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Nonparametric Efficiency Analysis for Coffee Farms in Puerto Rico

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Abstract

Coffee production in Puerto Rico is labor intensive since harvest is done by hand for quality and topography conditions. Färe's nonparametric approach was used to estimate technical, allocative, scale and overall efficiency measures for coffee farms in Puerto Rico during the 2000 to 2004 period. On average Puerto Rico coffee farms were 46% technically efficient, 79% scale efficient, and 74% allocatively efficient.

Keywords: coffee production, nonparametric efficiency.

Introduction

Coffee is one of the most traded commodities in the world. From 1997 to 2002 world coffee prices declined reaching their lowest point, in 2003 when coffee prices started to slowly increase until present (ICO, 2002). Low coffee prices affect developing countries especially those in which coffee is the major contributor in export revenues. Low coffee prices have a negative impact on trade resulting in higher unemployment rates and increasing poverty levels in developing countries (ICO, 2002, 2003).

To produce a high quality product, coffee is grown in high altitudes or in mountains. This makes it difficult to mechanize coffee operations, for example harvesting, fertilizing and other production practices. Therefore production of this commodity is labor intensive. In addition, since coffee beans do not ripen at the same rate, cherry coffee beans are picked several times in the same area during the harvest season. To reduce labor costs, producers would harvest once for both ripe and green coffee[1] which leads to a lower quality product (ICO, 2002). If

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[1] Green coffee bean is a coffee that has not ripened completely. Green beans are coffee beans that have been processed by either dry or wet methods and have not been roasted.

growers are able to mechanize their harvest operations, the product will be of lower quality since both ripe and green coffee beans are picked and no selection of cherry coffee beans occurs.

There are two varieties of coffee grown in the world, Arabica and Robusta. Figure 1 shows world coffee producers by coffee variety grown. In 2006, world coffee production was 121.6 million coffee bags[2] or 16,085 million pounds[3] (ICO, 2007). The world's largest producer for 2006 was Brazil followed by Vietnam and Colombia with 35%, 12.3% and 9.5% of world production, respectively. The Americas (Mexico, Central America, and South America) produced 62.9% of world's coffee in 2006 while Africa, and Asia and Oceania produced 12.8% and 24.3%, respectively. The U.S. was the biggest coffee importer for 2005 with 20,759 coffee bags (2,746 billion pounds) which corresponds to 31% of world consumption (ICO, Feb. 2007). Germany was the second largest importing country with 8,356 million bags (1,105 billion pounds) 12% of world consumption. The country with the most per capita consumption was Finland with 28 pounds annually followed by Norway, Switzerland, and Denmark with 21.27, 20.15, and 19.84 pounds, respectively (ICO, 2007). US per capita consumption is about 9.21 pounds annually and other importing countries per capita consumption is less than 15 pounds annually. U.S. coffee manufacturers roast and grind green coffee beans, using both Arabica and Robusta varieties, which are mostly imported from Brazil, Colombia, Mexico, and Guatemala (Leibtag, Nakamura, Nakamura, and Zerom, 2007).

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[2] One bag contains 60 kg of coffee, ICO.

[3] One kilogram is equivalent to 2.2046 pounds.

