An Economic Analysis of Smallholder Coffee Production in Guatemala, Honduras, Nicaragua and Vietnam

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ABSTRACT

Salazar, Marcia, M.S., Purdue University, August 2006. An Economic Analysis of Smallholder Coffee Production in Guatemala, Honduras, Nicaragua and Vietnam. Major Professor: Dr. Gerald Shively.

Coffee is one of the most important export commodities in Guatemala, Honduras, Nicaragua and Vietnam. Unfortunately, a recent decline in the price of coffee due to an oversupply in the world market has dramatically lowered farmgate prices and reduced farmers' incomes on coffee-growing countries. By studying and comparing production experiences, this study seeks to identify mechanisms that might permit smallholder coffee farmers to increase efficiency, especially technical efficiency, by optimizing their use of inputs and thereby maximizing their net income.

Data for the study were collected through surveys conducted by CATIE, ANACAFE, IHCAFE, CAFENICA, and the World Bank (2003) in the communities of San Marcos, Huehuetenango, Olancho, El Paraiso, Francisco, Morazan, Matagalpa, Boaco, and Segovia in Guatemala, Honduras, and Nicaragua. The Vietnam survey was conducted by researchers at Nong Lam University under support of USAID in the communities of EaTul, Quang Phu, Eakpam, and Ea Pok. Production parameters and technical efficiency scores are derived and presented to explain patterns of inefficiency. In addition, a profit model based on production estimates for a representative farm is also presented. Results from the production function suggest that all inputs contribute positively to yield, with the exception of organic fertilizer. In addition, all models imply sharply diminishing returns to increase use of all inputs per hectare. Results from the inefficiency analysis suggest that Guatemalan farmers, on average, were the most technically efficient in the sample, followed by Vietnamese, Nicaraguan and Honduran farmers. It was also found that larger farms were more technically efficient and that higher levels of organic fertilizer and labor were correlated with lower relative technical efficiency. Results from the profit maximization model suggest that farmers in Guatemala, Honduras, Nicaragua and Vietnam were not behaving optimally, typically applying inputs at below the optimization rules, with the exception of organic fertilizer in Central America countries and chemical fertilizer in Vietnam.

Results provide insights that could help coffee farmers and those who work with them on topics related to on-farm efficiency and profitability. Results also inform policy makers who seek to effectively meet the needs of farmers.

CHAPTER I - INTRODUCTION

1.1 Overview

A recent decline in the price of coffee has dramatically reduced the incomes of coffee producers in developing nations. The negative impacts of this decline on smallholders are apparent in many coffee producing countries, including those of interest in this thesis, Guatemala, Honduras, Nicaragua, and Vietnam. The history of coffee in these countries differs, and the ways in which coffee producers in each country have managed the recent decline in coffee prices have also differed. By studying and comparing their experiences this thesis aims to identify mechanisms to permit smallholder coffee farmers in these countries optimize their use of inputs and maximize their net income in the world's highly volatile coffee market.

For each of the countries studied here coffee is one of the most important export commodities. Figures 1.1 and 1.2 show coffee as a share of agricultural export in these countries. Guatemala is the world's sixth largest exporter of Arabica coffee, having more than 150 years of coffee growing history (USGS-EROS and ANACAFE, 2004). In 2004, Coffee represented 23% of the value of agricultural exports. Guatemala has up to 59,646 small-scale coffee producers, 317 medium enterprises and 213 large enterprises, employing 11% of the active population in Guatemala (and up to 20% at harvest time). In the last 20 years coffee has represented on average, 6.6% of Guatemala's GDP and a third of all its exports (Anzueto, 2000).

In Honduras coffee is one of the most important export products, representing 25% of agricultural exports (FAO, 2005). There are more than 100,000 farmers producing coffee and more than half million citizens directly or indirectly involved in coffee production (Instituto National de Estadistica, 2001).

In Nicaragua, coffee is one of the principal products of export. Coffee represented 25% of the value of agricultural exports in 2004. In the 1990's coffee production employed 32% of the rural workforce. About 30,000 families produce coffee and other 150,000-200,000 individuals are involved in its production and processing (IICA, 2004).

Vietnam is a relative newcomer to coffee, but is now recognized as the second largest coffee exporter, and in recent years has become the world's largest exporter of Robusta coffee. In 2001, 95% of Vietnam's coffee production was destined for exports (ICARD and Oxfam, 2002). In Vietnam 80% of its rural population of 76 million people rely on small-scale farming (Sinnema, 1999). Coffee related jobs have increased from 300 thousands a decade ago to approximately 3-5 million in 2004 (Lindsey, 2004). Coffee was first planted in Vietnam at the end of the 19th century. Coffee area increased in the early 20th century to 20,000 ha in 1975. During the 1980's the coffee production area was expanded through investment and the help of former socialist countries. Between 1998 and 2000, Vietnam's coffee production increased from 409,300 tons to 672,600 tons (FAOstat, 2000). The main reasons for the rapid increase in planted area in Vietnam include government incentives and an increase in the world coffee price. The global coffee price increased considerably to $1,873/ton in 1994 and then to $2,411/ton in 1995, due mainly to a severe frost in 1994 that substantially cut coffee output in Brazil. Another reason was state support for migration to coffee growing areas (ICARD and Oxfam, 2002).

In 2001, the world coffee price dropped to its lowest level in 40 years. In 1999, the price of Robusta coffee was US$1,300/ton and by January 2000 it had declined to US$948/ton. It fell further to US$638/ton by December 2000, and to just US$500/ton by 2001 (ICARD and Oxfam, 2002). The main reasons for the decrease in price were a worldwide oversupply of coffee combined with inelastic demand (Ha and Shively, 2006).

Given the important role of coffee in the economies of Guatemala, Honduras, Nicaragua and Vietnam, an increase in efficiency, especially technical efficiency, is a priority. This thesis will analyze the profitability of smallholder coffee producer in these countries and compare the overall efficiency of smallholder farming operations and the sources of inefficiencies. This will help policy makers to design agricultural programs to reach specific goals and help small farmers in Guatemala, Honduras, Nicaragua and Vietnam allocate their resources more wisely.

1.2 Population and Distribution

The majority of coffee producers in Guatemala, Honduras, Nicaragua and Vietnam are smallholder farmers who individually account for a small percentage of total production. These farmers depend on cash income from coffee to pay for food, school, health and other needs. In Central America, the recent coffee crisis has created an imbalance in the rural economy precipitating migration to urban areas and other countries (Varangis, Siegel, Giovannucci and Lewin, 2003).

The population of Guatemala was estimated at 12.3 million in 2006, with an annual growth rate of 2.27% (The World Factbook, 2006a). The population is largely rural with 53% of the total population residing in rural areas in 2005 (United Nations, 2005) Average annual growth in the urban population from 2000 to 2005 was 3.31% while for the rural population it was 1.7% (United Nations, 2005). The overall population density in Guatemala was 135 persons per square kilometer in 2005 (Geographic, 2005).

The population of Honduras was estimated at 7.3 million in 2006, with an annual growth rate of 2.16% (The World Factbook, 2006b). The population in Honduras is largely rural with 54% of the total population residing in rural areas in 2005 (United Nations, 2005). Average annual population growth from 2000 to 2005 was 3.25% in urban areas and 1.58% in rural areas (United Nations, 2005). The overall population density was 63 persons per square Kilometer in 2005 (Geographic, 2005).

The population of Nicaragua was estimated at 5.6 million in 2006, with an annual growth rate of 1.89% (The World Factbook, 2006c). The population in Nicaragua is largely urban with 57% of the total population residing in urban areas in 2003 and 43% residing in urban areas (United Nations 2005). The average annual growth rate of the urban population from 2000 to 2005 was 3.12% and the rural growth rate was 1.51% (United Nations, 2005). The overall population density was 45 persons per square kilometer in 2005 (Geographic, 2005). The largest city is Managua, which is situated in the Pacific Lowlands. About 27% of the entire population lives in and around Managua.

The population of Vietnam was estimated at 84.4 million in 2006, with an annual growth rate of 1.02% in 2006 (The World Factbook 2006d). The population is largely rural, with 74% of the population residing in rural areas in 2005 (United Nations, 2005). The average annual growth rate of the urban population from 2000 to 2005 was 3% and the rural growth rate was 0.80% (United Nations, 2005). The introduction of Market reforms in Vietnam two decades ago has led to rapid urbanization. The urban population is located in the South East and along the Central Cost. Between 1994 and 1999, 6% of the population had migrated to urban areas (Oxford Policy Management, 2004). The overall population density was 249 persons per square kilometer in 2004, with large differences among regions. The regions with the highest population density were the Red River Delta and the Mekong River Delta with 1204 and 430 persons per square kilometer in 2004. Regions with lower population density include coffee growing areas such as the Central Highlands with 86 persons per square kilometer in 2004 (General Statistics Office in Vietnam, 2004).

1.3 Economic Overview

In 1998, Guatemala’s real GDP growth rate of 4.7% increased by 0.6% from previous year. Agriculture continues to be the primary sector of the economy contributing about 70% of exports. In 2003, green coffee accounted for 22.9% of agricultural exports, sugar accounted for 16.2% and bananas accounted for 16.1% (FAO-ESSA, 2005). Nontraditional products such as cut flowers, fruits, shrimp and textiles are also growing in importance in Guatemala (Wetzel, 2003). In 2005, 22.8% of Guatemala’s GDP was attributed to agriculture, 19.1% to the industrial sector and 58.1% to services sector. GDP per capita of $4700 and real GDP growth rate was 3.2% in 2005 (Figure 1.3) (The World Factbook, 2006a). Today's population suffers from income inequality: 56% of the population lives in poverty and 20% lives in extreme poverty. Child mortality is among the worst in the region (at 39 per 1,000 live births) and maternity mortality is extremely high (at 153 per 100,000 births) (USAID, 2005).

Honduras is considered one of the poorest countries in the Western Hemisphere with an unequal distribution of income and an unemployment rate of 28% in 2005 (The World Factbook, 2006b). In 1998, the country was devastated by Hurricane Mitch, which generated approximately 2 billion dollars in damage; destroyed 70% of all agricultural crops, and seriously damaged houses, services and infrastructure. Honduras has created a Poverty Reduction Strategy with help from the international donor community, the World Bank and the International Monetary Fund, focusing on economic growth, poverty reduction in rural and urban areas, and investment in human capital. In 2005, 12.7% of Honduras's GDP could be attributed to the agriculture sector, 31.2% to industry sector and 56.1% to services. GDP per capita stood at $2,900 in 2005 and real GDP annual growth rate was 4.2% in 2005 (Figure 1.3) (The World Factbook, 2006b). In 1993, 53% of the Honduran population fell below the poverty line. The 2006 child mortality rate was 26 per 1,000 live births (The World Factbook, 2006b).

Nicaragua is one of the poorest countries in the hemisphere with an unemployment rate of 22% in 2003. The Nicaraguan economy grew by 4% in 1998, until Hurricane Mitch devastated the production, infrastructure and lives of Nicaragua's citizens. The primary economic sectors are agriculture, livestock and fishing, all of which were greatly affected by the hurricane. In 1998 agricultural activity grew by 7% compared with 10% in 1997; the products most affected by the hurricane were basic grains, coffee, sugar cane and bananas. Secondary sectors such as manufacturing grew 2% in 1998 compared with 4% in 1997. Construction grew 8% in 1998 compared with 10% in 1997. Hurricane Mitch and tariff adjustments affected the prices for basic family products (IDB, 2000). In 2005, 18.1% of Nicaragua's GDP was attributed to the agriculture, 26.6% to industry and 55.4% to services. GDP per capita was $2,900 and the GDP annual growth rate was 4% in 2005 (Figure 1.3) (The World Factbook, 2006c). Today's 50% of Nicaragua's population falls below the poverty line and child mortality was 28 per 1,000 live births in 2006 (The World Factbook, 2006c).

The Vietnamese economy experienced strong growth during the 1990's because of economic reforms begun in the 1980's. Agriculture continues to be the primary sector of the economy with rice, fish and coffee as principal exports. Vietnam is the second largest exporter of coffee (after Brazil) and the second largest exporter of rice (after Thailand). In 1998 the economy was affected by the South East Asian regional financial crisis, during which GDP fell by 4%. Because of the strong economic growth in the 1990's, Vietnam's poverty rate fell from 37% in 1998 to 23% in 2005. In 2005 the Vietnamese economy maintained a growth rate of 8.4%. This economic environment helped to generate 1.14 million new jobs, reducing the urban unemployment rate from 17.5% in 2001 to 5.3% in 2005 (Asian Development Bank, 2006).

1.4 Coffee Plant: Agronomic Overview

The coffee plant belongs to the botanical genus *Coffea* in the Rubiaceae family. The Rubiaceae family has approximately 500 genera and 6,000 species; 25-100 species belong to *Coffea*. The commercial green coffees are C. arabica and C. canephora, which are commercially referred to as Arabica and Robusta. Coffee grows in altitudes over 2,000 ft, usually between 4,000 and 6,000 ft above the sea level. Robusta coffee can grow below 2000 ft. In early years, the area under Arabica cultivation was significantly higher than Robusta (more than 80%), but due to uncontrollable pest and disease in Arabica coffee, the area planted has been reduced dramatically. Today, Arabica accounts for 45% and Robusta for 55% of the area planted worldwide (Titus and Pereira, 2006).

The coffee tree has a main vertical trunk and primary, secondary and tertiary horizontal branches. Its fruit requires a good balance of rain, sunshine and adequate climate. Some coffee trees can grow to a height of 30 to 40 feet but farmers tend to maintain trees at reasonable height for easy harvest. The flavor in coffee can be affected by the soil, climate and altitude (Starbucks, 2006). The coffee plant is a major producer of oxygen: one hectare of coffee produces 86 pounds of oxygen per day, which is half the production of the same area in the rainforest (Anacafe, 1995).

1.4.1 Coffee Plant Development

Coffee flowers start emerging three to four years after planting. Arabica is self-pollinating while Robusta depends on cross pollination. The root system can be extended 20-25 km in total length and the surface ranges from 400 to 500 m^2 (Coffee Research

Institute, 2006). There are three types of roots vertical, tap and lateral roots. The tap roots can extend 30-45cm below the soil surface. The lateral roots can extend 2m from the trunk. About 80-90% of the feeder root is in the first 20cm of soil. The greatest concentration of roots is in the 30 to 60 cm depth (Nutman, 1933). Table 1.1 shows the differences between Arabica and Robusta coffee.

1.4.2 Coffee Harvesting

In general, it takes 5 years for an Arabica tree to mature and produce cherries. Robusta trees take only 2 years (Coutts Company, 2006). Coffee is harvested during the dry season, when the cherries are bright read, shiny and solid. Collection is either made by hand or machine. In harvesting it is necessary to collect the ripe beans and leave the unripe beans to be collected at a later time (coffee Research Institute, 2006). Because all coffee beans on a tree do not ripen at the same time, it usually takes 3-7 pickings to complete the harvest (Equal Exchange, 2006). Harvesting the same coffee tree several times is costly, and in Brazil growers use the stripping method for harvesting, which means that the coffee is collected when 75% of the coffee is perfectly ripe. Under stripping, the beans are pulled from the tree and fall to the ground where they are caught by sheets (Coffee Research Institute, 2006).

1.4.3 Robusta Coffee

Robusta coffee is native to West Africa, starting at the west coast to Uganda and south of Sudan. It is produced primarily in the lowlands tropics, at latitudes 10° North and 10° South and elevations from sea level to 3000 ft. Coffee Canephora is a small tree reaching 10-20 ft in height. Robusta trees are more resistant to pests and diseases and produce more fruits than Arabica trees. Robusta is cultivated in Africa and Brazil and not much in Central America. It is considered inferior in taste, with a higher caffeine content, and its fruits are often used for instant coffee. People will use a little amount of Robusta coffee "to increase crema and lessen the acidity of the Arabica coffee" (Coffee Research Institute, 2006). The quality of Robusta grain is inferior to Arabica's grain but Robusta coffee presents favorable characteristics including immunity or resistance to mildew, high production capacity, strong fruit attachment at maturity, and adaptation to warm temperatures (Infoagro, 2006). Robusta coffee is grown in West and Central Africa, South-East Asia and some areas in Brazil (International Coffee Organization, 2006). C. canephora is a plant diploid and self-sterile that produces many varieties in the wild. Two main forms are documented: 'Robusta' and 'Nganda' (International Coffee Organization, 2006).

