantas secamiento			
Patios secamiento			
Caneyes			
Bañaderas			
Bebederos			Cubiertos ________ Descubiertos ______
Saladeros			Cubiertos ________ Descubiertos ______
Cercas alambre			Longitud ______ Nº hilos___ Dist.poste___
Comederos			

OBSERVACIONES: ____

____

____

14. MAQUINARIA Y EQUIPO

	Cantidad	Capacidad HP	Año	OBSERVACIONES
TRACTOR				
		70 - 80		
		80 - 90		
		100 - 120		
		180		
Combinadas		85 - 100		
Camiones		____		
		____		
		____		
Arados		3 x 26"		
		4 x 26"		
		5 x 26"		
Californianos				
		16 x 24" (95)		
		20 x 24" (95)		
		24 x 24" (95)		
		18 x 24" (120)		
		20 x 24" (120)		
		24 x 24" (120)		
Rastrillos pulidores				
		24 x 20" (50)		
		32 x 20" (50)		
Cortamalezas		1.85		
Sembradora de cereales		3.60		
Sembradora de granos		3.60	—	
Niveladora		4.00		
Cultivadora		4.00		
Rotovator		1.60		
Encaladora		5.00 a 6.00		
Voliadora		10.00		
Aspersora		6.00		
Zorras		____		
Rodillos		3.00		
Motobombas		____		
Desgranadora		____		
Descascaradora		____		
Plantas eléctricas		____		

OBSERVACIONES: ____________________

15. SEMOVIENTES

	PROPIO	EN COMPAÑIA	
Vacas de cría			
Vacas horras			
Novillas			
Novillos			
Toros			
Equinos labor			
Cerdas de cría			
Cerdas de levante			
Cerdas de ceba			
Aves de Postura			
Aves de engorde			

OBSERVACIONES: ____________________

____

____

____

____

16. MANO DE OBRA PERMANENTE

DETALLE	CANTIDAD AÑO AGRICOLA
Mayordomo Vaqueros Peones Paleros Operarios de Maquinaria Profesionales	
OBSERVACIONES:	

17. INVENTARIO TECNOLOGICO

CULTIVO: ARROZ, MAIZ, SORGO Y SOYA.

ACTIVIDAD	Epoca	Frecuencia.	Método.	USO DE FACTORES E INSUMOS/ha			
				Horas/ Maq.	Nº de Jornales	Materiales	
						Tipo	Dósis/Ha.
Arada							
Rastrillada							
Nivelada							
Rotoveiteada							
Semilla							
Siembra							
Tapada							
Agua							
Instalación y sostenim.							
Mantenimiento:							
Canales de riego							
Drenajes							
Caballones							
Fertilizantes compuestos							
Fertilizantes simples							
Fertilizantes foliares							
Correctivos							
Raleo							
Cultivadas- aporques							
Desyerbas							
Control malezas							
________________							
________________							
________________							
________________							
Contol plagas							
________________							
________________							
________________							
Control enfermedades							
________________							
________________							
________________							
Control de roedores							
despalilles							
Rendimiento (kg)							

18. Usted conoce que de un lote a otro y de un semestre a otro, hay diferentes rendimientos. Podría usted decir a cuáles de los siguientes factores se pueden atribuír esas diferencias?

FACTOR DE DIFERENCIAS	X		% atribuible a cada factor.		OBSERVACIONES
Clima					
Temperatura diruna					
Precipitación					
Temperatura agua					
Nubosidad					
Vientos					
Altura					
Suelos					
Textura					
Profundidad					
Acides					
Alcalinidad					
Fertilidad					
Erosión					
Pendiente					
Toxicidad					
Presencia de malezas					
Presencia de Plagas					
Presencia de enfermedades					
Niveles de semilla					
Niveles de fertilizantes aplicados					
Niveles de correctivos					
Niveles de Pesticidas					
Vaneamiento					
Volcamiento					

OBSERVACIONES:

19. Como juzga usted la disponibilidad de crédito para la producción de su finca:

Suficiente ___ Explicación: ______________________________

____

Oportuno ___ Explicación: ______________________________

____

20. Considera usted que el crédito en su caso es:

Fácil de obtener ___ Explicación: ______________________________

____

Difícil de obtener ___ Explicación: ______________________________

____

21. Considera usted que el crédito es:

Barato ___ Explicación: ______________________________

____

Costoso ___ Explicación: ______________________________

____

22. Cuáles de los siguientes factores considera usted que han afectado los ingresos de su finca:

Fluctuación de los precios del producto ___ Productos: ____________________

____

Altos precios de los insumos ___ Insumos: ____________________

____

Falta de insumos apropiados _____ Insumos: __________________________

____

Falta de oportunidad en la consecución de los insumos _______ Insumos: ______

____

Falta de recolección oportuna del producto ______ Productos: ______________

____

Falta de oportunidad en la aplicación de los insumos _____ Insumos: ________

____

Falta de compradores del producto ______ Productos: ____________________

____

Falta de mano de obra durante el año _____ Meses: ____________________

____

Alto costo de la mano de obra ______ Labores: ________________________

____

____

23. De la siguiente lista de expresiones diga usted cuáles se aproximan más a sus metas como agricultor:

a. Maximizar las ganancias en efectivo de la finca para:

Educar su familia _______

Financiar las actividades de la finca ______

Mejorar sus comodidades en la casa ______

b. Asegurar los requerimientos de alimentación de la familia ______

c. Combinar la agricultura con otras actividades ______

APPENDIX B

AGRIBUSINESS FIRMS SURVEY FORM

MINISTERIO DE AGRICULTURA

INSTITUTO COLOMBIANO AGROPECUARIO -ICA-

ESTUDIO ADOPCION TECNOLOGIA ARROZ

Información sobre Precios

(Confidencial)

1. Departamento: ______________________
2. Municipio: ______________________
3. Nombre Vendedor o Razón Social: ______________________
4. Nombre comprador o Razón Social: ______________________
5. Nombre entrevistador: ______________________
6. Nombre informante: ______________________
7. Fecha: ______________________
8. Revisó: ______________________

Anexo 1

LISTA MUNICIPIOS ARROCEROS.

Meta	Tolima - Huila
Villavicencio	Espinal
Puerto López	Guamo
Granada	Saldaña
Acacías	Purificación
Fuente de Oro	Armero
Cabuyera	Campoalegre
Restrepo	Neiva
Cumaral	Ambalema
Castilla	Ibagué
San Carlos de Guava.	

LISTA DE PRODUCTOS Y RENGLONES INCLUIDOS EN EL ESTUDIO.

Ajonjolí
Algodón
Arroz
Maíz
Pastos
Tabaco Rubio.

Ganadería de Cría
Ganadería Levante
Ganadería Ceba
Maní
Sorgo

Anexo 2

LISTA DE ENTIDADES DE VENTA DE SEMILLAS, FERTILIZANTES, CORRECTIVOS, PLAGUICIDAS, DROGAS Y BIOLOGICOS.

Meta	Tolima - Huila
Fedearroz	Fedearroz
Caja Agraria	Caja Agraria
Cereales del Llano	Cereales del Llano
Coagrometa	Colsemillas
Colsemillas	Almacén Particular
Almacén Particular	Casa Comercial
Agroariari	Cecora
Semillano	Cooperativa AgroHuila
Agrollano	Prosemillas
Casa Comercial	Coopinagro
Cecora	Coopaltol
Agroganaderos Llanos.	