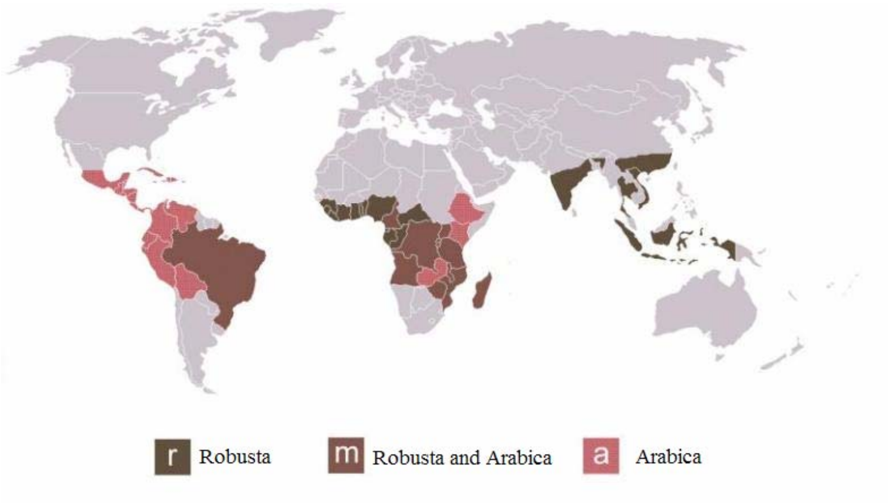

Figure 1: World Coffee Producers by Grown Coffee Variety.

Source: Wapedia, 2007.

A few studies have examined coffee supply or productivity for Mexico, Brazil and Costa Rica (Vedenov, Houston, and Cadenas, 2007; Wickens and Greenfield, 1973; Saylor, 1974; Lyngbæk, Muschler, and Sinclair, 2002). Since coffee is a vital commodity for the economy of many developing countries, more research should be conducted on production, specifically cost and efficiency analysis so coffee farmers understand the most efficient and profitable production practices. One of the objectives for this study is to contribute to the literature on coffee production particularly in estimating efficiency by using a nonparametric approach. This study examines the case of coffee production in Puerto Rico.

Coffee Production and Practices in Puerto Rico

Traditionally coffee has been an essential commodity for Puerto Rican consumers and the agricultural sector. Coffee is the second largest crop and fourth most important commodity in the agricultural sector in Puerto Rico. During 2005/2006, coffee bean production was 20 million pounds and the value of production was around $41.6 million US dollars (AGI, 2005/2006). In 2006, ground coffee consumption was 30 million pounds where 27 million pounds were locally produced representing 90% of local consumption. Consumption per capita is around 7.9 pounds per year that is 1.3 pounds less than in the U.S. (DAPR, 2006; ICO, 2007). Puerto Rico is neither a large exporter nor importer of coffee but coffee production faces the same problems as large and small exporters, specifically high labor costs, and low labor supply. In addition, Puerto Rico faces the same climatic phenomena as occurs in Central America and Mexico. Puerto Rico's coffee plantations are located in the mountains; therefore harvest costs and other production practices are labor intensive. Another problem that coffee growers face is the fact that Puerto Rico has to comply with the Fair Labor Standard Act (FLSA) where they have to pay U.S. minimum wages to employees. To deal with high labor costs, Puerto Rico's Department of Agriculture offers wage subsidies to farmers. In 2005/2006, subsidies for coffee growers were around $6.5 million U.S. dollars. Furthermore to guarantee fair prices to both producers and consumers, the Department of Consumers Affairs (DACO) controls coffee prices at all stages of production as well as consumer prices.

There are three coffee species produced in the world: *Coffea arabica, Coffea canephora* and *Coffea liberica* were Arabica produces the best quality coffee (EEA, 1999). The most planted species in Puerto Rico is the Arabica, but some growers plant Robusta and Excelsa varieties which belong to the *Coffea canephora* and *Coffea liberica* respectively. Puerto Rican coffee growers plant 8 varieties of Arabica coffee: Bourbon, Mundo Nuevo, Puerto Rico 401, Catura, Pacas, Limani, and Froton. Arabica coffee in Puerto Rico is classified into two grades: 1st and 2nd grade, where Robusta coffee is considered to be inferior quality which can only be mixed with 2nd grade coffee. First grade consists of only ripe coffee and second grade is a mixture of ripe and green coffee[1]. By regulation Puerto Rican ground coffee has to contain at least 60% of 1st grade and no more than 40% of 2nd grade coffee to meet quality standards

(Pérez, 2007). Prices for each grade will vary and depend on the processing method that the coffee receives. The last time that coffee prices were revised in Puerto Rico was in 2006, more than ten years (1991) after their last amendment. Three years after the 2006 regulation amendment, Robusta coffee could be no longer be mixed for Puerto Rico's ground coffee since it is considered to be a low quality coffee.