1.4.4 Arabica Coffee

Arabica coffee grows best at high altitudes, and is considered to have a higher quality flavor. Arabica represents 75% of world production. Arabica coffee has two optimal growing climates: (1) subtropical regions (latitudes of 16-24° and altitudes of 1800-3600 ft), where dry and rainy seasons are well defined, and (2) equatorial regions (latitudes below 10° and altitudes of 3600-6300 ft), where there is frequent rainfall causing continuous flowering resulting in two harvesting seasons. The main harvesting period occurs at the period highest rainfall, the second harvesting period occurs in the period of least rainfall. In these regions artificial drying with mechanical dryers is used since rainfall is too frequent. Arabica coffee is grown in relative cool regions between the Tropic of Cancer and Capricorn at optimum temperature between 15-24°C (59-75°F) (Coffee Research Institute, 2006). Arabica coffee is grown in throughout Latin America, Central and East Africa, India and in some areas in Indonesia (International Coffee Organization, 2006).

Coffea arabica Cultivars:

C. Arabica cultivars include var. typica and var. bourbon. Although these two cultivars are important there are other cultivars that have a significant importance in the world such as caturra, catuai, pache comum, pache colis, catimor, kent, mundo novo, maragogype, amarello, and blue mountain. The following discussion of the main characteristics of these cultivars is taken from the International Coffee Organization (2006).

Typica: Is the base for many coffee cultivars, it can reach a height between 3.5 and 4 m. Typica is a good quality coffee but has a low production.

Bourbon: C. bourbon is a good quality coffee, it produces 20-30% more coffee than Typica but still producing lower than most cultivars. The fruit is relatively small and dense, and matures very quickly, but is at risk of falling with high winds. Bourbon is best grown at altitudes between 3,500 and 6,500 ft.

*Caturra***:** Caturra is a mutation of bourbon, it was discovered in Brazil. The coffee has a high production and quality which require extensive fertilization. It adapts to most environments. The Caturra coffee is best grown at altitudes between 1500 and 5500 ft with an annual precipitation of 2500-3500 mm.

*Catuai***:** Catuai is a result from a cross between Mundo Novo and Caturra. The fruit does not fall easily and the plant is relatively short and needs a lot of care and fertilization.

Pache comum: It is a mutation of Typica. It was first observed on the farm El Brito, Santa Cruz Naranjo, Santa Rosa in Guatemala. This cultivar adapts well between 3500 and 5500 ft.

*Pache colis***:** It adapts to altitudes between 3,000 and 6,000 ft with temperatures between 20-21°C. It was found in Guatemala on a farm that has Caturra and Pache comum.

*Catimor***:** Catimor is a cross between Timor and Caturra created in Portugal. Maturation is early and production is very high. Shade and fertilization must be monitored very carefully.

Kent: It has high yield and resistance to coffee rust.

Mundo Novo: It is a natural hybrid between Typica and Bourbon. Mundo Novo has a high yield and matures slightly later than other cultivars. It thrives with annual rainfall of 1200-1800 mm and adapts well to altitudes between 3500 and 5500 ft.

Maragogype: It is a mutation of Typica discovered in Brazil. Maragogype plant production is low, it adapts well at altitudes between 2000 and 2500 ft.

Blue Mountain: It is well known for its resistance to coffee berry disease. It is grown in Jamaica.

1.4.5 Arabica and Robusta Hybrids

In order to improve coffee characteristics such as disease resistance, vigor or quality, Arabica and Robusta coffees have been selectively bred. Among some of the crosses between Arabica and Robusta are:

Hibrido de Timor: It is a natural hybrid of Arabica and Robusta

Catimor: It is a cross between Caturra and Hibrido de Timor, this coffee plant is resistant to coffee leaf rust.

Icatu hybrids: It is a backcrossing of Arabica and Robusta to Arabica cultivars Mundo Novo and Caturra.

Arabusta hybrids: It is a crossing between Arabica and induced auto-tetraploid Robusta coffee.

1.5 Problem Statement and Objectives

As production of coffee outpaces demand, the producer price of coffee drops. According to Oxfam (2005), small-scale farmers do not have the information necessary to make accurate decisions about production. Such information includes consumer demand, global production and trends. Without this information and the understanding of how to employ it, producers are incapable of planning for price volatility. Therefore, smallholder farmers and agricultural policy makers need to understand patterns of smallholder farming production efficiency to help smallholder farmers in these countries deal with unstable world coffee prices.

The objective of this research is to provide information to help smallholder farmers in Guatemala, Honduras, Nicaragua and Vietnam allocate resources more wisely and increase their efficiency, especially technical efficiency. Figure 1.4 shows the stylized relationship between coffee input and output. The figure shows that, an inefficient farmer (at point A: X_0, Y_0) can be more efficient in two ways. For example, the farmer can gain higher levels of output by using same levels of inputs in production, by moving from point A (X_0, Y_0) to point B (X_0, Y_1) on the production frontier. Alternatively, the farmer can achieve the same level of output as in point A by reducing his levels of inputs, by moving from a point A(X_0, Y_0) to point C (X_1, Y_0) on the production frontier. To explore such empirical patterns, data from coffee production in Guatemala, Honduras, Nicaragua and Vietnam are used. Data are drawn from 338 smallholder farms in 2003.

1.6 Hypothesis

One goal for this thesis is to investigate levels of profitability of farms and to study whether sources of profitability and/or inefficiency differ across countries.

Several hypotheses motivate the analysis. The main hypothesis can be stated as follows:

H1: Controlling for observed factors and levels of input use, there are no significant differences in technical efficiency among smallholder farmers in Guatemala, Honduras, Nicaragua and Vietnam.

H1n: Controlling for observed factors and levels of input use, there are observable and statistically significant differences in technical efficiency among smallholder farmers in Guatemala, Honduras, Nicaragua and Vietnam.

1.7 Structure of the Thesis

This thesis has 5 chapters. Chapter 1 provides an overview of the coffee situation in Guatemala, Honduras, Nicaragua and Vietnam, and outlines the objectives and hypotheses for the thesis. Chapter 2 describes the methods and model used in this study and locates the study within the larger literature on technical and allocative efficiency in agricultural production. Chapter 3 describes the data and their collection. Chapter 4 reports the results from the study, including measures of profitability and technical efficiency in coffee production for small-farmers in Guatemala, Honduras, Nicaragua and Vietnam. Chapter 5 discusses the results and provides policy recommendations and suggestions for further research.

Table1.1. Differences between Arabica and Robusta coffees

Characteristics	**Arabica**	**Robusta**
Chromosomes (2n)	44	22
Time from flower to ripe cherry	9 months	10-11 months
Flowering	after rain	irregular
Ripe cherries	Fall	stay
Yield (kg beans/ha)	1500-3000	2300-4000
Root system	Deep	shallow
Optimum temperature	15-24°C	24-30°C
Optimal rainfall	1500-2000 mm	2000-3000 mm
Growth optimum	1000-2000 m	0-700 m
Hemileia vastatrix	susceptible	resistant
Koleroga	susceptible	tolerant
Nematodes	susceptible	resistant
Tracheomycosis	resistant	susceptible
Coffee berry disease	susceptible	resistant
caffeine content of beans	0.8-1.4%	1.7-4.0%
Shape of bean	Flat	oval
Typical brew characteristics	Acidic	bitter

Source: International Coffee Organization, 2006

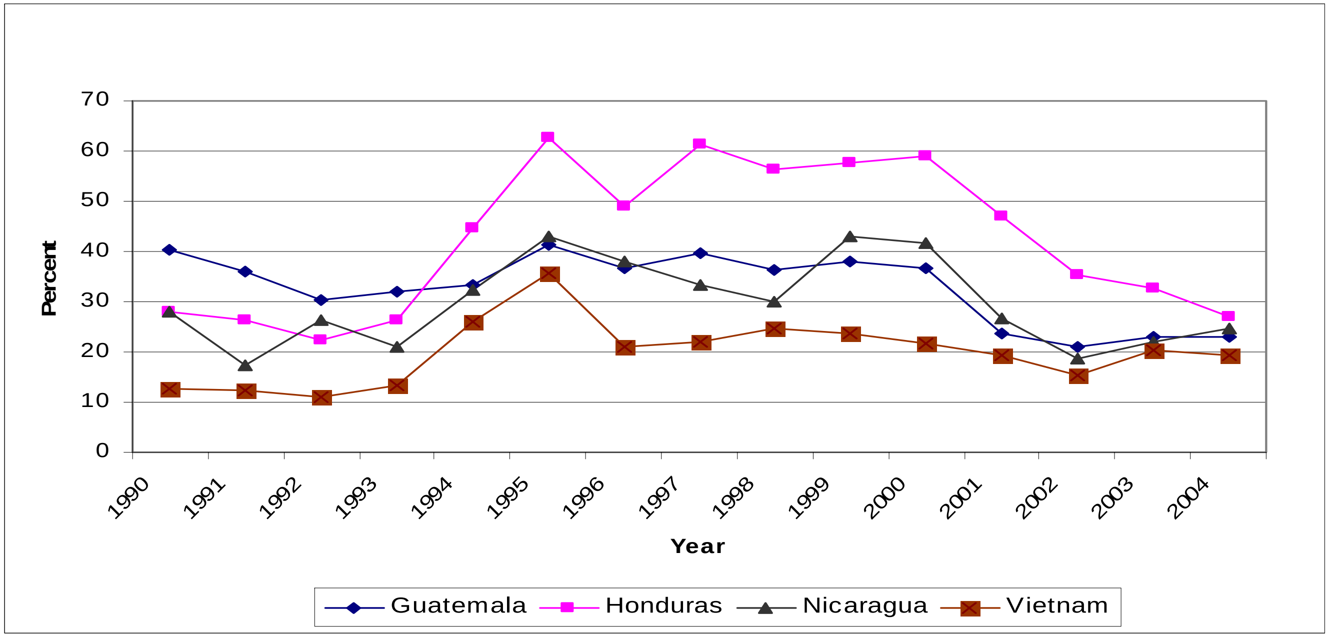

Figure 1.1 Coffee as a Share of Agricultural Exports, 1990-2004, FAOSTAT

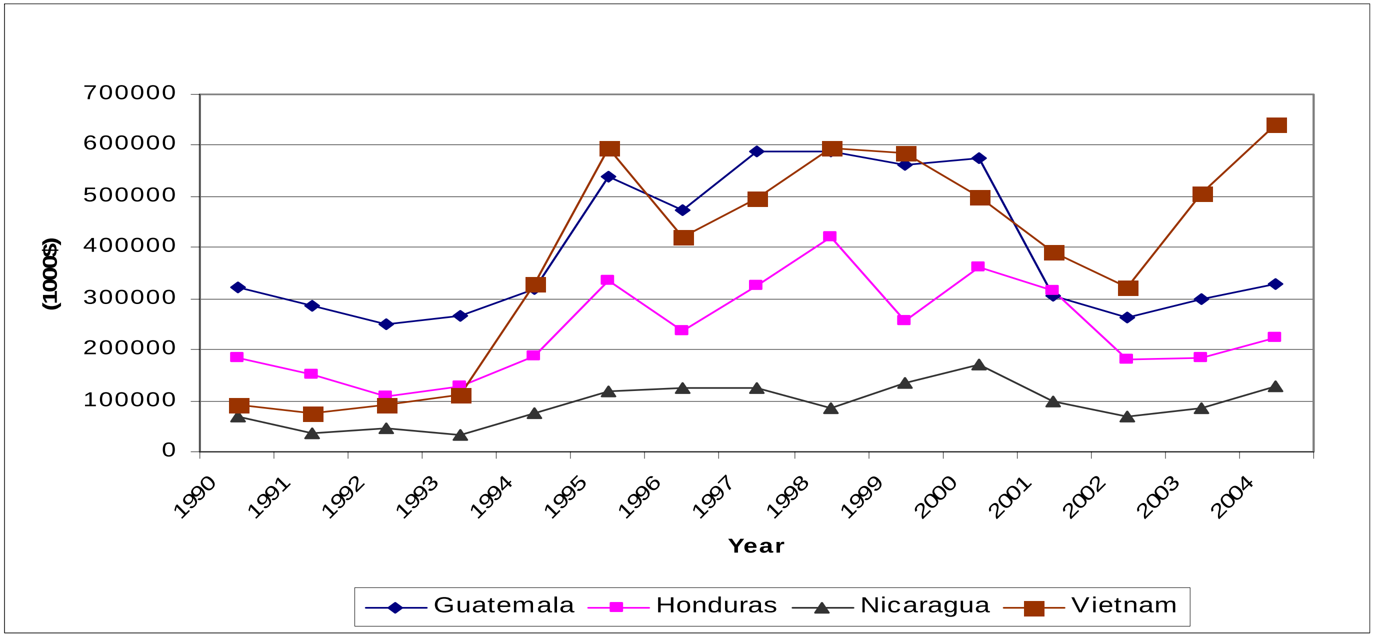

Figure 1.2 Total Value of Coffee, 1990-2004, FAOSTAT

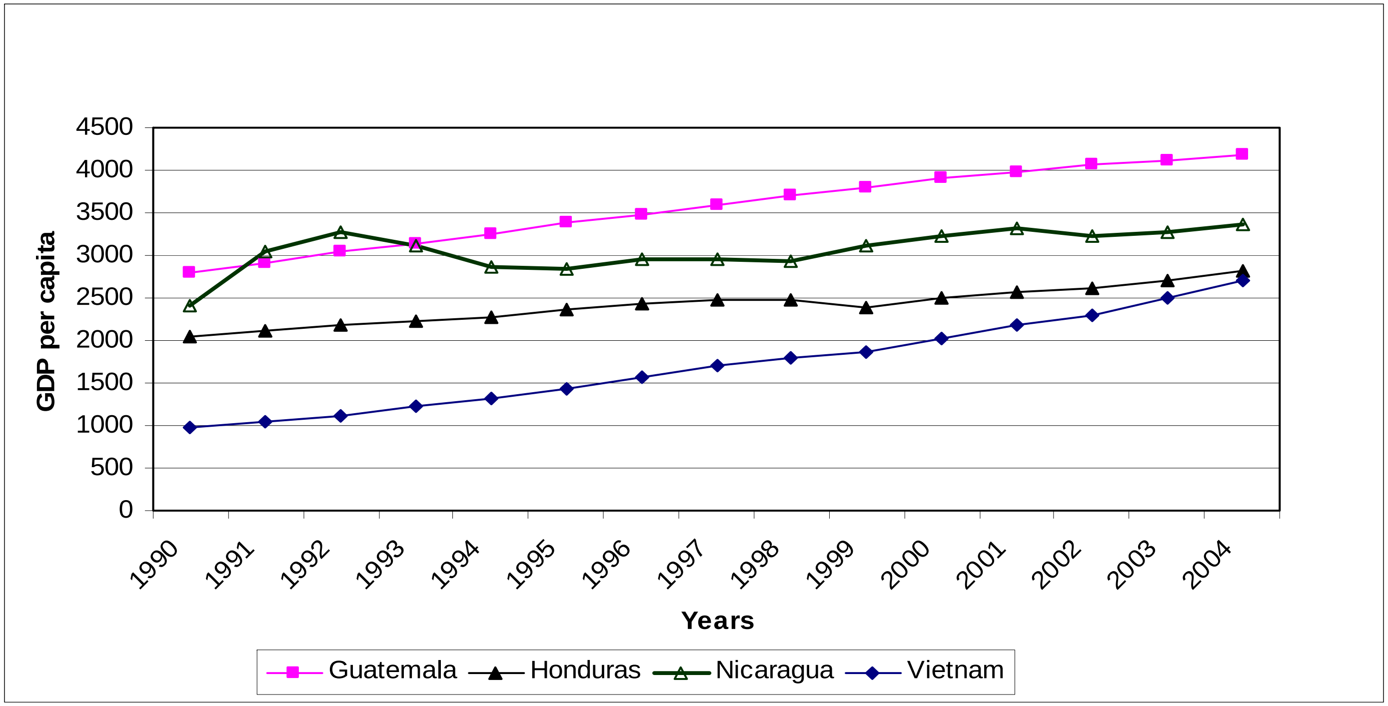

Figure 1.3 GDP per capita (current $), 1990-2004**,** World Development Indicators