ANEXO 3

PRECIOS DE SEMILLAS ($/kilo)	80-B	81-A
Arroz		
Blue Bonnet 50		
IR-22		
CICA 4		
CICA 8		
CICA 9		
Maíz		
H-207		
Pioner		
Penta 10-11		
Algodón		
Deltapine 55		
Deltapine 16		
Deltapine 9		
Gossica 22		
Gossica N 21		
Gossica 20		
Colombia 1		
Sorgo		
ICA Nataima		
Pioner P-203		
NK-266		
NK-222		
NK-1116		
Pastos		
Brachiaria		
Leguminosas		
Kudzú		
Ajonjolí		
ICA Pacandé		
Maní		
ICA Tatui		

ANEXO 4

PRECIOS DE FERTILIZANTES Y CORRECTIVOS ($/tonelada)	80-B	81-A
Compuestos		
13-26-6		
15-15-15		
10-30-10		
10-20-20		
6-24-6		
18-46-0		
14-14-14		
20-5-53-0		
Simples		
Urea 46%		
Nitron 26%		
Cloruro de potasio 60%		
Sulfato de Amonio 21%		
Tetraborato de sodio		
Enmiendas		
Cal apagada		
Roca fosfórica molida		
Escorias Thomas		
Azufre		
Foliares		
Nitrofoska		
Agriminis		
Coljap producción		
Coljap floresc		
Coljap desarrollo		
Japoncol desarrollo		
Nutrimins		
Microcoljap 12		
Sulfozinc		

ANEXO 5

PRECIOS DE HERBICIDAS ($/Unidad de envase más común).

Herbicidas	80-B	81-A	Herbicidas	80-B	81-A
Stam F-34			Saturno Plus		
Stam 100			Saturno 50 CE		
Tordón 10 K granular			Propanex 300		
Tordón 101			Propanex 500		
Tordón 472			Cotorán 50 WP		
Gesaprim 80 WP.			Cotorán 80 WP		
Gesaprim combinado			Cotorán 500 FW		
Gesaprin 500, FW			Atrazina 50		
Avirosan 500 EC.			Atrazina 80		
Gramoxone			Ronstar		
Esterón 47			Machete		
Esterón 50-D			Roundup		
Esterón 40			Lazo		—
Surcopur			Karmex		
Anikil 4			Matamaleza 40		
Basarroz			Treflan CE		
Basagrán					
Celanil 360 CE					
Celanil 500					

ANEXO 5. Continuación.

Reguladores Fisiológicos	80-B	81-A
Cloro IPC		
MH-30		
Drop		
Aditivos (emulsificantes, adherentes)		
Sur-Fac-Cela 90		
Surfactante WK		
Nifapon 4%		
Triton AE		

ANEXO 6

PRECIOS DE INSECTICIDAS ($/Unidad de envase más común)

Insecticidas	80-B	81-A	Insecticidas	80-B	81A
Dipterex granulado			* Cottinex Triple M		
Dipterex SP 80%			Cottinex triple 400		
Dipterex SP 95%			Endrín 19.5		
*Metafen 4-2-1			Roxion		
*Metafen Ultra			Malathion Polvo 4%		
Parathion 50%			Malathion LV Concent.		
Parathion metílico 48			Malathion 1000-E		
Ambush 50			Malathion 57%		
Cimbush			Dimecron 50 SCW		
Perfektion			Dimecron 100 SCW		
Aldrín 2,5%			Dimecron 250 ULV		
Aldrín 25%			Galecron 50 E.C.		
Aldrín 40%			Galecron 50 S.P.		
Aldrín 5%			Galecron 50 P.S.		
*Celbane 60 C.E.			Galecron 80 P.S.		
*Celbane Metil 6-3 B.V.			Nuvacron 40 E.C.		
*Celbane DDT 5-2,5 B.V.			Nuvacron 60 E.C.		
*Celbane M-3			Nuvacron 250 U.L.V.		
*Celbane Metil 4-1 C.E.			Toxapheno 60%		
*Cottinex M-2			*Toxapeno DDT 40-20		

ANEXO 6. Continuación. (pág. 2)