There are two types of coffee plantations with and without shade. Coffee production for all coffee varieties is lower when the crop is shaded that than when it is not. A non shaded crop can produce up to 40% more coffee than a shaded crop (UPR/EEA, 1999). Shaded plantations are recommended where the climate is hot, windy and when farmers do not have the economic resources to grow coffee without shade. There are two types of shade plantations; permanent shade and temporal shade. When a permanent shade is used, the farmer would have to control the source of the shade by pruning where so the shade should not be greater than 30%. A temporal shade is used for the first two years after a new planting. The main source for temporal shade in Puerto Rico are plantain plants, where this crop will generate extra income, reduce herbicide costs and reduce soil erosion up until coffee's first harvest. In Puerto Rico there are around 56,000 acres of coffee grown where 23,000 are grown with shade and 33,000 are grown without shade (Census of Agriculture, 2002). Production for coffee in 2002 was 22 million pounds where 7 million pounds come from coffee with shade and 15 million pounds came from coffee without shade.

There are two methods that coffee can be process: wet and dry. In Puerto Rico, the wet process is used to produce 1st graded coffee, the final product is known an "Pergamino B" or Parchment coffee (Monroig, 2007; ICO, 2007). The dry method is used to process 2nd grade coffee and Robusta coffee where the final product is known as "Collor C" or Dry Cherry. There are three types of coffee farmers in Puerto Rico. Figure 2 show the market chain for coffee growers in Puerto Rico. “Beneficiado” is the entity that process coffee by either wet or dry methods. Some farmers can process their own production and act as “Beneficiados”. “Torrefactores” are the processors who roast and grind coffee. Few farmers can do the entire process, that is produce and process up to ground coffee.

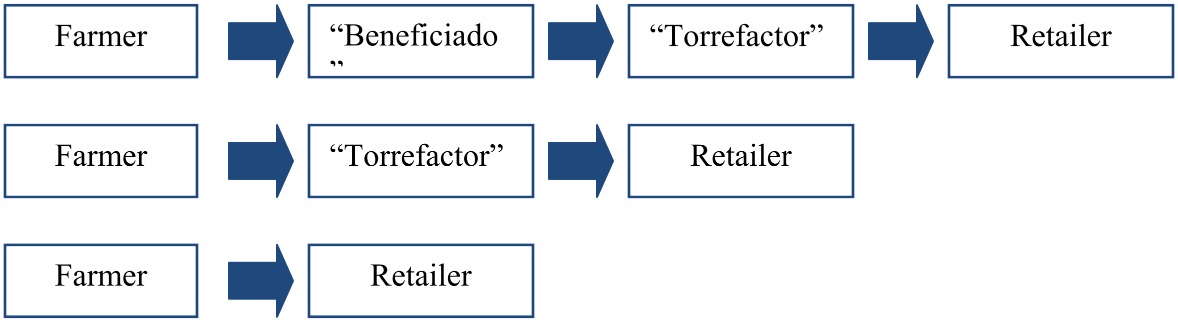

Figure 2: Coffee Market Chain in PR

There are eight master’s theses written on coffee at the Agricultural Economics Department, University of Puerto Rico. These have examined coffee production and soil practices, consumer demand, the feasibility of the establishment of coffee nurseries and new non-shaded crops, pruning cost analysis, return on investment of coffee research by the Agricultural Experimental Station, and production analysis of coffee processors (Badillo-González, 1983; Mejia-Maymí, 1986; Alamo-González, 1988; Ferrer-Urbina, 1988; Rivera-Alvarado, 1997; Montoya-Ospina, 1999; and Rullán, 2000). To our knowledge there are no studies that have estimated efficiency measures for coffee production in Puerto Rico. The objective of this study is to examine the efficiency of coffee production in Puerto Rico. Nonparametric methods are used to estimate different measures of efficiency using a linear programming approach. Technical, allocative, scale, and overall efficiency will be measured for every farm and compared to the cost frontier.