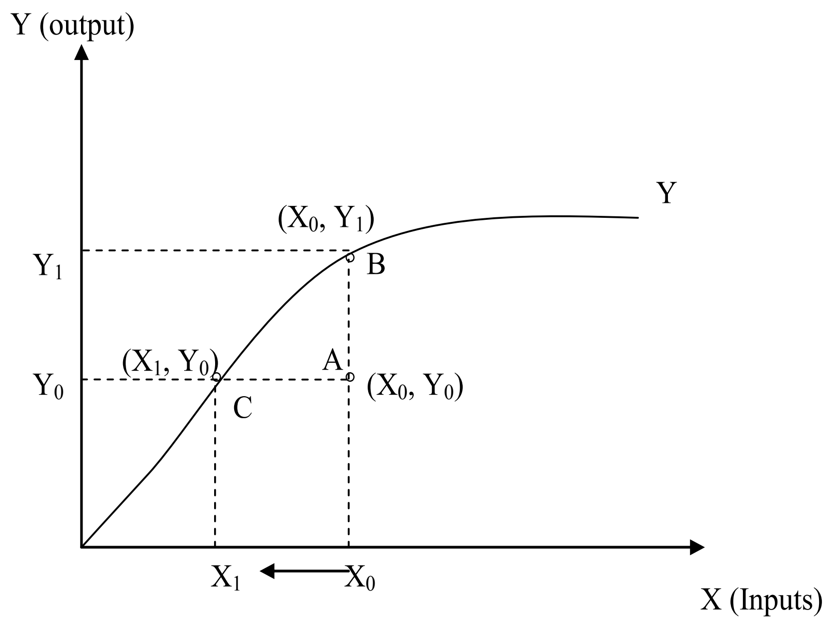

Figure 1.4 Stylized Input-Output Relationship

CHAPTER II - DATA AND DESCRIPTION OF STUDY SITE

1.1 DATA COLLECTION

Data for this study come from surveys undertaken in Guatemala, Honduras, Nicaragua and Vietnam in 2003. The surveys describe the situation of coffee farmers living in the communities of San Marcos, Huehuetenango, Olancho, El Paraíso, Francisco Morazan, Matagalpa, Boaco, Segovia, EaTul, Quang Phu, Eakpam, and Ea Pok.

The Guatemala survey was conducted by ANACAFE and CATIE, and funded by the World Bank. The purpose of the survey was to characterize coffee production techniques, farm activities and commercialization in the communities of San Marcos and Huehuetenango. The survey was conducted among a group of 41 smallholder coffee farmers who are members of cooperatives in these communities. The total population in these cooperatives was 1295 farmers. A 3.2% sample was interviewed for this study. A project report from CATIE and ANACAFE reported low yields, especially in the community of San Marcos; some of the reasons given were the low dose and infrequent use of fertilizer, insufficient pruning, shade, and control of diseases and weeds. Moreover, the cost of production was found to be high in San Marcos because of the high use of labor. In terms of income generated in these two communities, the community of Huehuetenango had higher income because of higher yields and a lower cost of production.

The Honduras survey was completed by CATIE, IHCAFE, and the World Bank. A total of 36 smallholder coffee farmers were interviewed with the objective to evaluate coffee production, technical assistance, commercialization and trade in the communities of Olancho, El Paraiso and Fco. Morazan. All farmers surveyed were members of cooperatives. There were a total of 16 cooperatives that were part of three central organizations: Central de Cooperativas Cafetaleras de Honduras Central (CCCH), Asociacion Hondurena de Productores de Café (AHPROCAFE) and Union de Cooperativas (UNIOCOOP). Two members from each cooperative were selected, with the exception of two cooperatives where 3 to 5 members were selected because of a larger number of members. The project report recommended the renovation of coffee trees, as tree ages varied between 4 and 31 years.

The Nicaragua survey was completed by CAFENICA, CATIE and the World Bank with an aim to characterize coffee production, process, quality, technical assistance and commercialization. The study took place in the communities of Matagalpa, Boaco and Segovias. A total of 52 farmers were selected from CAFENICA, which is a group of 10 cooperatives. From each cooperative 1 to 3 members were interviewed. CAFENICA has 6300 members who produce 15% of the national coffee output in Nicaragua and 12% of the exportable production.

The Vietnam survey was completed by researchers at Nong Lam University under the support of USAID. The study took place in EaTul, Quang Phu, Eakpam and EakPok villages. The goal was to study farmer responses to falling coffee prices. A total of 209 farmers were surveyed. Rios and Shively (2006) analyzed efficiency using the Vietnam sample. Results from their study indicate lower technical and cost efficiency on small farms. Inefficiencies observed on these farms may be due to factors other than farm size. As length of irrigation pipelines increased especially on small farms, efficiency fell. Furthermore, based on the same survey data, Ha and Shively (2006) suggest that farmers in Vietnam responded to falling coffee prices in different ways: reducing, shifting input use and changing crops. Small farmers appear to have had some restriction in their willingness or ability to respond to falling coffee prices compared to larger farms. Results from a multinomial logit model suggested that larger farms, households with greater labor capacity and greater tenure security were more likely to adjust input use. Crop changes were correlated with expected prices but uncorrelated with observed household features.

1.2 Communities, Their Differences and Similarities and Farms Specific Characteristics

1.2.1 Farms Location

Guatemala's study took place in the department of San Marcos and Huehuetenango. San Marcos's farms are located approximately between 600 and 1800 meters above sea level, in the South Occidental Region, 252 kilometers from the Capital Ciudad de Guatemala. Its territory area is 2,397 square kilometers. Neighboring at the North is Huehutenango, at the South is the Pacific Ocean and Retalhuleu, at the East is Quetzaltenango and at the West is Mexico (Wikipedia, 2006a). Huehuetenango's farms are located approximately 900-1800 meters above sea level, in the Nor-Occidental Region, neighboring at the North and West with Mexico, at the South with the departments of San Marcos, Qetzaltenango y Totonicapan and at the East with the department of El Quiche. It is situated at latitude 15°19’14” with a territory area of 7,403 square kilometers. Figure 2.1 shows the Guatemalan departments of San Marcos and Huehuetenango (Wikipedia, 2006b).

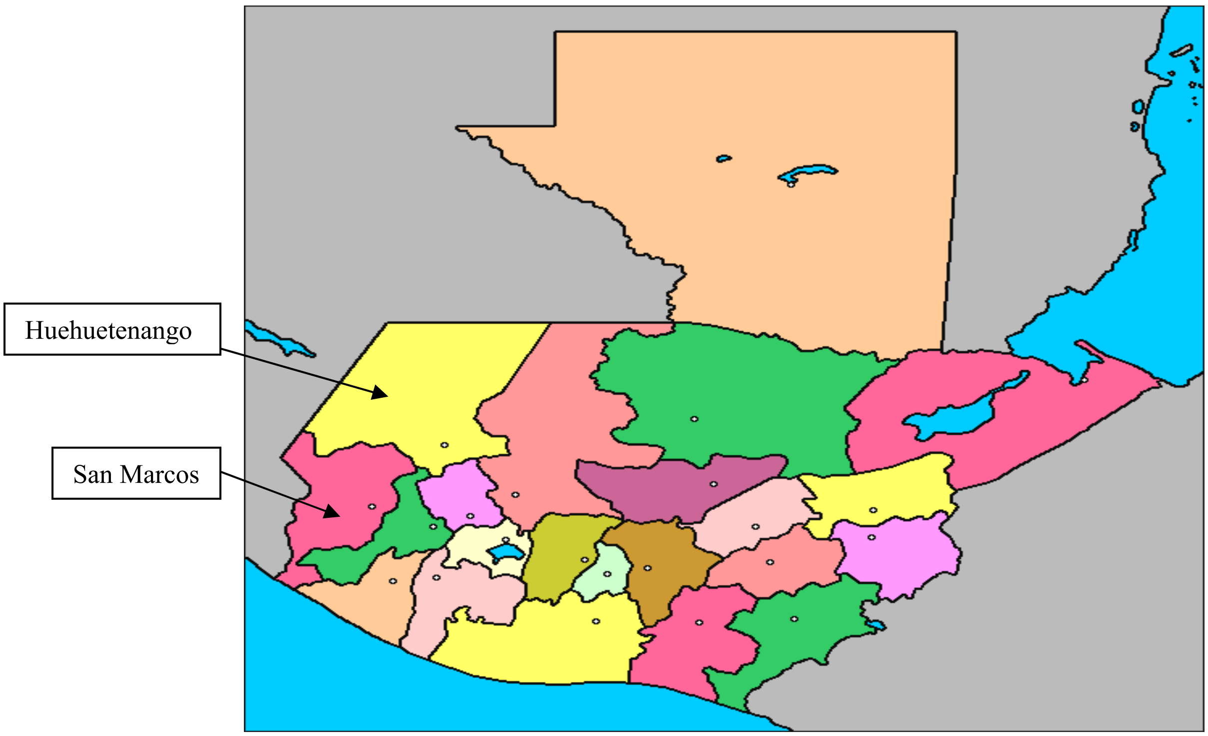

Figure 2.1 Location Map of Study Site in Guatemala

Honduras’s study was situated in the communities of Olancho, El Paraiso and Fco. Morazan. These farms are located approximately between 708 and 1537 meters above sea level. Olancho department is one of the 18 departments of Honduras. The eastern and northern part of the department is surrounded by mountains; the central part has plains that people sometimes call pampas (for its similarities to the Argentinean pampas). Its area is 24,351 square kilometers with an estimated population of 408,869

(Wikipedia, 2006c). El Paraíso department was formed in 1878 from part of Tegucigalpa Department; its capital is Yucatan, its area is 7218 square kilometers and it had an estimated population of 277,000 people in 1991 (Wikipedia, 2006d). Francisco Morazán department is located in the central part of the nation; its surface area is 7,946 square kilometers and it had an estimated population of 1,180,700 (2001) (Wikipedia, 2006e). Figure 2.2 shows Honduran departments of Olancho, El Paraíso and Francisco Morazán.

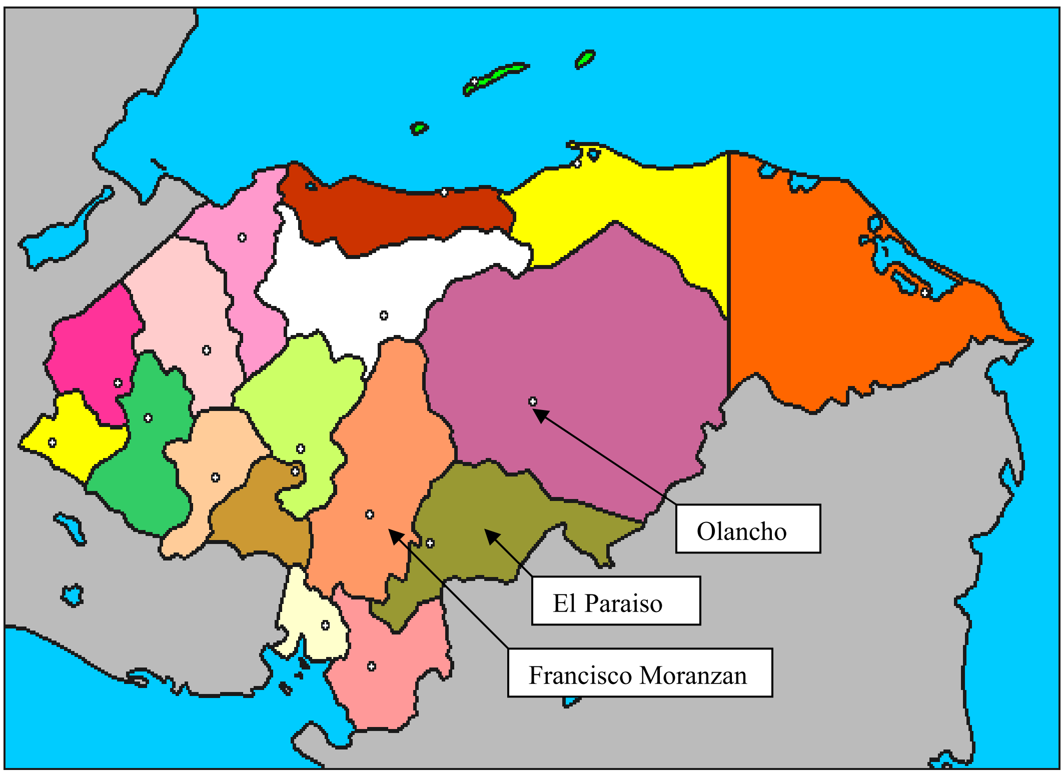

Figure 2.2 Location Map of the Study Side in Honduras

The Nicaragua survey took place in the communities of Matagalpa, Boaco and Segovia. The farms that participated in the study were located between 500-1450 meters above sea level. Boaco department was formed in 1938. It has an area of 4,244 square kilometers and a population of 168,600 (2005 census) (Wikipedia, 2006f). Segovia department covers an area of 3,123 square kilometers and has a population of 211,200 (2005 census) (Wikipedia, 2006g). Matagalpa department is located in central Nicaragua. It has an area of 8,523 square kilometers and a population of 484,900 (2005 census) (Wikipedia, 2006h). Figure 2.3 shows the Nicaraguan departments of Boaco, Segovia, and Matagalpa.

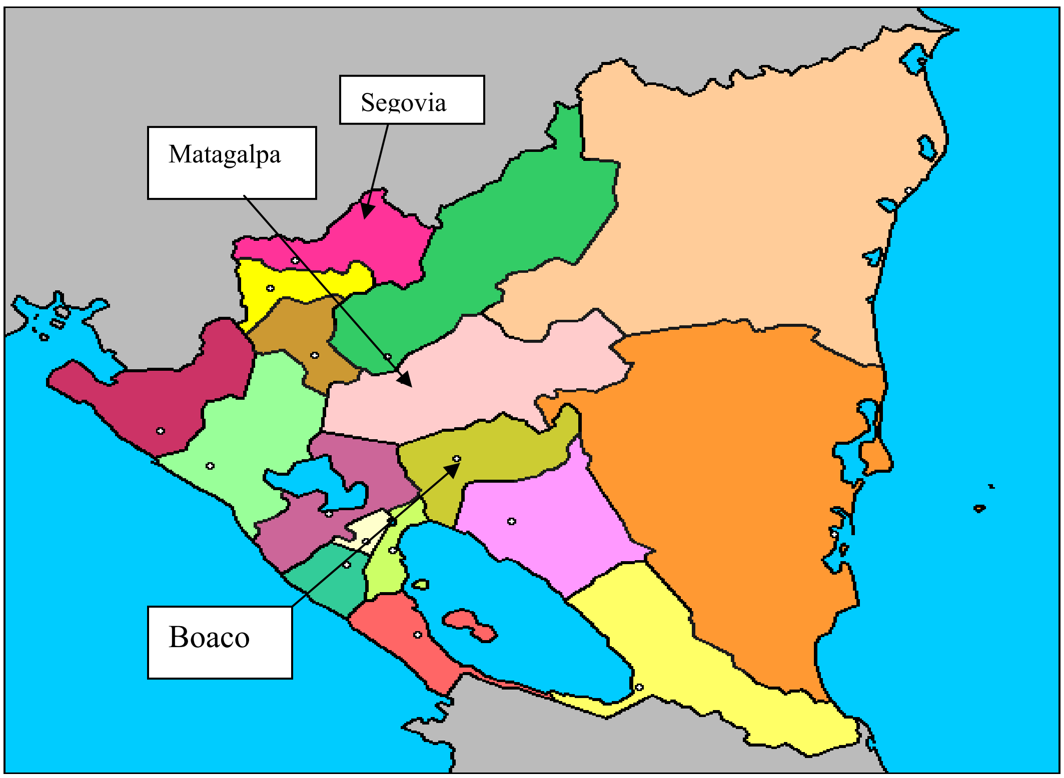

Figure 2.3 Location Map of Study Site in Nicaragua

Vietnam's farms that participated in the survey were located in Dak Lak District between 500-800 meters above sea level. Dak Lak district is located southeast of the Truon Son Mountains and it shares a 240 kilometer with Cambodia. Total area is 13,062 square kilometers; its population is around 1,667,000 (2004). The area is tropical, and has distinct dry and rainy seasons. Dak Lak has many lakes such as Ea, Eas No, and Eo Don (Sawadee, 2006). Figure 2.4 shows Dak Lak district and its surroundings.