Insecticidas	80-B	81-A
*Toxapheno DDT-20-10		
*Toxapheno DDT 5-2.5 B.V.		
Lorsban 4 E		
Lorsban 5% granular		
Lorsban 360 ULV		
Lannate		
Lannate 1,25 G		
Lannate L		
Decis 2-5 C.E.		
Furadan 3 Granulado		
Furadan 4 F		
Furadan 3 F		
Furadan 5 granulado		
Furadan 10 granulado		
Furadan 75 PM		
Thiodan 4 Polvo		
Thiodan 3% G		
Thiodan S 24		
Thiodan 50 P.M.		
Thiodan 4% G		
Thiodan 35% C.E.		
Thiodan 30 U.B.V.		
Thuricide		
Dipel		

Insecticidas	80-B	81-A
Bactospeine		
Orthene 75%		
Azodrin 400		
Azodrin 600		
Cebiran granulado		
Cebiran 80 SP		
Cidial 2% granulado		
Cidial 500		
Diostop C.E.		
Fundal 500		
Fundal 800		
Belmark		
Dimetoato 40		
Sevin 3 Polvo		
Sevin 5 Polvo		
Sevin 3 granulado		
Sevin 80		
Endrex		
Aldrex 2		
Bidrin 1000 CMA		
Politrin		
Nodrin		
Sherpax		
Sistemin		
Bux 360		

ANEXO 7

PRECIOS DE FUNGICIDAS ($/unidad de envase más común) .

Fungicidas	80-B	81-A	Fungicidas	80-B	81-A
Antracol			Manzate 200		
Bayleton			Bim 75 P.M.		
Baytan			Brestan 60		
Bayleton C.E. 25			Bla -5		
Hinosam			Du-ter 20%		
Kitazin 48 CE			Kasumin		
Benlathe			Dithane M-22		
Manzate			Dithane M-45		
Manzate D			Captan 50		
			Elosal		

ANEXO 8

PRECIOS DE INSUMOS PECUARIOS ($/Unidad de envase más común)

Antiparasitarios	80-B	81-A
Bovizole		
Asuntol		
Neguvon		
Sulfamethozina		
Thibenzole		
Gametox		
Vacunas		
Antiaftosa		
Carbón bacteriano		
Carbón sintomático		
Cepa 19		
Septicemia hemorrágica		
Desinfectantes		
Eterol		
Negasum		
Nexa-unguento		

Drogas y antibióticos	80-B	81-A
Oxitetraciclina		
Novalgina-Xilocaina		
Unguento No. 100		
Sulfametacina		
Sulmet		
Azul de Metileno		
Sales Minerales y Reconstituyentes		
Agrosal		
Calfos		
Gluconato de Calcio		
Fosfosal		
Seledec		
Calmedex		

ANEXO 9

PRECIOS DE MANO DE OBRA PERMANENTE (Precios actuales 81-B)

Detalle	Salario/año	Prestaciones sociales/año
Mayordomo		
Vaqueros		
Peones		
Paleros - regadores		
Operarios Maquinaria		
Profesionales (Asist. técnica):		
Arroz		
Algodón		
Sorgo		
Maíz		
Ganado Carne		
Ganado leche		

Mano de Obra Ocasional	80 - B	81 - A
Vaqueros		
Peones		
Paleros - regadores		
Operarios maquinaria		
Otros		
Número de horas por jonal-día		

En el Municipio: ______________________

ANEXO 10

PRECIOS DE CONSTRUCCIONES E INSTALACIONES (Precios Actuales).

Obras de Civilización	Unidades	Valor
Destronconada	1 Ha. $	
Canales de drenaje/metro	m. ancho x m. profundo x m. base:	
	a.	
	b.	
	c.	
Canales de riego/metro	m. ancho x m. profundo x m. base:	
	a.	
	b.	
	c.	
Nivelación	1 Ha. $	

Construcciones	V/r. $ Col.
Casas	m^2
Campamentos	m^2
Bodegas	m^2
Establos	m^2
Corrales	m^2
Bañadera	Una (1)
Bebedero	Uno (1) cubierto ___ descubierto ____
Saladero	Uno (1) cubierto ___ descubierto ___
Cercas alambre	Uno (1) Km.