Review of Literature

Wickens and Greenfield estimate a supply function for Brazilian coffee. They showed that Nerlove's supply model does not perform well on tree crops, specifically for the case of coffee. Saylor estimated supply elasticities for Sao Paulo coffee using Nerlove's model with and without supply shifters where both models perform well. Lyngbæk, Muschler, and Sinclair study compared organic and conventional coffee farms in Costa Rica. Their research provided a descriptive comparison of productivity, labor use, production costs, and net income. During the coffee crisis, 80 percent of coffee farmers in Costa Rica adjusted their production by decreasing the use of chemical inputs for 1990-1991 (Sick, 1997). Lyngbæk, Muschler, and Sinclair recommended that more research on productivity is needed for coffee crops since crop diversification and spread of economic risk are becoming more important to coffee producers. Recently Vedenov, Houston, and Cardenas (2007) estimated a translog production function and technical efficiency measures for corn, coffee and other crop farms in Veracruz, Mexico. Their results for technical efficiency from 1997 to 2002 ranged from 0.875 to 0.892. To our knowledge, besides Vedenov, Houston, and Cardenas (2007), there are no other research studies that have measured efficiencies in any coffee growing country.

Previous studies in the U.S. have studied the coffee industry, asymmetric price transmission, cost past through, and price rigidity on retailers and coffee markets (Leibtag, Nakamura, Nakamura, and Zerom, 2007). Leibtag, Nakamura, Nakamura, and Zerom estimated that the average manufacturer price for coffee in the U.S. for 2002 was $0.17 per ounce, a reduction of $0.06 cents compared to 1997, Figure 3. This reduction was mostly due to the decrease in coffee prices; where in 1997 cost of coffee bean represented around 42% of the average manufacturer price while in 2002 around 18%. The authors found that U.S. coffee manufacturers “do not take advantage of commodity-cost variation to raise prices” and that “coffee prices do not respond systematically more to commodity costs increases than to costs decreases.” Even though manufacturers do not take advantage of commodity costs decreases, lower world coffee prices still affect coffee farmers in developing countries where U.S. manufacturers pay $0.07 less in 2002 for coffee beans compared to 1997, Figure 3.

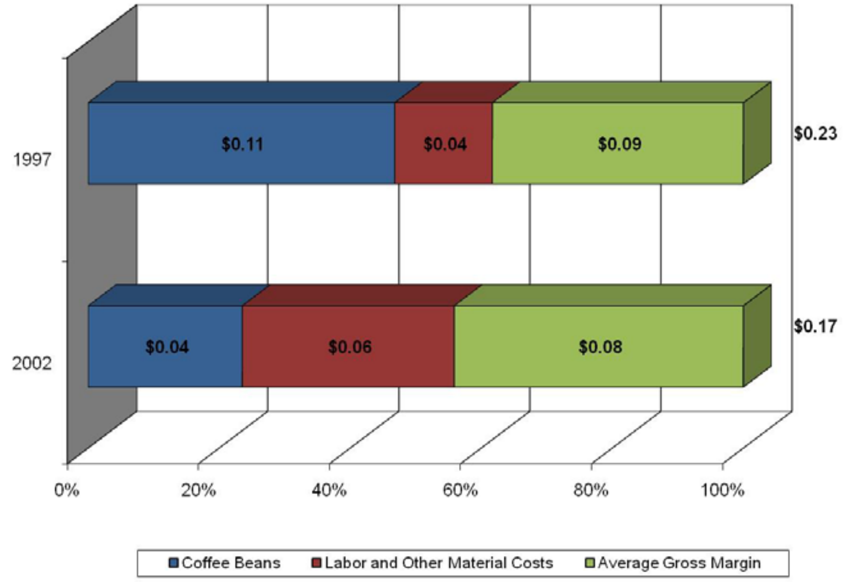

Figure 3: US Average Manufacturer Coffee Price by Costs and Average Gross Margin, 1997 and 2002.