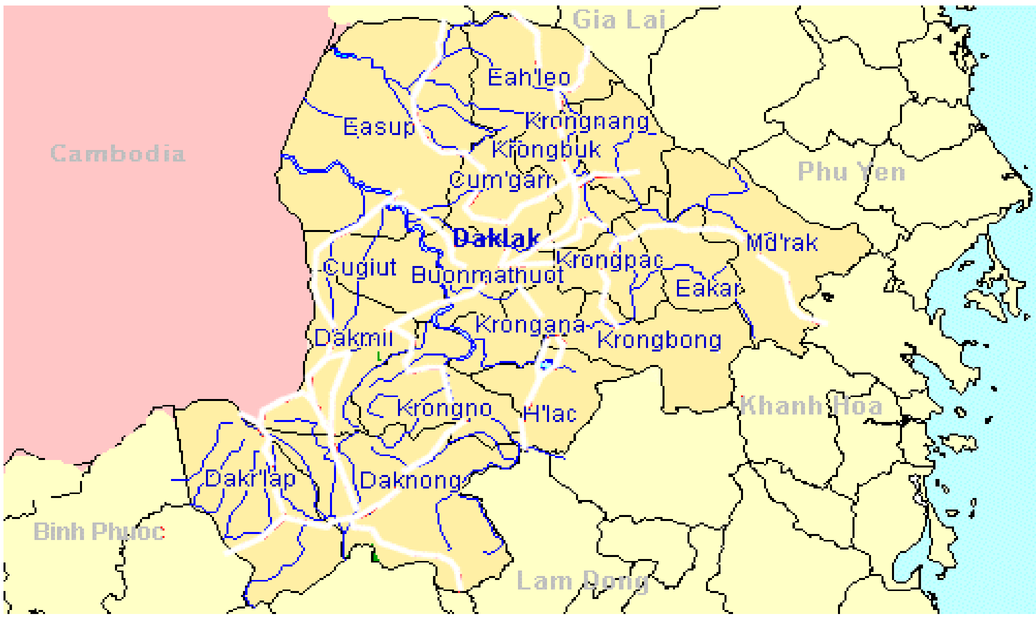

Figure 2.4 Location Map of Study Site in Vietnam

1.2.2 Coffee Varieties Planted in the Study Communities

A range of coffee varieties are grown in the study areas. In the Guatemala sample the varieties of Caturra, Bourbon and Catuai dominate production, with 73%, 66% and 20% of farmers planting the varieties, respectively. Other important varieties are Típica, Catimor, Pache, Robusta, Sarchi and Mundo Novo (41% of the sample farmers cultivated these varieties) (CATIE, ANACAFE, and the World Bank, 2005). Table 2.1 shows the varieties, number of farmers and percentage of farmers growing the above varieties of coffee (the total percentage is greater than 100% because some farmers plant more than one variety).

In the Honduras sample the varieties planted are Ihcafe 90, Catuai, Caturra, Pacas, Lempira, Bourbon, Indio, Villa Sarchi, and Apache. In the study 31% of the farmers cultivated Caturra, 19% cultivated Bourbon, 55% planted Catuai and 58% cultivated others (CATIE, IHCAFE, and the World Bank, 2005). Table 2.1 shows the varieties, number of farmers and percentage of farmers growing the above varieties of coffee.

In the Nicaragua sample the majority of coffee farmers grow Caturra variety (98% of the farmers). Bourbon is the second most important variety cultivated in the Segovias, Matagalpa y Boaco (37%). There were a total of 8 varieties of coffee cultivated by the farmers, including the ones mentioned above these are: Catuai, Paca, Catimor, Maracaturra, Arabica, Maragogipe (CATIE, CAFENICA, and the World Bank, 2005). Table 2.1 shows the varieties, number of farms and the percentage of farmers growing the above varieties of coffee in the Nicaraguan sample.

1.2.3 Descriptive Statistics

Descriptive statistics for the key variables used in this analysis are presented and compared in Table 2.2 In 2003, the average coffee yield in Vietnam study site was 2733 kgs per ha which differs from the average coffee yield[1] for Guatemala (970 kgs per ha), Honduras (627 kgs per ha) and Nicaragua (452 kgs per ha). Furthermore, the results show that the communities of Guatemala, Honduras, Nicaragua and Vietnam are very different

[1] In this study, reported yield in the case of Guatemala, Honduras and Nicaragua was converted from cherry coffee into parchment coffee (1qq parchment coffee = 25 latas of uva coffee)

in terms of average family size (6.68 in Guatemala), (5.97 in Honduras), (5.73 in Nicaragua), and Vietnam (2.33) with 95% confidence level. The average farm size indicates that mean for specific country is significantly different from mean for remaining countries with the exception of Nicaragua. The average farm size was 2.68 ha in Guatemala; 27.94 ha in Honduras, 7.80 ha in Nicaragua, and 1.49 in Vietnam. The average coffee area[2] was 1.7 ha, 7.15 ha, 3.04 ha, and 1.29 ha in Guatemala, Honduras, Nicaragua, and Vietnam respectively. These means are statistically different from each other. The data in Table 2.2 shows that for observed levels of farm inputs, a typical hectare of coffee in Guatemala uses on average about 105 workdays of labor, 4046 kg of organic fertilizer, 322 kg of chemical fertilizer and its average age of trees is 14.89 years. In the case of pesticide used, it was found that 12% of the farms in Guatemala used pesticides but unfortunately its dose was not registered in the survey. In Honduras a typical hectare of coffee uses, on average, about 131 workdays of labor, 1130 kg of organic fertilizer, 313 kg of chemical fertilizer, 1.07 kg of pesticide (19% of the farms), and its average age of three is 10.88 years. For Nicaragua a typical hectare of coffee uses, on average, 211 workdays of labor, 4967 kg of organic fertilizer, 9.7 kg of chemical fertilizer (6% of the farms), 7.32 kg of pesticide (54% of the farms), and its average age of tree is 15 years. The figures in Table 2.2 also show observed levels of farm inputs use of a typical hectare of coffee in Vietnam. On average, a hectare of coffee in the Vietnam sample uses about 223 workdays of labor, 191 kg of organic fertilizer, 2194 kg of chemical fertilizer, and 4.67 kg of pesticide. The average tree age is 12.59 years.

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[2] Farm size and coffee areas for Guatemala, Honduras and Nicaragua were reported in cuerdas and manzanas. For the purpose of this study these areas were converted into hectares. (1cuerda=450m^2, 1m^2= 0.0001 ha, 1 mz= 0.7 ha)

From the input used results we can conclude that the average number of workdays differs across countries. In terms of other inputs, such as organic fertilizer, the farms in Central America on average used organic fertilizer more than chemical fertilizer. We can attribute this to the fact that some farms in Central America produced organic coffee.

Table 2.1 Coffee Varieties in Guatemala, Honduras, and Nicaragua sample, area and percentage of total area planted, 2005.

Country	**Guatemala**		**Honduras**		**Nicaragua**	
Varieties	# farms	% farms	# farms	% farms	# farms	% farms
Caturra	30	73	14	39	51	98
Bourbon	27	66	7	19	19	37
Catuai	8	20	20	55	6	12
Other	17	41	21	58	26	50

Sources: CATIE, ANACAFE, and the World Bank, 2005; CATIE, IHCAFE, and the World Bank (2005); CATIE, CAFENICA and the World Bank, 2005.

Table 2.2 – Summary statistics of smallholder coffee production in Guatemala, Honduras, Nicaragua and Vietnam, 2003.

Variables	Guatemala		Honduras		Nicaragua		Vietnam		All	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Farm Size	2.69*	2.62	27.94*	42.28	7.80	8.02	1.50*	1.00	5.43	16.20
Family Members	6.68*	3.09	5.97*	2.69	5.73*	1.76	2.33*	1.31	3.77	2.62
Yield (kgs/ha)	896.16*	614.13	448.00*	302.58	524.41*	515.86	2733.71*	1244.38	1927.47	1456.16
area coffee (ha)	1.71*	1.39	7.15*	6.30	3.04*	2.52	1.29*	0.87	2.24	3.01
Labor (days/ha)	105.32*	71.80	130.86*	112.20	210.72	106.56	223.68*	65.77	197.44	90.93
Pesticide (l/ha)	0.00*	0.00	1.07*	2.14	7.32*	9.30	4.67*	5.01	2.89	4.54
age of trees (years)	14.89*	2.60	10.88*	5.81	15.04*	7.73	12.59	4.91	13.07	5.46
Org. Fertilizer (kg/ha)	4046.05*	4090.06	1129.81	2099.86	4967.25*	3782.73	191.15*	570.24	1493.52	2920.68
Ch. Fertilizer (kg/ha)	322.02*	348.62	313.34*	671.65	9.74*	47.87	2194.08*	1419.07	1430.63	1503.47
N	41		36		52		209		338	

note * indicates mean for specific country is significantly different from mean for remaining countries at 95% confidence level (two sample t-test with unequal variances).

CHAPTER III – METHODOLOGY

1.1 Overview

This chapter provides an overview of the method used to measure production efficiency and profitability of smallholder coffee farms. The approach uses a standard profit maximization framework to study how farms will organize activities to maximize profit. Empirical analysis of production relies on a series of statistical models including a Frontier Production function, which is used to measure technical efficiency of coffee production on smallholder farms in Guatemala, Honduras, Nicaragua and Vietnam. Technical efficiency scores are used in a subsequent econometric analysis to understand factors correlated with productive efficiency in the sample. In terms of Figure 1.4, the aim of this approach is to measure the relative distance of sample households from their production frontier, as well as factors correlated with those measures of relative inefficiency.

1.2 Previous Comparative Studies on Measuring Technical Efficiency

Yilma (1996) measured smallholder efficiency in Uganda coffee and food-crop production, using a production function and technical efficiency analysis of coffee and food-crop farming. The production function was estimated across a range of farm sizes (small, medium and large) using a Cobb-Douglas form. Yilma found that labor, tree age, insecticide, and acres of land under coffee had different impact on coffee production depending on farm size. A Cobb-Douglas production function was used to estimate a stochastic frontier production function for coffee and food crops.

Coelli and Fleming (2004) studied mixed food and coffee smallholder farming Systems in Papua New Guinea. In Papua New Guinea farming systems are characterized by an integrated set of cash cropping and subsistence food cropping activities, where the subsistence food crop sub-system is dominated by sweet potato production and coffee dominates the cash crop sub-system. Diversification of commercial agricultural production can influence productivity and efficiency of crop production in smallholders. In Coelli and Feming's study diversification economies were found between subsistence food production and the production of either coffee or cash food items. Diversification diseconomies were also found between coffee and cash food production, although the result was weak. The authors indicate existence of technical inefficiency, concluding that there may be opportunities to expand crop output without increasing factor inputs or improving production technologies.

Among those who have studied efficiency in other areas of agriculture are Aigner et al. (1977), Kalirajan (1990), Bravo-Ureta and Pinheiro (1997), Aguilar and Garcia (2002), and Coelli and Fleming (2004). Kalirajan (1990) applied a production frontier analysis to estimate firm-specific technical efficiency and input-specific allocative efficiency, using a trans-log technology to examine the effect of the functional form on the measurement of technical efficiency. Aguilar and Garcia (2002) applied a stochastic frontier analysis in other to measure technical efficiency in Cuban agriculture, using a Cobb-Douglas functional form.

Among those who have applied models for measuring technical inefficiency are Battese and Broca (1997) and Villano and Fleming (2005). In 1997, Battese and Broca prepared a comparative study for wheat farmers in Pakistan using functional forms of stochastic frontier production functions and models for technical inefficiency effects. That paper considered translog and Cobb-Douglas stochastic frontiers, where technical inefficiency effects were defined by three different models: the time-varying inefficiency model proposed by Battese and Coelli (1992), and the inefficiency effects model, proposed by Battese and Coelli (1995), and the non-neutral frontier model, proposed by Huang and Liu (1994). Villano and Fleming (2005) analyzed technical inefficiency at the farm level using a stochastic frontier production function with a heteroskedastic error structure in a 8 year panel dataset collected from 46 rainfed rice farmers.

1.3 Optimization and Stochastic Production Frontier Models

In order to estimate economically optimal inputs used in coffee production, it is necessary to formulate a production function and combine it with an objective function to identify optimal input levels with given input and output prices. This section describes the framework for analysis, which assumes profit maximization as the farmer's objective.[3]

[3] A profit maximization model is applied in this study. Alternative explanations for farmer objectives, such as risk-aversion or safety-first motivations, would lend to a different framework and a different interpretation of relative efficiency. In studies of smallholder food crop production, especially among subsistence farmers, such perspectives are likely to be important. In the current context, farmers have

I compare the profit-maximizing results to current average input levels observed among farmers in Guatemala, Honduras, Nicaragua and Vietnam.

The profit model uses the elasticity estimates for labor, fertilizer (organic and chemical), and pesticide inputs, derived from a production function, to estimate expected profit model given a set of input and output prices. Some assumptions that underlie this approach are that farmers perform as profit maximizers and farmers are assumed to be price takers in all input and output markets. Begin by assuming that farmers maximize total profit subject to area and capital constraints. Suppressing the individual farm index, the optimization problem can be expressed as:

(3.1) $Max\ \pi_i = p_i y_i - c_i$

$$s.t. \quad y_i = f(x)$$

$$c_i = \sum_{j=1}^{k} w_{ij}\ x_j$$

where i= country and j= inputs

In equation (3.1) π_i represents profits per hectare in country i, p_i represents the country specific unit price of output, and w_{ij} represents the country specific cost of input j. The production function is $y_i = f(x)$, where y_i represents yield per hectare as a function of a vector (x) of variable inputs in per hectare units (labor per hectare, chemical fertilizer per hectare, organic fertilizer per hectare, pesticide per hectare and tree age), and i represents

already made a decision to specialize (to a large category in must cases) in production of a commercial crop. For this reason, an assumption of profit maximization seems appropriate.

country (Guatemala, Honduras, Nicaragua and Vietnam). The optimality condition for profit maximization is:

$$(3.1.1)\quad \frac{\partial \pi_i}{\partial x_i} = p_i \frac{\partial y_i}{\partial x_i} - w_i = 0 \qquad or \qquad p_i \frac{\partial y_i}{\partial x_i} = w_i$$

Equation (3.1.1) implies that the marginal revenue associated with an additional unit of input (the left hand side) should equal the marginal cost of that input (the right hand side). The hypothesis that $y_i = y$ for all *i* is tested below.

To understand how coffee yield responds to levels of inputs, Cobb-Douglas, quadratic and frontier productions functions are estimated. Parameter estimates from the regressions are used to construct versions of the profit model. Observed input and output prices are used to solve for optimal input levels, yields and profits using unconstrained optimization.

1.4 The Production Function

A general production function that relates yield to inputs per hectare and a given technology is:

$$(3.2)\quad y_i = f(x)$$

where *x* is a vector of inputs and *i* = {Guatemala, Honduras, Nicaragua and Vietnam} represents country. Marginal physical product (*MPP*) is defined as:

$$(3.3)\quad \frac{\partial y_i}{\partial x_j} \geq 0 \qquad \forall_j$$

For all inputs this is expected to be positive, at least up to some maximum point.