ANEXO 11

PRECIOS DE MAQUINARIA Y EQUIPO (Precios Actuales).

Maquinaria	Capacidad	Precio en el mercado local ($)
Tractor	70-80	
	80-90	
	100-120	
	180	
Combinada	85-100	
	______	
	______	
	______	
Camiones	Toneladas:	
	______	
	______	
Arados	3 x 26"	
	4 x 26"	
	5 x 26"	
	______	
Californianos	16 x 24" (95)	
	20 x 24" (95)	
	24 x 24" (95)	
	18 x 24" (120)	
	20 x 24" (120)	
	24 x 24" (120)	
	______	
Rastrillos pulidores	24 x 20" (50)	
	32 x 20" (50)	
Cortamalezas	1.85	
	______	
Sembradora de cereales	3.60	
	______	
Niveladora	4.00	
	______	
	______	

ANEXO 11. Continuación (pág. 2).

Maquinaria	Capacidad	Monof.	Trifás.	Precio en el mercado local $
Cultivadora	4.00			
Retovator	1.60			
Voliadora	10.00			
Aspersora	6.00			
Zorras	5 Tons.			
	10 "			
	+ 10 "			
Motobombas	2 HP. 5 pulgadas			
	5 HP 10 pulgadas			
	10 HP 20 pulgadas			
Plantas eléctricas	10 HP ó 9 Kw/horas			
	20 HP 17 Kw/horas			
	60 HP 50 Kw/hora			
	75 HP 62 Kw/horas			
Abonadora de chorro ó surco				
Surcador				
Zanjadora				
Sembradora abonadora				

ANEXO 11. Continuación (pág. 3).

Maquinaria	Capacidad	Precio en el mercado local ($)
Caballoneador	______________ ______________ ______________	
Palas	Unidad.........................$	
Azadones	Unidad.........................$	
Machetes	Unidad.........................$	
Bomba de espalda	3 galones	
	5 galones	

ANEXO 12

PRECIOS DE MAQUINARIA ARRENDADA

Detalle	80-B		81-A	
	($/ha.)	($/hora)	($/ha.)	($/hora)
Arada (tractor grande)				
Arada (tractor pequeño)				
Rastreada (tractor grande)				
Rastreada (tractor pequeño)				
Rastrillado (tractor grande)				
Rastrillada (tractor pequeño)				
Nivelada (tractor grande)				
Nivelada (Tractor pequeño)				
Encalada (tractor pequeño)				
Treflianada (tractor pequeño) */				
Caballoneada (tractor pequeño)				
Siembra voliadora (tractor grande)				
Siembra voliadora (tractor pequeño)				
Siembra sembradora chorro (tractor grande).				
Siembra sembradora chorro (tractor pequeño)				
Tapada-rastrillo pulidor (tractor grande).				
Tapada-rastrillo pulidor (tractor pequeño)				

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* Incluyendo marcada y tapada.

ANEXO 12. (Continuación, pág. 2).

Detalle	80-B		81-A	
	($/ha.)	($/hora)	($/ha.)	($/hora)
Abona o ganchada (tractor pequeño)				
Cultivada o rejiada (ganchos) (tractor pequeño)				
Aporcada-cultivada con discos (tractor pequeño)				
Rotospeed (tractor pequeño)				
Cortada-combinada-arroz (con tractor y zorreo).				
Cortada-combinada-sorgo (sin tractor y zorreo).				

ANEXO 13

PRECIOS DE GANADO Y ESPECIES PECUARIAS (Valor/Unidad)

	80-B	81-A
Vacas de cría		
Vacas horras		
Novillas		
Novillos		
Toros		
Equinos labor		
Cerdas cría		
Cerdos Ceba		
Aves postura		
Aves engorde		

ANEXO 14

PRECIOS DE LA TIERRA (Precios actuales)

Pesos/Ha. (compra-venta) cultivos

Pesos/Ha. (compra-venta) pastos

Pesos/Ha. cosecha (arriendo cultivos)

Pesos/cabeza - mes (arriendo) pastos.