Source: Leibtag, Nakamura, Nakamura, and Zerom, 2007.

Efficiency measures can be estimated using parametric and nonparametric approaches (Varian, 1984; Chavas and Cox, 1988: Chavas and Aliber, 1993; Featherstone, Langemeier, and Ismet, 1997). The parametric approach consists of specifying the production function, cost function or profit function (Varian, 1984; Chavas and Aliber, 1993; Featherstone, Langemeier, and Ismet, 1997). Varian described this approach as “defective” since the parametric form can never be tested: “it must be taken on faith.” Bauer describe it as a “weak approach” due to the parametric restrictions imposed on technology and the distributions of inefficiency terms

(Chavas and Aliber, 1993). The nonparametric approach proposed by Färe, Grosskopf, and Lovell is more flexible since it does not impose parametric restrictions on technology and there is no need for a functional form for production relationships. Pure technical, allocative, scale, and overall efficiencies can be estimated using this approach (Färe, Grosskopf, and Lovell, 1985; Chavas, and Aliber, 1993; Featherstone, Langemeier, and Ismet, 1997).

Methodology

This study estimates technical, allocative, scale and overall efficiency using a nonparametric approach. The minimum cost (C_i) of the i^{th} farm's output levels y_i can be calculated by multiplying input prices (w_i) times the input level (x_i) given constant returns to scale technology (T_c). The following program is used to calculate this as follows:

$$C_i\,(w,y,T_c) = Min\ w_i^{'} x_i^{*} \tag{1}$$

$$\text{subject to:} \qquad \mathbf{X'Z} \leq x_i^{*}$$

$$\mathbf{Y'Z} - y_i \geq 0$$

and measures the intensity of the use of the k^{th} farm's technology. The subscript k represents the number of farms, i characterizes an individual firm, n the number of inputs, j is the number of outputs, and x_i^{*} is the optimal input level.

Färe and Lovell (1978) defined technical efficiency as the "degree to which the actual output of production unit approaches its maximum." Technical efficiency seeks whether a firm uses the best technology in its production process (Chavas and Aliber, 1993), it measures how far off is the farm from the production function under variable returns to scale (Featherstone, Langemeier, and Ismet, 1997). The following program is used to determine technical efficiency using an input orientation and the dual approach, λ_i:

$$\text{Min } \lambda_i \tag{2}$$

$$\begin{aligned} \text{subject to:} \quad & \mathbf{X'Z} \leq \lambda_i x_i \\ & \mathbf{Y'Z} - y_i \geq 0 \\ & \textstyle\sum z_i = 1 \\ & z_k \in R^+ \end{aligned}$$

In this scenario the intensity vector restriction allows the technology function to consist of variable returns to scale. A firm is technically efficient if λ_i is equal to one, and technically inefficient if less than 1.

Allocative efficiency or "price efficiency" examines whether a farm is using the best optimal input mix in a cost minimizing manner (Chavas and Aliber 1993; Featherstone, Langemeier, and Ismet, 1997). Allocative efficiency α_i, is determined by solving the following:

$$\alpha_i = \frac{C_i(w, y, T_v)}{w_i^{'} \lambda_i x_i} \tag{3}$$

where the minimum cost under variable returns to scale (T_v) is found by solving the following:

$$C_i(w,y,T_v) = Min\ w_i^{'} x_i^{*} \tag{4}$$

$$\begin{aligned} \text{subject to:} \quad & \mathbf{X'Z} \leq x_i^{*} \\ & \mathbf{Y'Z} - y_i \geq 0 \\ & \textstyle\sum z_i = 1 \\ & z_k \in R^+ \end{aligned}$$