This means adding more units of any input will increase output (or at least not reduce it). We also expect (but do not require):

(3.4) $$\frac{\partial^2 y}{\partial x_j^{\ 2}} < 0 \qquad \forall_j$$

Equation (3.4) refers to diminishing marginal productivity for the j^{th} factor. This means that, as we add more of a particular input, holding all other remaining factors constant, output expands but by a smaller amount than with previous units of input. These conditions ensure that the isoquants of a production function are negative in slope and convex to the origin.[4] The slope of the isoquant defines marginal rates of substitution (*MRS*) or rates of technical substitution (*RTS*) between inputs. The rate of substitution is determined by the negative ratio of marginal products between two inputs, that is,

(3.5) $$MRS_{jk} \text{ or } RTS_{jk} = -\frac{MP_j}{MP_k}$$

The marginal rate of substitution (*MRS*) indicates the rate at which one input can be substituted for another input, for example, substituting fertilizer for labor while leaving output unchanged.

Three standard forms are considered for the production function: the exponential Cobb-Douglas, Quadratic and frontier Cobb-Douglas.

Using country-specific dummy variables, and letting Nicaragua serve as the reference (intercept) country, the Cobb-Douglas form in this study is:

[4] An Isoquant defines all combinations of inputs that yield the producer the same level of output.

(3.6) $\ln(Y) = \beta_0 + \beta_1 \ln(L) + \beta_2 \ln(F) + \beta_3 \ln(O) + \beta_4 \ln(P) + \beta_5 \ln(T) + \gamma_1$ Guatemala + γ_2 Honduras + γ_3 Vietnam + ε

where Y = Yields (Kgs/ha)

L = Labor days used on the farm (Days/ha)

F = Chemical fertilizer quantity applied on the farm (Kgs/ha)

O = Organic fertilizer quantity applied on the farm (Kgs/ha)

P = Pesticide quantity applied on the farm (Kgs/ha)

T = Tree Age (years)

ε = An error term with an assumed exponential normal distribution

In equation (3.6) the productivity of labor, fertilizer, and pesticide are expressed by β_1, β_2, β_3, and β_4. The sum of these four coefficients represents returns to scale present in the data. A sum greater than one implies increasing returns to scale, a sum less than one implies diminishing returns to scale and a sum equal to one implies constant returns to scale. Cobb-Douglas isoquants imply (1) that inputs are not perfectly substitutable; (2) diminishing marginal rate of technical substitution and (3) that the input level for each factor must be greater than zero for any output to occur. One disadvantage of this form is that it implies one constant proportion of inputs at all level of outputs. It implies factor-neutral technology.

The Quadratic production function in this study is:

(3.7) $Y = \beta_0 + \beta_1 L + \beta_2 F + \beta_3 O + \beta_4 P + \beta_5 T + \beta_6 L^2 + \beta_6 F^2 + \beta_7 O^2 + \beta_8 P^2 + \beta_9 T^2 + \gamma_1$ Guatemala + γ_2 Honduras + γ_3 Vietnam + ε

where variables are defined as above.

Equation (3.7) differs from the Cobb-Douglas form, in that the isoclines in the Quadratic form allow variable proportions of inputs for different output levels. However this form has some disadvantages: it produces isoquants that are not asymptotic to the factor axes, implying possible output with some factor levels at zero. This form also imposes diminishing marginal product of factors at a constant rate.

The Frontier production function, assuming a Cobb-Douglas form is:

(3.8) $\ln(Y) = \beta_0 + \beta_1 \ln(L) + \beta_2 \ln(P) + \beta_3 \ln(T) + \beta_4 \ln(F) + \beta_5 \ln(O) + \gamma_1 \text{ Guatemala} + \gamma_2 \text{ Honduras} + \gamma_3 \text{ Vietnam} + \varepsilon$

where ε now differs from the OLS regression (equation 3.7) in that it presents the frontier error component, which is discussed below.

1.5 The Stochastic Frontier and the Inefficiency Models

The stochastic production frontier approach has been used to measure efficiency in different areas of agricultural economics. Using this approach, phenomena that are common in agriculture and can not be controlled such as pests, diseases and measurement errors in the variables can be separated from the technical efficient component. The inefficiency component can be controlled and is the measure of the underperformance of farms in relation to farms with high performance.

The stochastic production frontier model estimates frontiers which envelop the data (Kumbhakar and Knox Lovell, 2000). The first stochastic frontier production function was proposed by Aigner, Lovell and Schmidt (1977), and by Meeusen and van den Broeck (1977). The model can be expressed as:

(3.9) $y = f(x; B) * \exp[\varepsilon]$

For now, we suppress the country-specific subscript and use the subscript i to represent an individual farm-level observation.

If equation (3.9) takes a log-linear Cobb-Douglas form then the stochastic production frontier model can be written as:

(3.10) $\ln y_i = \beta_0 + \sum_i \beta n \ln xn_i + v_i + u_i$

where ln y is output, ln x is a vector of inputs and β is a vector of technology parameters. The error term is composed of two components $\varepsilon = v - u$, where $v \sim N(0, s^2)$ captures the effects of the statistical noise and the second error component $u \geq 0$ is intended to capture the effects of technical inefficiency. The v component represents things that can not be controlled by the farms like pests, insects and so on making the stochastic frontier allowing for variation across farms. The u component represents the effects that can be controlled by the manager. Thus the producer operates on or beneath stochastic production frontier according to whether $u = 0$ or $u > 0$. Meeusen and van den Broeck (1977) assigned an exponential distribution to u. Battese and Corra (1977) assigned a half-normal distribution to u and Aigner, Lovell, and Schmidt (1977) considered both distributions for u. This study uses the Normal Exponential Model by allowing u to follow an exponential distribution. The distributional assumptions that support the model are provided in Appendix A to this Chapter:

Investigating inefficiency is a two-stage procedure. The first stage uses the stochastic production frontier model to estimate the efficiency scores. In the second stage, the efficiency scores are regressed on a set of explanatory variables (Fried and Lovell, 1993). This approach can be traced to Timmer (1971) who used it in an attempt to explain variation in technical efficiency in U.S. agriculture.

The first stage (stochastic production frontier model) is characterized by:

(3.11) $y_i = f(x_i;\beta)\exp\{v_i + \mu_i\}$ $\qquad i = 1,\ldots, I$

The second stage is expressed as:

(3.12) $\exp\{u_i\} = g(z_i;\delta)\exp\{\varepsilon_i\}$ $\qquad i = 1,\ldots, I$

The technical inefficiency component, *u*, is assumed to follow an exponential distribution. Equation (3.12) represents the technical inefficiency model in the sample:

(3.13) $u_i = \delta_0 + \delta_1$ size + δ_2 treeAge + δ_3 organic + δ_4 chemical + δ_5 labor + δ_6 pesticide + δ_7 Guatemala + δ_8 Honduras + δ_9 Vietnam + ε

The inefficiency model decomposes the technical inefficiency term (*u*), into a set of observable characteristics, *z*, and unknown parameters, *δ*. In this study, characteristics hypothesized (*z*) to explain technical inefficiency include: size (the total size of the farm in hectares), treeage (in years), Organic fertilizer (kg per hectare), chemical fertilizer (kg per hectare), labor (the number of labor days per hectare), pesticide (kg per hectare), Guatemala, Honduras and Vietnam country dummies.

CHAPTER IV - RESULTS AND DISCUSSION

1.1 Overview

This chapter presents empirical results for the profit, technical efficiency, and inefficiency models. To begin, results from tests for the equality of coefficients of different regressions (pooled and country-specific) and heteroskedasticity are presented. This is followed by regression results for the production functions (Cobb-Douglas, Quadratic, and Frontier). Production parameters and technical efficiency scores are presented to explain patterns of inefficiency. Results for the farm-level optimization model based on production function estimates for a representative farm are also presented. A summary of the results is presented at the end of the chapter.

1.2 Test the Equality of Coefficients of Different Regressions

A basic test of the equality of coefficients from different regressions developed by Chow (1960) was used. This chow test is applicable when one is not sure whether a single model applies to two different data sets. To test whether a single regression model applies to different data sets, one tests the null hypothesis that the regression parameters are identical. Consider the following regression equations:

(4.1a) $Y_i = \beta_1 + \beta_2 X_{2i} + \ldots + \beta_k X_{ki} + \varepsilon_i$

(4.1b) $Y_j = \alpha_1 + \alpha_2 X_{2j} + \ldots + \alpha_k X_{kj} + \varepsilon_j$

Now assume that the null hypothesis is true (i.e. $\alpha_1 = \beta_1$, $\alpha_2 = \beta_2$, . . . , $\alpha_k = \beta_k$). Then the regression model can be written as a single equation.

(4.2) $Y_i = \beta_1 + \beta_2 X_{2i} + \ldots + \beta_k X_{ki} + \varepsilon_i$

Using ordinary least squares one calculates the restricted residual sum of squares ESS_R associated with model 4.2. If the null hypothesis is true, the restriction will not hurt the explanatory power of the model and ESS for a restricted model will not be much larger than for an unrestricted model. An F-test is used to see whether the residual sum squares were significantly different. The test statistic is:

(4.3) $$F_{k,\, N+M-2k} = \frac{(ESS_R - ESS_{UR})/k}{ESS_{UR}/(N+M-2k)} .$$

In the current context, ***N***, *M*, and *k* refer to the number of observations in the Central America sample (129), the number of observations in the Vietnam sample (209), and total number of restrictions (5). ESS_R is the restricted residual sum of squares obtained from the pooled regression, this residual sum of squares were calculated by regressing all data set at once using Vietnam and Central America countries. The ESS_{UR} are the unrestricted residual sum of squares obtained for region regressions (ESS_{CA}[5] + ESS_{VN}[6]). These residual sums of squares were obtained by performing 2 individual regressions (one for Central America countries and the other for Vietnam) and adding their individual residual sum of squares. Results gave us an F-statistic of 4.09.[7] Comparing it with the F-critical value of 2.21 (5% confidence level) we can reject the null hypothesis of equal coefficients. The Chow test result supports the use of separate regressions for Central

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[5] Residual sum of squares for Central America.
[6] Residual sum of squares for Vietnam.
[7] The test results are reported in Appendix B.

America countries (Guatemala, Honduras, and Nicaragua) and Vietnam. However, the optimization model results (reported later) support the use of the parameters derived from the pooled regression parameters. Further studies of optimization, technical efficiency and inefficiency models for Guatemala, Honduras, Nicaragua and Vietnam discussed in this chapter are based on pooled regression results. Results from the country-specific regressions are not discussed in this chapter but are reported in Appendix C.

1.3 Production Function Estimates

For the purpose of this study, yield is considered to be a function of labor input, tree age, and levels of pesticide, chemical fertilizer and organic fertilizer. Preliminary analysis (see chapter 2) indicates that there are yield differences across the countries. Therefore, countries are represented in the production function by dummy variables, allowing a shift in intercept (Nicaragua serves as the base).

Three standard forms are considered for the production function: the exponential Cobb-Douglas, the Quadratic and the Frontier Cobb-Douglas forms.

Using country dummy variables and letting Nicaragua serve as the reference (intercept) country, the per-hectare Cobb-Douglas production function is:

(4.1) $\ln(Y) = \beta_0 + \beta_1 \ln(L) + \beta_2 \ln(F) + \beta_3 \ln(O) + \beta_4 \ln(P) + \beta_5 \ln(T) + \gamma_1 \text{ Guatemala} + \gamma_2 \text{ Honduras} + \gamma_3 \text{ Vietnam} + \varepsilon$

where Y = Yield (Kgs/ha)

L = Labor days used on the farm (Days/ha)

F = Chemical fertilizer quantity applied on the farm (Kgs/ha)

O = Organic fertilizer quantity applied on the farm (Kgs/ha)

P = Pesticide quantity applied on the farm (Kgs/ha)

T = Tree Age (years)

ε = An error term with an assumed exponential normal distribution

The Quadratic production function is:

(4.2) $Y = \beta_0 + \beta_1 L + \beta_2 F + \beta_3 O + \beta_4 P + \beta_5 T + \beta_6 L^2 + \beta_6 F^2 + \beta_7 O^2 + \beta_8 P^2 + \beta_9 T^2 + \gamma_1$ Guatemala $+ \gamma_2$ Honduras $+ \gamma_3$ Vietnam $+ \varepsilon$

where variables are defined as above.

The frontier production functions, assuming a Cobb-Douglas form are:

(4.3) $\ln(Y) = \beta_0 + \beta_1 \ln(L) + \beta_2 \ln(P) + \beta_3 \ln(T) + \beta_4 \ln(F) + \beta_5 \ln(O) + \gamma_1$ Guatemala $+ \gamma_2$ Honduras $+ \gamma_3$ Vietnam $+ \varepsilon$

where $\varepsilon = \nu + \mu$; ν is the two-sided noise component, and μ is the technical inefficiency component.

Based on examination of parameters estimates, standard errors and goodness of fit measures it was decided that the Cobb-Douglas and the Frontier forms were more appropriate to these data than the Quadratic form. Most of the coefficients in the Quadratic form are not significantly different from zero and do not possess the expected signs.

1.4 Regression Results

Results from four different regression models for the production function are reported in Table 4.1. All are based on pooled regression data.[8] Model 1 is a Cobb-

[8] One might reasonably postulate that larger farms face different (lower) input prices than smaller farms, due to better access to credit or economics of scale in purchasing inputs. Similarly, large and small farms might use inputs differently. If so, regressions might exhibit heteroskedasticity related to farm size. To examine this conjecture, a Breusch-Pagan test (1979) for homoskedasticity was applied to the sample data using as explanatory variables ln(labor), ln(treeAge), ln(farmsize), ln(chemical) and ln(organic fertilizer) and country dummies (Guatemala, Honduras, and Vietnam). Based on the test we can reject the null hypothesis of homoskedasticity in the sample data. The F-test shows that the coefficients are jointly significant at 95% confidence level.

Douglas production function; Model 2 is a quadratic production function; Model 3 is a stochastic production frontier using a Cobb-Douglas functional form; and Model 4 is a stochastic production frontier corrected for heteroskedasticity. In terms of expected relationships and statistical power, Models 1, 3, and 4 gave the best results.

Models 1 and 2 are corrected for heteroskedasticity. This correction reduces the standard errors. In Model 1, all parameter estimates exhibit the expected signs with the exception of organic fertilizer which has a negative sign. With the exception of the parameter estimates for tree age and organic fertilizer, all coefficients are significantly different from zero at a 95% confidence level. The sign of organic fertilizer indicates that organic fertilizer use is negatively correlated with yield. This might point out omission of important variables in the equation or differences in soil or labor quality. Alternatively, it might just indicate that organic coffee provides lower yield.[9] Model 2 is presented in Table 4.1 for sake of completeness but not discussed because of its unsatisfactory results. Model 3 is estimated under the assumption of homoskedasticity.[10] Model 4 is the same as Model 3 but corrects for heteroskedasticity using farmsize. All parameter estimates in Model 4 have the expected signs. Labor, tree age, pesticide, chemical and organic fertilizer all are positively correlated with yield. In this case the negative coefficient on organic fertilizer reverses sign (although it remains statistically weak). With the exception of the parameters estimates for tree age and organic fertilizer, all coefficient are significant at the 95 percent confidence level.

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[9] We could not resolve this discrepancy in the regressions by using a dummy variable for each type of fertilizer (organic and chemical fertilizer). In the data set was not possible to separate farmers that use only chemical and organic fertilizer since we find farmers that use both inputs.

[10] This model was used later to estimate the technical efficiency scores in each country.

The elasticities using the Cobb-Douglas and the frontier forms (Models 1, 3, and 4) imply decreasing returns to scale. Return to scale is determined by adding the estimated coefficients of the input variables. For the Cobb-Douglas (Model 1), it is 0.49, and for the frontier forms (Models 3 and 4) it is 0.49 and 0.50. All models imply diminishing returns to increased use of all the inputs per hectare.

In Model 1, the elasticity of yield with respect to labor is 0.33. This means a 1% increase in the level of labor is associated with a 0.33% increase in yield. In addition, the contribution of pesticide to yield is 0.07, indicating that a 1% increase in the amount of pesticide is correlated with a 0.07% increase in yield. Furthermore, the contribution of chemical fertilizer to yield is 0.09. This means that a 1% increase in the amount of chemical fertilizer is correlated with a 0.09% increase in yield. These input elasticities show that yield is sensitive to changes in input levels for labor, pesticide, and chemical fertilizer. This suggests changes in input prices could affect yield by changing the incentives for input levels.