PRECIOS DE AGUA-RIEGO POR DISTRITO (HIMAT)	80-B	81-A
a. Tarifa fija Pesos/Ha-año El Juncal (Huila)		
Pesos- cosecha-Río Recio (Tol.)		
Coello (Tolima)		
Saldaña (Tolima)		
b. Tarifa volumétrica Pesos/metro cúbico		
c. Tarifa voluntaria Peso/ha. cosecha		

Caudal de cada distrito = metros cúbicos/seg.

____

____

____

____

(Averiguar: años 1960-65-70-75-80)

ANEXO 15

PRECIOS SERVICIO "FUMIGACION AEREA" ($/vuelo)

Avión	Capacidad (galones)	Tipo de Vuelo					
		Alto volumen		Medio volumen		Bajo volumen	
		80-B	81-A	80-B	81-A	80-B	81-A
Pawnee 235	120						
Pawnee 260	150						
Cesna 300	200						
Pawnee Brave 300	260						

Número de has/vuelo:

Alto volumen: ______________

Medio volumen: ______________

Bajo volumen: ______________

PRECIOS DE COMBUSTIBLE ($/Galón)	80-B	81-A
1. Gasolina		
2. ACPM		
3. Aceite para motor		

ANEXO 16

PRECIOS DE EMPAQUE ($/carga)	80-B	81-A
Lona Nueva		
Fique nuevo		

PRECIOS DE TRANSPORTE ($/tonelada-Kilómetro) PRECIOS ACTUALES

De: ________ A: _________ De: ______ A: ______

Tractomula
Camión
Canoa
Zorra-tractor
Zorra-animal
Bestia - (flete por animal-día)

ANEXO 17

LISTA DE COMPRADORES DE PRODUCTOS

- Minorista
- Mayorista
- IDEMA
- Molinos arroceros
- Agremiación algodonera
- Transportador
- Pasteurizador

ANEXO 18

PRECIOS DE PRODUCTOS ($/tonelada)

Producto	Con empaque		Sin empaque	
	80-B	81-A	80-B	81-A
Arroz Paddy				
Arroz blanco				
Fibra algodón				
Semilla algodón				
Ajonjolí grano				
Maíz blanco				
Maíz amarillo				
Maní grano				
Sorgo grano				
Tabaco rubio				
Leche ($/litro)				
Carne ($/kilo en pié)				

APPENDIX C

RICE BUDGETS FOR SEVERAL SCENARIOS

RICE BUDGET ENTERPRISE FOR TWO LAND CROP TENURE CLASSES (ONE HECTARE)

Item			Value per Hectare	
Total Revenue			LANDT 1[a]	LANDT 2[b]
5869 kgs at $13.44 per kg			78980.98	
5468 kgs at $13.49 per kg				73765.40
Variable Costs	LANDT 1	LANDT 2		
Seed	7876.69	7014.37		
Fertilizer	13097.67	11689.00		
Chemicals	5033.25	5780.90		
Machinery Fuel and Repairs	4817.64	5728.59		
Labor	4446.86	5166.47		
Hauling	2880.96	2885.74		
Total Variable Costs	38153.06	38265.08		
Return Above Variable Costs	40827.92	35500.32		
Fixed Costs				
Machinery Depreciation, Interest, Taxes	5747.16	4850.71		
Land Charge	20395.15	12933.33		
Total Fixed Costs	26142.31	17784.04		
Total Costs			64295.37	56049.12
Estimated Net Revenue			14685.61	17716.28

[a] Owner-operated rice farms

[b] Cash-renter operated rice farms

RICE BUDGET ENTERPRISE FOR TWO PRODUCTION REGIONS
(ONE HECTARE)