Scale efficiency measures if the operation is producing at the most efficient size. Scale efficiency (β_i), can be determined by the following:

$$\beta_i = \frac{C_i(w, y, T_c)}{C_i(w, y, T_v)} \tag{5}$$

Overall efficiency for each farm can be estimated using the following equation:

$$\rho_i = \frac{C_i(w, y, T_c)}{w_i^{'} x_i} = \alpha_i \times \lambda_i \times \beta_i \qquad (6)$$

where $w_i^{'} x_i$ is the cost the *ith* farm incurs to produce y_i. Overall efficiency is the product of pure technical, allocative and scale efficiency or the multiplication of equations 2, 3, and 5. To determine if whether the operating under increasing, decreasing or constant returns to scale, the following program is solved:

$$C_i(w,y,T^*) = Min\ w_i^{'} x_i^* \qquad (7)$$

$$\text{subject to:} \quad \mathbf{X'Z} \leq x_i^*$$

$$\mathbf{Y'Z} - y_i \geq 0$$

$$\sum z_i \leq 1$$

$$z_k \in R^+$$

If there are nondecreasing returns to scale, then the summation of the intensity variables is less than one. If $\beta_i \neq 1$, and if $C_i(w,y,T^*) = C_i(w,y,T_c)$ then there are increasing returns to scale but if $C_i(w,y,T^*) \neq C_i(w,y,T_c)$ then there are decreasing returns to scale.

Data Description

Data from the Commercial Coffee Survey from 2001-2004 was obtained from Puerto Rico's Department of Agriculture, Agricultural Statistics Office. A total of 892 observations were available for that period of time. Coffee prices were obtained from DACO, "Reglamento de Precios Núm. 6, Control de Precios de Venta de Café, 1991." Since coffee prices for that period of time were fixed in 1991, these prices were deflated. Producers that no longer produced coffee, producers with missing information, and producers with a cost of production equal to zero were dropped from the data set. A total of 129 producers were deleted.

Due to the fact that fertilizer and harvesting costs are the highest costs both were used as inputs in this analysis. The analysis included 6 outputs: first and second grade shaded and non-shaded Arabic coffee, and shaded and non-shaded Robusta coffee. There are five inputs in the model: labor for employees with and without pay, fertilizer quantity, and shaded and non shaded land.

Table 1 shows the summary statistics for the data set. Outputs, average harvest for employees and fertilizer quantities are express in 100 pounds, while land is express in "cuerdas"[4], and all prices are in US dollars. Eighty one percent of production is Arabica Non Shaded coffee, while only twelve and a half percent is Robusta coffee.

Table 1. Summary Statistics of Farm Production Levels

	UNITS	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
OUTPUTS					
Robusta Shaded	*100 lbs*	1.1173	6.2309	0.00	75.00
Robusta Non Shaded	*100 lbs*	14.1633	54.4438	0.00	700.00
Arabica 1st Shaded	*100 lbs*	4.8845	25.4191	0.00	420.00
Arabica 2nd Shaded	*100 lbs*	2.6564	16.3160	0.00	280.00
Arabica 1st Non Shaded	*100 lbs*	65.3570	141.4417	0.00	1145.40
Arabica 2nd Non Shaded	*100 lbs*	33.8822	83.8734	0.00	763.60
INPUTS					
Fertilizer	*100 lbs*	271.1862	559.6510	0.00	4500.00
Average Harvest of Empleyees with Pay	*100 lbs*	34.3227	93.9184	0.00	1145.40
Average Harvest of Empleyees without Pay	*100 lbs*	6.9954	24.9360	0.00	280.00
Shaded Land	*cdas*	2.6409	11.1057	0.00	160.00
Non Shaded Land	*cdas*	23.2668	41.8979	0.00	265.00

Efficiency Results

Equations 1, 2, 4, and 7 were estimated using GAMS. Table 2 shows descriptive statistics for all estimated efficiency measures while Table 3 shows efficiency measure ranges. Technical efficiency (TE) ranged from 0.06 to 1.00, with an average of 0.46. When TE is closer to one, the farm is more technically efficient. Therefore, coffee growers in Puerto Rico can increase production by 54% if each grower was purely technically efficient that is if each farm produces

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[4] 1 "cuerda" = 0.9712 acres.

in the production frontier. Around 10% of the farms were technically efficient (88 farms out of 892). Sixteen percent of the farms had TE measure greater than 80%.