In Model 3, the elasticity of yield with respect to labor to yield is 0.34 which means that a 1% increase in the amount of labor is associated with a 0.34% increase in yield. Furthermore, the contribution of pesticide to yield is 0.06 saying that a 1% increase in the amount of pesticide is correlated with a 0.06% increase in yield. In addition, the contribution of chemical fertilizer to yield is 0.10 saying that a 1% increase in the amount of chemical fertilizer is correlated with a 0.10% increase in yield. These input elasticities show that yield is sensitive to changes in input levels, again suggesting that changes in input prices could affect yields.

In Model 4, the elasticity of yield with respect to labor is 0.34. This means that a 1% increase in the amount of labor is correlated with a 0.34% increase in yield. In addition, the contribution of pesticide to yield is 0.06 saying that a 1% increase in the amount of pesticide is associated with a 0.06% increase in yield. Furthermore, the contribution of chemical fertilizer to yield is 0.10 saying that a 1% increase in the amount of chemical fertilizer is correlated with a 0.10% increase in yield. These input elasticities show that yield is sensitive to changes in input levels.

The patterns reflected in the data are illustrated in figures 4.1, 4.2 and 4.3. These figures were obtained by using individual country regressions for each variable (organic fertilizer, chemical fertilizer, and tree age). The equations are in quadratic form with respective independent variable and yield as dependent variable. For instance, $y = \beta_0 + \beta_1(\text{tree age}) + \beta_2(\text{tree age})^2$. After running the regressions for each country and variable, the parameter estimates were used to generate predicted values in conjunction with the error term in the original equation in order to generate the graphs showing the relationship between each variable and yield. Figure 4.1 illustrates the relationship between organic fertilizer and yield in each country. This graph shows that in Guatemala, Honduras and Nicaragua organic fertilizer has almost no impact on coffee yield. Vietnam differs in that it shows that organic fertilizer has a positive correlation with coffee yield. Figure 4.2 shows the relationship between chemical fertilizer and yield in Guatemala, Honduras, Nicaragua and Vietnam. According to this graph chemical fertilizer has a positive correlation with coffee yield in all country samples, but the impact differs in each. Also, we illustrate the effect that age of trees has with respect to yield across countries. Figure 4.3 shows that coffee yield will increase with years until the trees reach their optimal production level, after which yield will start declining. Parikh (1979) demonstrated that a coffee tree reaches it optimal level of production of between 9 and 20 years, and declines until the age of 30. Using the first order condition for an interior solution it was possible to estimate for each country the age at which trees reached their optimal level of production. In the case of Guatemala the decline in coffee production occurs at the age of 19, in Honduras at the age of 13, in Nicaragua at the age of 14 and in Vietnam at the age 13. All of these peaks fall into the range reported by Parikh.

1.5 Technical Efficiency Scores

Farm level technical efficiency scores were calculated from Model 3 in order to identify factors associated with technical inefficiency. The percentage distribution per country for technical efficiency is presented in Figure 4.4 and the percentage distribution for all sample data is presented in Figure 4.5. The mean technical efficiency for all the sample data is 0.72, which implies that the production, on average, is about 28% below the frontier. This means that a considerable amount of output, on average, is being lost due to technical inefficiency, or, similarly, that for given levels of output, more inputs are being used than is necessary. The percentage distribution for technical efficiency for all sample data shows that there is a large variation in the level of technical efficiency. The technical efficiency estimates vary from a minimum of 8% to a maximum of 92%. The frequency distribution for the whole sample shows about 18% of the sample were operating below the mean and 82% above the mean. Only 35% of the sample farms were operating at the 90-100% level of efficiency.

The percentage distribution for individual countries technical efficiency (Figure 4.4) shows that, in the Guatemala sample, 24% of the farmers were operating below the mean of 72% (all sample mean), while the other 76% were operating above it. Going into more detail, 2% of the farmers were operating at 0-10% level of efficiency while other 2% were operating at 20-30% level of efficiency. The results further indicate that 15% were operating at 60-70% level of efficiency, 39% were operating at 70-80% level of efficiency, and 37% were operating at 80-90% level of efficiency.

In the Honduras sample, 39% were operating below the mean of 72% (all sample mean), while the other 61% were operating above it. Going into more detail, 6% of the farmers were operating at 10-20% level of efficiency, while other 3% of the sample was operating at 20-30% level of efficiency. Also, the results suggested that 11% of the farmers were operating at 40-50% level of efficiency and other 11% was operating at 60-70% level of efficiency, 36% were operating at 80-90% and only 3% were operating at 90-100% level of efficiency.

In the Nicaragua sample, 42% of the farmers were operating below the mean of 72% (all sample mean), while 58% were operating above it. Going into more detail, 2% of the farmers were operating at 10-20% level of efficiency, while other 8% of the farmers were operating at 30-40% level of efficiency. Furthermore, the results revealed that 13% of the farmers were operating at 50-60% level of efficiency, 11% were operating at 60-70% level of efficiency, 26% were operating at 70-80% and only 6% were operating at 90-100% level of efficiency.

In Vietnam, 30% of the farmers were operating below the mean of 72% (all sample mean), while 70% were operating above it. Furthermore, 47% of the farmers were operating at 40-50% level of efficiency, other 35% were operating at 70-80% level of efficiency and other 35% were operating at 80-90% level of efficiency.

These patterns reflect the inefficiency in the sample data. In terms of figure 1.4 they suggest farmers could have additional more output with the same inputs or could have maintained the same output with fewer inputs. The next section focuses on understanding the sources of these patterns of technical inefficiency.

1.6 The Inefficiency Model

The technical efficiency scores calculated from Models 3 and 4 were used to estimate technical inefficiency models reported in Table 4.2. Inefficiency Models 3A, 3B and 4A were obtained from Model 3, which is a simple stochastic production form. Inefficiency Model 4B was obtained from a stochastic production form corrected for heteroskedasticity using farm size. After estimating Models 3 and 4, the technical efficiency scores were saved for each individual farm and used the scores as a dependent variable in the technical inefficiency model. A general functional form is $u_i = z_i\delta$ (where z_i is a vector of values of observable variables and δ are unknown parameters to be estimated). Technical efficiency scores range from 0 to 1, therefore the OLS regression was not used, instead a Tobit model with Maximum Likelihood Estimation procedure was used to study the technical efficiency scores. Table 4.2 summarizes the results from Tobit regressions for the inefficiency models. This table reports results from four inefficiency models.

The parameters estimates for the inefficiency model provide an interesting insight regarding technical inefficiency in the sample. The first model (3A) includes only country dummies, the second model (3B) includes country dummies and farmsize, the third model (4A) includes country dummies, farmsize, inputs and treeage, and the fourth model (4B) is a modification of model (4A) that uses results from the stochastic production function that corrects for heteroskedasticity using farmsize.

The inefficiency models are summarized as follows:

(3.A) $u_i = \delta_0 + \delta_1$ Guatemala + δ_2 Honduras + δ_3 Vietnam + ε

(3.B) $u_i = \delta_0 + \delta_1$ farmsize + δ_2 Guatemala + δ_3 Honduras + δ_4 Vietnam + ε

(4.A) $u_i = \delta_0 + \delta_1$ farmsize + δ_2 treeAge + δ_3 organic + δ_4 chemical + δ_5 labor + δ_6 pesticide + δ_7 Guatemala + δ_8 Honduras + δ_9 Vietnam + ε

(4.B) $u_i = \delta_0 + \delta_1$ farmsize + δ_2 treeAge + δ_3 organic + δ_4 chemical + δ_5 labor + δ_6 pesticide + δ_7 Guatemala + δ_8 Honduras + δ_9 Vietnam + ε

Model 3A, the coefficient estimate for Vietnam is significantly different from zero, indicating that Vietnam, on average, is the most technically efficient country followed by Guatemala, Nicaragua, and Honduras.

Model 3B country dummies and farmsize were used as explanatory variables. The coefficient for farmsize was positive and significantly different from zero. This indicates that smaller farms tend to be less technically efficient than larger farms. One possible explanation is economies of scale; implying that as production increases, the cost per unit for each additional unit produced falls, and therefore larger farmers might be able to employ inputs at higher levels than smaller farms. The coefficient estimate for Vietnam was again significantly different from zero. Its magnitude suggests that Vietnam is the most technically efficient country followed by Guatemala, Nicaragua, and Honduras.

Model 4A, the coefficient for farmsize is positive and significantly different from zero. This indicates that, on average, larger farms again tend to be more technically efficient than smaller farms. The negative coefficient for labor indicates that, on average, the more farmers use labor to carry out farming activities the less technically efficient they are. However the coefficient of this variable is not significantly different from zero. The negative coefficient for organic fertilizer indicates that, on average, more organic fertilizer is associated with less technical efficiency. However the coefficient of this variable is not significantly different from zero. The positive coefficient for chemical fertilizer indicates that, on average, as use of this input increases, technical efficiency rises. This coefficient is significantly different from zero. The parameter estimates for pesticide, and country dummies (Guatemala, Honduras, and Vietnam) are not significantly different from zero in this model.

Model 4B the coefficient for farmsize is positive but not significantly different from zero, which differs from the above models. A possible explanation is that this specific inefficiency model is corrected for heteroskedasticy using farmsize. The coefficients for labor and organic fertilizer in model 4B are negative but not significantly different from zero. Furthermore, the positive coefficient for chemical fertilizer is significantly different from zero, indicating that, on average, the more used of this input, the more technically efficient farmers are. In addition, the coefficient for pesticide in the inefficiency model is positive but not significantly different from zero. Finally, the Guatemala, Honduras, Nicaragua and Vietnam coefficients are significantly different from zero, implying that Guatemala farmers on average are the most technically efficient in the sample, followed by Vietnam, Nicaragua, and Honduras.

The inefficiency models discussed above provide an interesting story. Models 3A and 3B gave almost the same results; the only difference between these two models is that the second model (3B) includes farm size as an explanatory variable. We found that in the simple models Vietnam is most technically efficient country, followed by Guatemala, Nicaragua and Honduras. However, Model 4B provides us with a different story. Model 4B uses a larger set of explanatory variables and corrects for heteroskedasticity using farm size. In this model, the parameter estimates for country indicate that Guatemala is the most technically efficient country followed by Vietnam, Nicaragua and Honduras. Even though, two of the models (3A and 3B) suggest that Vietnam is the most efficient country and model 4B suggests that Guatemala is the most efficient country, the most efficient farmer in the sample was found in Nicaragua and the least efficient was found in Guatemala.

1.7 Optimization of the Profit Function

The profit model provides a general idea about how the observed input levels used in the farm differ from the expected profit levels. In order to find profit maximizing levels of inputs, results from models 1 and 3 are used. The profit function can be estimated by:

(4.10) $\pi = P_0 * L^{\beta 2} F^{\beta 3} O^{\beta 4} P^{\beta 5} e^{\alpha} - w_l L - w_f F - w_o O - w_p P$

where $\alpha = \beta_0 + \beta_1$ Treeage $+ \gamma_1$ Guatemala $+ \gamma_2$ Honduras $+ \gamma_3$ Vietnam $+ \varepsilon$

The factor demand functions in terms of output price[11] (P_o) and factor prices[12] (w_l, w_f, w_o, and w_p) can be obtained by deriving the first order conditions from equation 4.10, and simultaneously solving these conditions for each factor *L*, *F*, *O* and *P* (labor, chemical fertilizer, organic fertilizer and pesticide). This maximization problem provides four factor demand equations (4.11, 4.12, 4.13 and 4.14). By substituting parameter estimates from the production functions, input prices and output prices, one can compute profit-maximizing levels of inputs, as well as optimal yields and profits.

$$(4.11)\quad L^* = \left[w_l (pe^{\alpha}\beta_l)^{-1} \left(\frac{\beta_p w_l}{\beta_l w_p}\right)^{-\beta_p} \left(\frac{\beta_f w_l}{\beta_l w_f}\right)^{-\beta_f} \left(\frac{\beta_o w_l}{\beta_l w_o}\right)^{-\beta_0} \right]^{\left(\frac{1}{\beta_l+\beta_f+\beta_o+\beta_p-1}\right)}$$

$$(4.12)\quad F^* = \frac{\beta_f w_l}{\beta_l w_f} \left[w_l (pe^{\alpha}\beta_l)^{-1} \left(\frac{\beta_p w_l}{\beta_l w_p}\right)^{-\beta_p} \left(\frac{\beta_f w_l}{\beta_l w_f}\right)^{-\beta_f} \left(\frac{\beta_o w_l}{\beta_l w_o}\right)^{-\beta_0} \right]^{\left(\frac{1}{\beta_l+\beta_f+\beta_o+\beta_p-1}\right)}$$

$$(4.13)\quad O^* = \frac{\beta_o w_l}{\beta_l w_o} \left[w_l (pe^{\alpha}\beta_l)^{-1} \left(\frac{\beta_p w_l}{\beta_l w_p}\right)^{-\beta_p} \left(\frac{\beta_f w_l}{\beta_l w_f}\right)^{-\beta_f} \left(\frac{\beta_o w_l}{\beta_l w_o}\right)^{-\beta_0} \right]^{\left(\frac{1}{\beta_l+\beta_f+\beta_o+\beta_p-1}\right)}$$

$$(4.14)\quad P^* = \frac{\beta_p w_l}{\beta_l w_p} \left[w_l (pe^{\alpha}\beta_l)^{-1} \left(\frac{\beta_p w_l}{\beta_l w_p}\right)^{-\beta_p} \left(\frac{\beta_f w_l}{\beta_l w_f}\right)^{-\beta_f} \left(\frac{\beta_o w_l}{\beta_l w_o}\right)^{-\beta_0} \right]^{\left(\frac{1}{\beta_l+\beta_f+\beta_o+\beta_p-1}\right)}$$

Tables 4.3, 4.4, 4.5, and 4.6 show the observed sample means and the profit maximizing levels of labor, chemical fertilizer, organic fertilizer, pesticide, yield, and profit for

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[11] Average price of coffee paid to the farmers in 2003.
[12] Average prices of inputs paid by the farmers in 2003. In the case of pesticide, a price relative to labor was estimated for all countries.

Guatemala, Honduras, Nicaragua and Vietnam. Table 4.3 reports the output and factor prices for each country. These are average observed prices per country in 2003.

The profit-maximizing results for Guatemala (Table 4.4) reveal that observed labor usage of 105 workdays/ha is extremely low compared to the profit maximizing level of 532 workdays/ha (Cobb-Douglas) and 1197 workdays/ha (frontier function).

With respect to chemical fertilizer used, farmers in the sample were applying below the profit maximizing levels. One reason might be that low coffee prices placed farmers under financial strain and possibly limited their ability to finance purchases. According to the Baranos, Paul, Daniel and Bryan (2003) the prices of coffee were reported low and below the cost of production for many producers in Central America.

The optimal level of organic fertilizer was found to be only 1 kg/ha, which may be due to the negative sign on its parameter estimate in the production function. Further analysis in order to explain the negative sign on organic fertilizer revealed that, on average, organic coffee yields are lower than conventional coffee yields. Another explanation for the negative sign on organic fertilizer might be labor efficiency. It is known that the farmers in Central America produce their own organic fertilizer, so they may not be using the formulations necessary to make it effective or the application form may not be the most appropriate one. This statement can be supported by the study made by ANACAFE, CATIE, and the World Bank (2003) where they mentioned the need for extension programs, fertilizer being one of the subjects requested by the farmers. In the case of pesticide usage, it was not possible to compare the observed level used since its dose was not collected in the study.

The observed yield of 896 kgs/ha for Guatemala is lower than the profit maximizing levels of 2460 kgs/ha (Cobb-Douglas) and 5421 kgs/ha (stochastic frontier). Observed profit of $1014/ha is lower than optimal of $2722/ha (Cobb-Douglas) and $5860/ha (stochastic frontier).

The profit maximizing results for Honduras (Table 4.5) reveal that observed labor usage of 131 workdays/ha is lower compared to the profit maximizing level of 201 workdays/ha (Cobb-Douglas) but extremely low compared to 801 workdays/ha (frontier function).