Item			Value per Hectare	
Total Revenue			Los Llanos	Central
4901 kgs at $13.19 per kg			64663.35	
6326 kgs at $13.61 per kg				85988.76
Variable Costs	Los Llanos	Central		
Seed	5591.27	8895.14		
Fertilizer	8904.70	15190.41		
Chemicals	3847.67	6015.65		
Machinery	6652.20	3973.78		
Labor	2867.89	5661.10		
Hauling	3696.75	3973.78		
Total Variable Costs	31559.11	42118.08		
Return Above Variable Costs	33104.24	43870.68		
Fixed Costs				
Machinery Depreciation, Interest, Taxes	5227.85	5879.75		
Land Charge	10073.95	24184.79		
Total Fixed Costs	15301.70	30064.54		
Total Costs			46860.81	72182.62
Estimated Net Revenue			17802.53	13806.13

RICE BUDGET ENTERPRISE FOR TWO CROPPING SYSTEMS (ONE HECTARE)

Item			Value per Hectare	
Total Revenue			Irrigated	Rainfed
6164 kgs at $13.55 per kg			83470.57	
4744 kgs at $13.18 per kg				62576.12
Variable Costs	Irrigated	Rainfed		
Seed	8486.38	5527.27		
Fertilizer	14310.10	8667.40		
Chemicals	5618.54	4021.67		
Machinery	4704.83	5727.45		
Labor	5312.28	2646.46		
Hauling	2648.12	3520.63		
Total Variable Costs	41080.25	30111.08		
Returns Above Variable Costs	42390.32	32465.04		
Fixed Costs				
Machinery Depreciation, Interest, Taxes	5641.69	5447.26		
Land Charge	21981.58	10162.40		
Total Fixed Costs	27623.27	15609.66		
Total Costs			68703.52	45720.74
Estimated Net Revenue			14767.04	16855.38

RICE BUDGET ENTERPRISE FOR TWO VARIETIES: CICA-8 AND IR-22 (ONE HECTARE)

Item			Value per Hectare	
Total Revenue			CICA-8	IR-22
5280 kgs at 13.28 per kg			69280.80	
6331 kgs at 13.42 per kg				84779.99
Variable Costs	CICA-8	IR-22		
Seed	6593.96	8575.05		
Fertilizer	10147.85	15621.44		
Chemicals	4434.63	6970.18		
Machinery Fuel and Repairs	6607.48	7436.12		
Labor	3268.77	5250.74		
Hauling	3352.43	5349.75		
Total Variable Costs	34405.12	49203.48		
Return Above Variable Costs	34875.68	35576.51		
Fixed Costs				
Machinery Depreciation, Interest, Taxes	4182.58	4229.57		
Land Charge	13457.56	22083.21		
Total Fixed Costs			17640.04	26312.78
Total Costs			52045.16	75516.26
Estimated Net Revenue			17235.64	9163.73

RICE BUDGET ENTERPRISE FOR THREE CROP SIZES OF RICE (ONE HECTARE)

Item				Value per Hectare		
Total Revenue				Farms 1	Farms 2	Farms 3
6229 kgs at $13.71 per kg				85300.37		
5647 kgs at $13.43 pper kg					75936.29	
5555 kgs at $13.26 per kg						73761.97
Variable Costs	Farms 1	Farms 2	Farms 3			
Seeds	9353.03	7790.98	6322.36			
Fertilizers	13744.98	14052.96	10997.86			
Chemicals	4551.21	6588.69	4498.14			
Machinery, fuel and repairs	1692.94	3766.45	5373.93			
Labor	4415.61	5577.64	3907.68			
Hauling	2361.14	2411.67	3687.70			
Total variable costs	36118.42	40188.40	34787.10			
Revenue above variable costs	49181.95	35747.89	38974.27			
Fixed Costs						
Machinery depreciation, interest, taxes	4645.88	7229.89	8118.91			
Land charge	23633.77	1935.31	14463.20			
Total fixed costs	28979.65	26765.2	22582.71			
Total costs				64398.07	66953.60	57369.81
Estimated net revenue				20902.03	8982.07	16392.11

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VITA

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