Allocative efficiency (AE) ranged from 0.02 to 1.00, with an average of 0.74 (Table 2). Forty five percent of the farms had AE measure greater than 80%, thus AE were higher than TE efficiencies. On the other hand scale efficiency (SE) ranged between 0.08 and 1.00, with an average of 0.79. Sixty percent of the farms had scale efficiency greater than 80%. Sixty eight percent (608) of the farms that were not SE are operating under the region of increasing returns to scale thus in the region of decreasing average costs. Thirty one percent (276) of the farms are operating under the region of decreasing returns to scale or increasing average costs. Overall efficiency (OE) ranged from 0.009 to 1.00, with an average of 0.27.

Table 2: Descriptive Statistics of Efficiency Measures for Coffee Farms in PR

STATISTIC	TECHNICAL	ALLOCATIVE	SCALE	OVERALL
Mean	0.4615	0.7374	0.7915	0.2653
Standard Deviation	0.2624	0.1869	0.1968	0.1781
Minimum	0.0550	0.0233	0.0769	0.0009
Maximum	1.0000	1.0000	1.0000	1.0000
Count	892	892	892	892

Table 3: **Distribution of Efficiency Measures for Coffee Farm in PR**

DISTRIBUTIONS	TECHNICAL	ALLOCATIVE	SCALE	OVERALL
Less than .40	464	51	65	711
.40 to .50	111	61	33	95
.50 to .60	93	75	47	49
.60 to .70	48	132	71	14
.70 to .80	36	174	144	8
.80 to .90	42	219	190	2
.90 to 1.00	10	164	334	10
1.00	88	16	8	3

Table 4 shows the means for all efficiency measures by output. TE results for all Arabica outputs and Robusta non shaded were close to the previous results, except that efficiency for Robusta shaded production was higher. Robusta shaded farmers were 60% technically efficient. The opposite occurs when it comes to AE, Robusta shaded farmers were 59% allocative efficient. Results for Scale and Overall efficiency did not vary much by coffee type.

Table 4: Efficiency Measure Means by Output

	TECHNICAL	ALLOCATIVE	SCALE	OVERALL
Robusta Shaded	0.6025	0.5921	0.8132	0.2813
Robusta Non Shaded	0.5438	0.7018	0.8287	0.3093
Arabica First Non Shaded	0.4415	0.7095	0.7262	0.2126
Arabica Second Non Shaded	0.4187	0.7304	0.7096	0.2019
Arabica First Shaded	0.4598	0.7506	0.8154	0.2801
Arabica Second Shaded	0.4336	0.7564	0.8166	0.2672

Conclusions

The objective of firms is assumed to be profit maximization or cost minimization. Since coffee prices are set by the government for all levels of production in Puerto Rico, coffee farmers have to minimize costs in order to have profits. Farmers must produce efficiently to ultimately remain in the industry.

This study used a nonparametric approach to estimate technical, allocative, scale, and overall efficiency measures. The data set included 892 farms for 2000 to 2004 period. On average, Puerto Rico coffee farms were 46% technically efficient, 73% allocatively efficient and 79% scale efficient. Technical efficiency for this study compares to that found by Vedenov, Houston, and Cardenas (2007) in their study of Mexican coffee production. Technical efficiency results for their study were 89%. Thirty one percent of Puerto Rico coffee farms operated under decreasing returns of scale.

Coffee is an important commodity in many developing countries therefore more research has to be done in production economics, specifically in costs and efficiency measures so farmers in developing countries receive fair prices. Specifically those countries in which coffee production is labor intensive and the economy depends on coffee trade.

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