With respect to chemical fertilizer used, farmers in the sample were applying below the profit maximizing levels. One of the reasons might be that farmers in Guatemala use more organic fertilizer than chemical fertilizer, since many of these farms produce organic coffee. Another reason might be that low coffee prices placed farmers under financial strain and possibly limited their ability to finance purchases.

In the case of organic fertilizer the optimal levels of 1 kg/ha it is because of the negative sign of its parameter coefficient from the production function. Doing further investigations in order to explain the negative sign on organic fertilizer, it was found that on average organic coffee yields are lower than conventional coffee yields. Another explanation for the negative sign in organic fertilizer might be labor efficiency. It is known that the farmers in Central America produce their own organic fertilizer in their farms, so probably they are not using the formulations necessary to make it effective and also the application mode is not the most appropriate one. This statement is supported by the study conducted by IHCAFE, CATIE, and the World Bank (2003) where they mentioned the need for extension programs, fertilizer being one of the requested subjects for these farmers. In the case of pesticide used, the observed average level used of 1 kg/ha is very low compared to optimal of 11 kgs/ha (Cobb-Douglas) and 26 kgs/ha (frontier function).

The observed yield of 448 kgs/ha for Honduras is lower than the profit maximizing levels of 862 kgs/ha (Cobb-Douglas) and 3359 kgs/ha (stochastic frontier). Observed profit of $547/ha is much lower than optimal of $799/ha (Cobb-Douglas) and $3043/ha (stochastic frontier).

The profit-maximizing results for Nicaragua (Table 4.6) reveal that observed labor usage of 211 workdays/ha are above the profit maximizing level of 143 workdays/ha (Cobb-Douglas) but below 471 workdays/ha (frontier function).

With respect to chemical fertilizer, farmers in the sample were applying fertilizer below the profit-maximizing levels. One of the reasons might be that farmers in Nicaragua use more organic fertilizer than chemical fertilizer, since many of these farms produce organic coffee. Another reason might be that low coffee prices placed farmers under financial strain and possibly limited their ability to finance purchases.

In the case of organic fertilizer, the optimal levels of 1 kg/ha is because of the negative sign of its parameter in the production function. Doing further investigations in order to explain the negative sign on organic fertilizer, it was found that on an average organic coffee yields are lower than conventional coffee yields. Another explanation for the negative sign on organic fertilizer might be labor efficiency. It is known that the farmers in Central America produce their own organic fertilizer in their farms, so probably they may not be using the formulations necessary to make it effective and also the application mode is not be the most appropriate one. Similar results are reported by

CAFENICA, CATIE, and the World Bank (2003) where they mentioned the need for extension programs, fertilizer being one of the subjects requested by the farmers. In the case of pesticide usage, the observed average level of 7 kg/ha was lower compared to optimal of 11 kgs/ha (Cobb-Douglas) and 31 kgs/ha (frontier function).

The observed yield of 524 kgs/ha for Nicaragua is lower than the profit maximizing levels of 772 kgs/ha (Cobb-Douglas) and 2485 kgs/ha (stochastic frontier) therefore the observed profit of $134/ha is much lower than optimal of $431/ha (Cobb-Douglas and $1356/ha (stochastic frontier).

The profit-maximizing results for Vietnam (Table 4.7) reveal that observed labor usage of 224 workdays/ha is below the profit maximizing level of 442 workdays/ha (Cobb-Douglas) and 808 workdays/ha (frontier function).

With respect to chemical fertilizer usage, farmers in the sample were applying above the profit maximizing levels of 399 kgs/ha (Cobb-Douglas) and 820 kgs/ha (Frontier function). In the case of organic fertilizer, the optimal levels of 1 kg/ha it is because of the negative sign of its parameter in the production function. Doing further investigations in order to explain the negative sign on organic fertilizer, it was found that on an average organic coffee yields are lower than conventional coffee yields. It is important to mention that in Vietnam coffee is grown conventionally therefore farmers use less organic fertilizer. In the case of pesticide usage, the observed average level of 5 kgs/ha was lower compare to 54 kgs/ha (Cobb-Douglas) and 81 kgs/ha (Frontier function).

In addition, the observed yield of 2734 kgs/ha for Vietnam is lower than the profit maximizing levels of 3352 kgs/ha (Cobb-Douglas) and 6007 kgs/ha (stochastic frontier).

The observed profit was $1167/ha compare to optimal of $1047/ha (Cobb-Douglas) and $1834/ha (frontier).

Summary

This chapter presented results for a chow test, testing the equality of the coefficients of different regressions (pooled and country-specific) and tests for heteroskedasticity. This was followed by results for the Cobb-Douglas, the quadratic, and the stochastic production function. Profit and technical efficiency and inefficiency results were also presented.

The parameter estimates for the Cobb-Douglas functional form (Model 1) are positive for all variables, except for organic fertilizer. All parameter estimates except tree age, organic fertilizer and Honduras are significantly different from zero at the 95% confidence level. For the case of the stochastic production frontier (Model 3), the parameter estimates are positive for all variables except for organic fertilizer. All parameter coefficients except those for tree age, organic fertilizer and Honduras are significantly different from zero at 95% confidence level. In addition, for the other stochastic production frontier (Model 4), all the parameter estimates are positive and significantly different from zero at 95% confidence level, except for tree age, organic fertilizer and Honduras.

Technical efficiency scores indicate that the mean technical efficiency score for all the sample data is 0.72, which implies that the production, on average, is about 28% below the frontier. This means that a considerable amount of output, on average, was missed due to technical inefficiency or that inputs were not at their optimal levels. The percentage distribution for technical efficiency for all the sample data shows that there is a large variation in the level of technical efficiency. The technical efficiency estimates varied from 8%-92%. Results from the inefficiency model reports that small farm size was a reason for inefficiency in coffee production. This was resolved when it was corrected for heteroskedasticity using farm size. In addition, it was found that labor and organic fertilizer were factors for inefficiency, implying that, more used of this input the less technically efficient farmers are. However these variables were not significantly different from zero.

Results from the profit maximization model suggested that farmers in Guatemala, Honduras, Nicaragua and Vietnam were not operating at the optimal level, usually below the profit maximization levels, especially in the case of labor and pesticide. In addition, it was observed that farmers in Central America were applying organic fertilizer above the optimal levels and applying chemical fertilizer below the optimal levels. On the other hand, farmers in Vietnam were applying organic fertilizer below the optimal levels and applying chemical fertilizer above the optimal levels.

Table 4.1 Summary of the Regression Results for Coffee Yield

Models	Model 1	Model 2	Model 3	Model 4
Type of Regression	**Cobb Douglas**	**Quadratic**	**Frontier**	**Frontier**
Intercept	3.96* (8.46)	7.67 (0.02)	4.41* (11.10)	4.46* (11.19)
Labor (days/ha)	0.33* (4.03)	0.15 (0.07)	0.34* (5.33)	0.34 * (5.32)
Labor-Squared (days/ha)	---	0.00 (0.70)	---	---
TreeAge (years)	0.07 (0.85)	43.29 (1.00)	0.05 (0.70)	0.05 (0.69)
TreeAge-Squared (years)	---	-1.49 (-1.19)	---	---
Pesticide (kg/ha)	0.07* (1.97)	-7.59 (-0.31)	0.06* (2.02)	0.06* (1.94)
Pesticide-Squared (kg/ha)	---	1.01 (1.02)	---	---
Chemical (kg/ha)	0.09* (4.68)	0.45 (3.63)	0.09* (4.91)	0.09* (5.51)
Chemical-Squared (kg/ha)	---	-0.00 (-1.05)	---	---
Organic Fertilizer (kg/ha)	-0.00 (-0.46)	0.042 (0.93)	-0.00 (-0.11)	0.00 (0.36)
Organic-Squared (kg/ha)	---	-5.51e-06 (-1.55)	---	---
Guatemala	0.68* (4.36)	387.64 (2.47)	0.61* (4.28)	0.49* (3.35)
Honduras	0.04 (0.24)	-64.56 (-0.49)	0.08 (0.58)	0.13 (0.91)
Vietnam	1.18* (6.60)	1349.89 (7.16)	1.09* (7.26)	0.92* (5.80)
lnsig2u				
ln (farm size) (ha)	---	---	---	0.45 (3.09)
Constant	---	---	---	-2.28 (-6.85)
R-squared	0.72	0.61	---	---
F-statistic	89.00	61.00	---	---
Log-likelihood	---	---	-265.39	-260.18
N	338	338	338	338

Notes: * = Significant at 5% test level respectively, t-values are in parenthesis. Model 1 and 2 are corrected for heteroskedasticity using white standard errors. Model 4 corrected using farmsize.

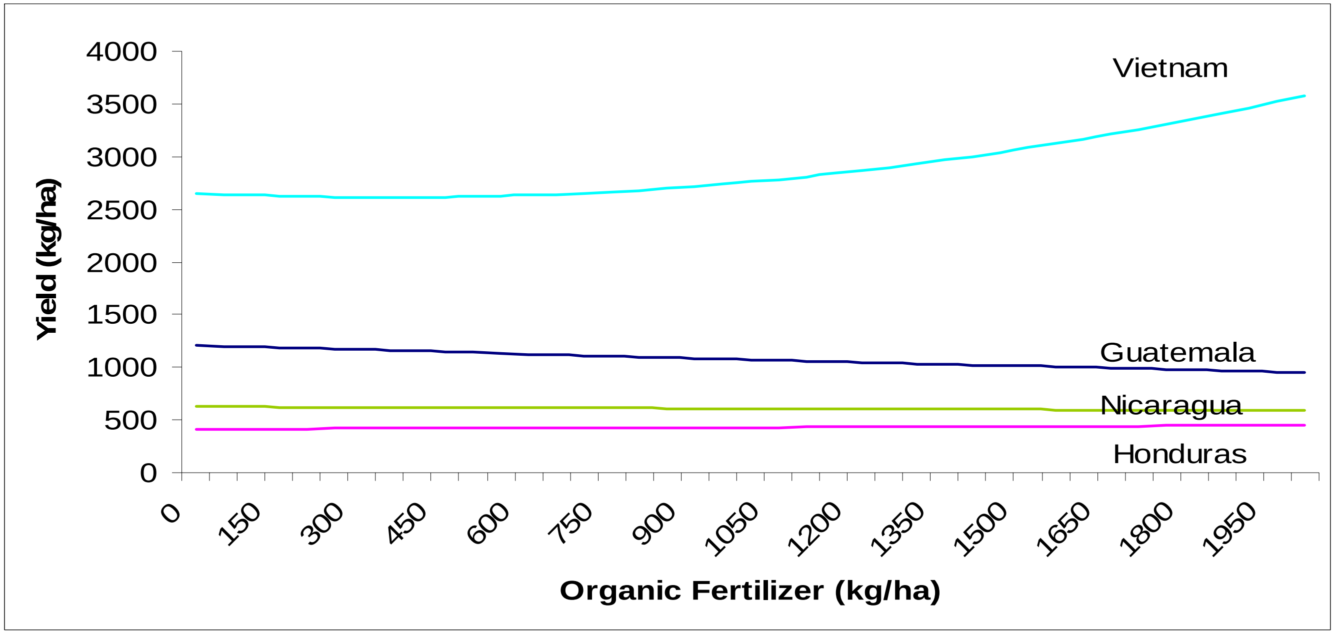

Figure 4.1 The Relationship between Organic Fertilizer and Yield, by Country

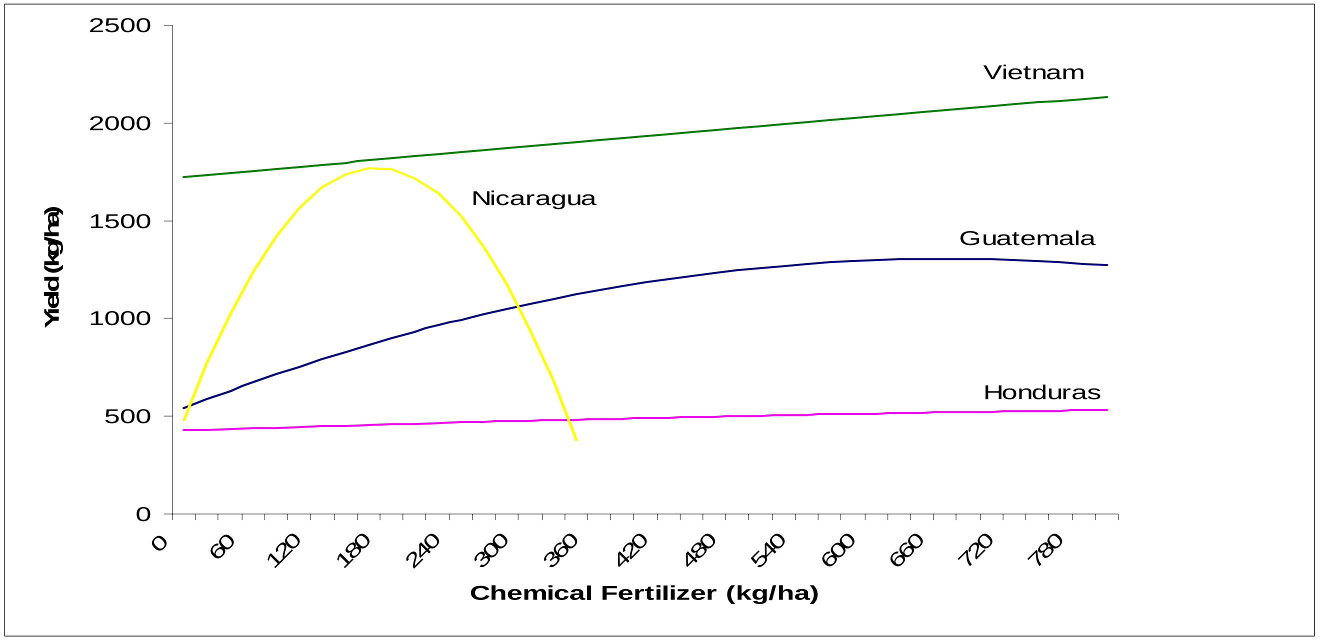

Figure 4.2 The Relationship between Chemical Fertilizer and Yield, by Country

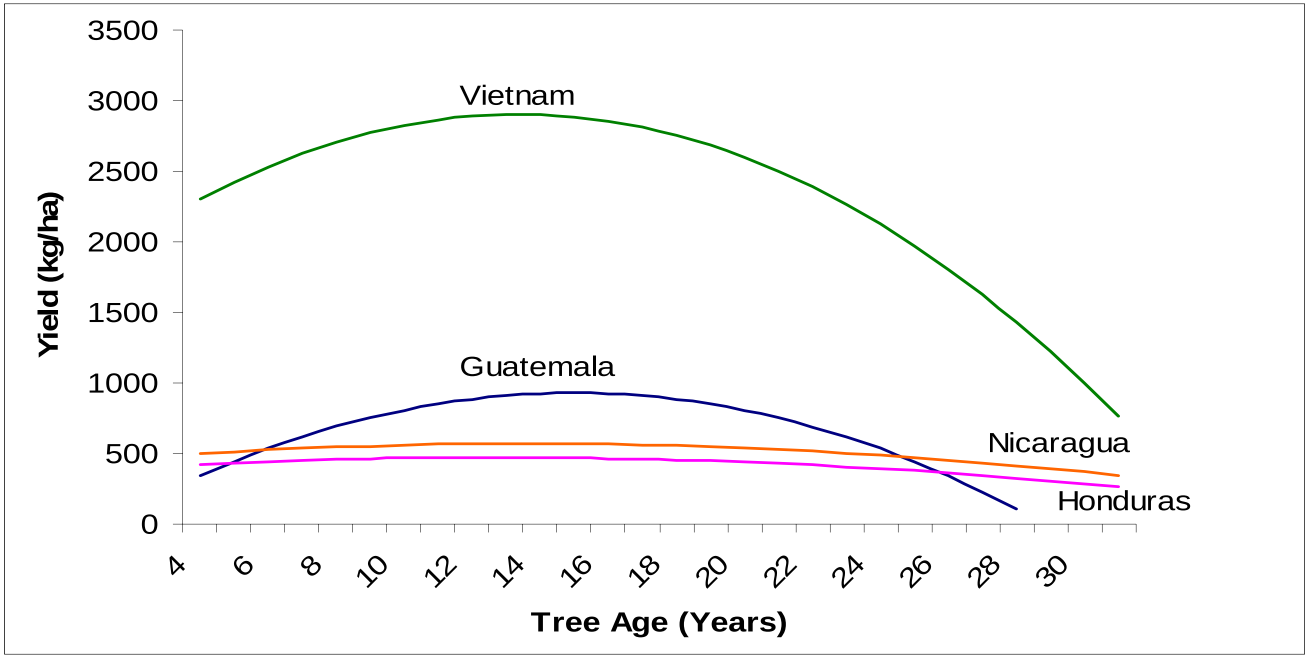

Figure 4.3 The Relationship between Tree Age and Yield, by Country

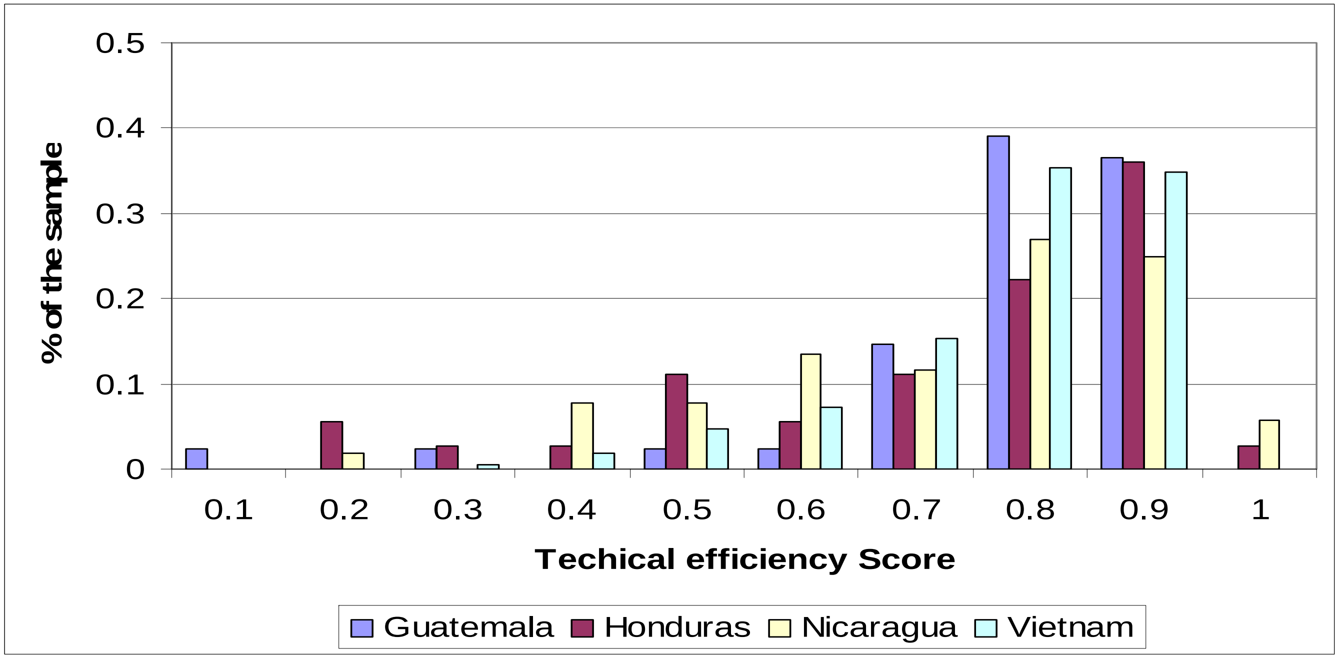

Figure 4.4 Percentage Distribution of Technical Efficiency Scores, by Country

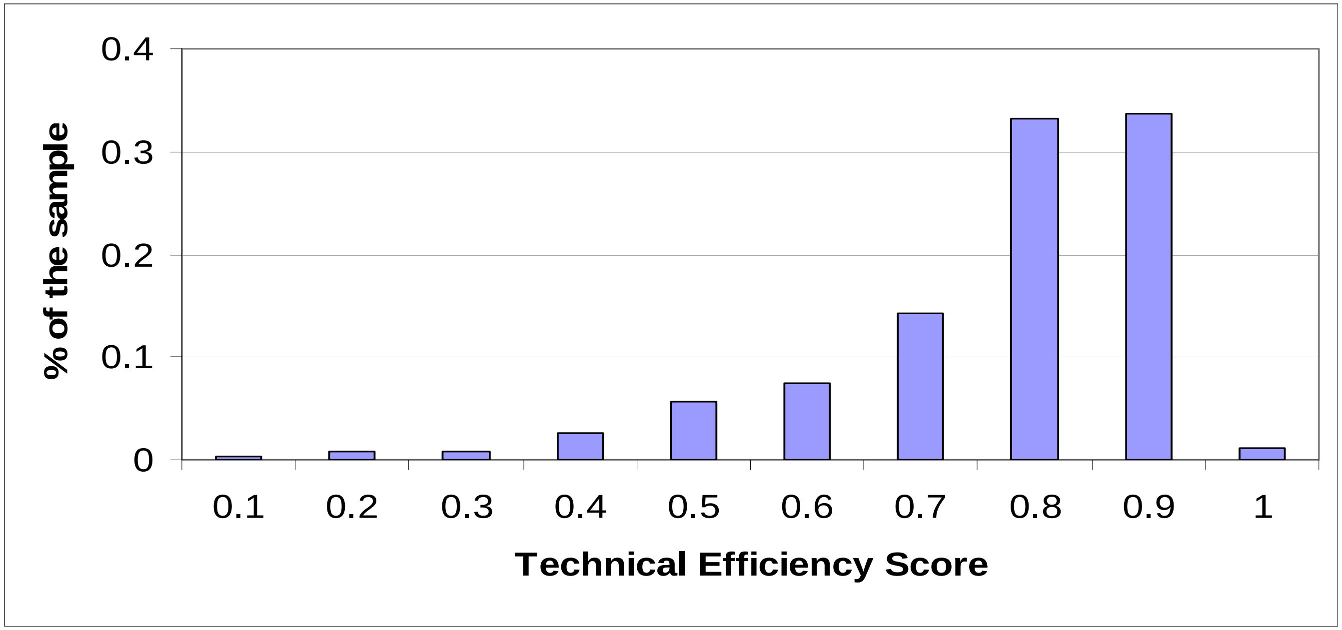

Figure 4.5 Percentage Distribution of Technical Efficiency Scores, All Sample Data

Table 4.2 Inefficiency Models

Type of Regression	**Model 3A**	**Model 3B**	**Model 4A**	**Model 4B**
Intercept	0.68 (32.92)	0.67 (31.95)	0.71 (17.01)	0.68 (16.20)
Guatemala	0.04 (1.41)	0.05 (1.56)	0.03 (0.95)	0.08 (2.23)
Honduras	-0.01 (-0.28)	-0.03 (-0.82)	-0.05 (-1.37)	-0.08 (-2.12)
Vietnam	0.05 (2.21)	0.06 (2.44)	-0.00 (-0.08)	0.06 (1.72)
Size (ha)	---	0.00 (1.64)	9.46e-04 (1.65)	8.23e-04 (1.42)
Labor (days/ha)	---	---	-9.41e-05 (-0.93)	-9.48e-05 (-0.92)
TreeAge (years)	---	---	1.37e-04 (0.09)	4.53e-05 (0.03)
Pesticide (kg/ha)	---	---	5.17e-04 (0.35)	5.59e-04 (0.38)
Chemical Fertilizer (kg/ha)	---	---	1.95e-05 (2.71)	1.6e-05 (2.19)
Organic Fertilizer (kg/ha)	---	---	-4.13e-06 -1.13	-4.92e-06 -1.32
Log-likelihood	159.51	160.84	165.84	161.64
N	338	338	338	338

Table 4.3 Coffee Output and Factor Prices

Prices ($)	**Guatemala**	**Honduras**	**Nicaragua**	**Vietnam**
Coffee ($/kg)	2.16	1.81	1.09	0.61
Labor ($/day)	3.30	2.56	1.94	1.53
Chemical Fertilizer ($/kg)	0.22	0.07	0.02	0.44
Organic Fertilizer ($/kg)	0.01	0.01	0.07	0.04
Pesticide ($/kg)	8.94	6.93	5.26	2.71

Note: All prices are observed prices per country, except pesticide prices which is a price relative to labor.

Table 4.4 Guatemala Profit Maximization Results

		Cobb Douglas	Frontier
	Observed	**Optimal**	**Optimal**
Labor (Days/ha)	105.32	532.24	1197.57
Chemical Fertilizer (Kgs/ha)	322.02	2076.55	5241.19
Organic Fertilizer (Kgs/ha)	4046.05	1.00	2761.25
Pesticide (Kgs/ha)	0.00	42.32	78.81
Yield (Kgs/ha)	896.16	2460.10	5420.55
Profit (Dollars/ha)	1014.31	2722.20	5860.13

Table 4.5 Honduras Profit Maximization Results

		Cobb Douglas	Frontier
	Observed	**Optimal**	**Optimal**
Labor (Days/ha)	130.86	201.45	801.68
Chemical Fertilizer (Kgs/ha)	313.34	2032.36	9072.72
Organic Fertilizer (Kgs/ha)	1129.81	1.00	2255.66
Pesticide (Kgs/ha)	1.07	16.03	52.80
Yield (Kgs/ha)	448.00	861.99	3359.29
Profit (Dollars/ha)	546.96	799.27	3043.23

Table 4.6 Nicaragua Profit Maximization Results

	Observed	Cobb Douglas Optimal	Frontier Optimal
Labor (Days/ha)	210.72	143.29	471.22
Chemical Fertilizer (Kgs/ha)	9.74	3443.06	1270.31
Organic Fertilizer (Kgs/ha)	4967.25	1.00	133.47
Pesticide (Kgs/ha)	7.32	11.38	30.99
Yield (Kgs/ha)	524.41	771.57	2484.77
Profit (Dollars/ha)	143.26	430.78	1355.57

Table 4.7 Vietnam Profit Maximization Results

	Observed	Cobb Douglas Optimal	Frontier Optimal
Labor (Days/ha)	223.68	441.64	808.45
Chemical Fertilizer (Kgs/ha)	2194.08	399.44	820.22
Organic Fertilizer (Kgs/ha)	191.15	1.00	302.49
Pesticide (Kgs/ha)	4.67	53.71	81.37
Yield (Kgs/ha)	2733.71	3351.29	6007.56
Profit (Dollars/ha)	919.83	1047.23	1834.16

CHAPTER V - CONCLUSIONS

1.1 Summary of the Results

During 1990s, there was an oversupply of coffee in the world market, which resulted in lower farmgate prices and shrinking farmers' incomes in coffee-growing countries. By studying and comparing the experiences of farmers in Guatemala, Honduras, Nicaragua and Vietnam this study has sought to identify mechanisms that might permit smallholder coffee farmers in these countries to optimize their use of inputs and maximize their net income.

The goal of this study was to provide information to help smallholder farmers in Guatemala, Honduras, Nicaragua and Vietnam allocate resources more wisely and increase their efficiency, especially technical efficiency. Data from 2003 coffee production from 338 smallholder farms in Guatemala, Honduras, Nicaragua and Vietnam were used in the analysis.

A basic review of the data shows that the average coffee yield in Vietnam (2733 kgs per ha) far exceeds the average coffee yield in Guatemala (970 kgs per ha), Honduras (627 kgs per ha) and Nicaragua (452 kgs per ha). These differences observed in coffee yield can be attributed to three factors (1) the types of coffee that is cultivated by Central American countries (primarily Arabica) and Vietnam (primarily Robusta); (2) organic vs. conventional production; and (3) differences in input use and tree age. Some farmers in Central America cultivate "special coffee" (high quality for both conventional and organic Arabica coffee), which help them to overcome lower coffee prices by obtaining on an average higher return. On the other hand, Vietnamese farmers produce conventional Robusta coffee, which on average appears to have higher yields but lower coffee price. From the data set, observed average profits in Guatemala ($1014/ha) were higher than profits in Honduras ($546/ha), in Nicaragua ($143/ha) and Vietnam ($920/ha). The main explanation for differences in outcomes explored in this thesis is technical inefficiency among farmers. It is interesting to note that findings from previous studies conducted in Guatemala, Honduras, and Nicaragua, by CATIE, ANACAFE, IHCAFE, CAFENICA and the World Bank suggest the need for extension programs in order to help farmers improve production efficiency. Farmers themselves have requested information on application and formulations of fertilizer, pests and disease, shading, trimming, harvest, and commercialization. Thus, it would appear that many farmers recognize the inefficiencies that have been confirmed and measured in this study.

Results from the production functions reported in chapter 4 suggest that all inputs contribute positively to yield, with the exception of organic fertilizer. In addition, all models imply diminishing returns to increase use of all the inputs per hectare. The computed return to scale is approximately 0.50, indicating sharply falling returns to scale. Results from inefficiency analysis suggest that Guatemalan farmers were, on average, the most technically efficient in the sample, followed by Vietnamese, Nicaraguan, and Honduran farmers. Also it was found that larger farms were more technically efficient and that organic fertilizer and labor usage reduced relative technical efficiency. Comparing countries using technical efficiency scores, it was found that 24% of the

Guatemalan farmers, 39% of the Honduran farmers, 42% of the Nicaraguan farmers, and 30% of the Vietnamese farmers were operating below the mean of 72% efficiency.

Results from the profit maximization model suggest that farmers in Guatemala, Honduras, Nicaragua and Vietnam were not behaving optimally, typically applying inputs at below the levels according to profit maximization rules, especially in the case of pesticide. In addition, it was observed that farmers in Central America were applying organic fertilizer above the optimal levels and applying chemical fertilizer below the optimal levels. It was also observed that farmers in Vietnam were applying organic fertilizer below the optimal levels and applying chemical fertilizer above the optimal levels. A partial explanation for these patterns might be that farmers in Central America are growing organic Arabica coffee and therefore the use of organic fertilizer is more popular than the use of chemical fertilizer. The results definitely accord with studies made by ANACAFE, IHCAFE, CAFENICA, and the World Bank about the need for technical assistance in order to help farmers understand the formulation and application of inputs in order to be more efficient.

1.2 Limitations

One of the limitations faced at the beginning of the research was finding data for coffee producers in Latin America. Once we obtained the data, another limitation emerged with respect to the interpretation of the data. In some cases, it was hard to read and to understand the meaning of some variables and its units, since in many cases the collectors used abbreviations for their own purposes. Thanks to substantial help and interaction with the data collectors it was possible to complete this study. Another limitation was to be able to find the same sets of information and variables across the countries. Due to gaps in some samples, some important variables such as education, credit, and so on were not included in this study. Also, another difficulty was to obtain more detailed information on production of Arabica and Robusta coffee. Central American farmers mainly produced Arabica coffee (organic and conventional) and Vietnamese farmers primarily produced Robusta coffee (conventional). In order to conduct a more accurate comparison of production outcomes, information on Arabica and Robusta coffee produced by both Central American and Vietnamese farmers would have been required. Also, separate information on organic and conventional coffee production in each country and for each variety would have facilitated a more detailed investigation of production efficiency.

1.3 Implications and Further Research

The results from this study could help provide farmers and those who work with them with information on important factors determining efficiency and profitability in coffee production. Important findings can be taken from this study and can assist extension programs and policy makers to effectively meet the needs of farmers in order to design programs and seminars in a way that it will be more helpful to farmers.

Recalling Figure 1.4, an inefficient farmer can improve profits by moving to the production frontier in one of two ways: (1) using the same level of inputs but increasing output, by moving from point 1 to point 2, or (2) reducing the level of inputs and producing the same level of output, i.e. moving from point 1 to point 3. From a policy perspective, keeping producer coffee prices high is a priority. Therefore, policy makers should concentrate on policies that increase the level of technical efficiency of farmers and at the same time do not generate an over-supply of coffee. These policies should encourage farmers to improve the allocation of inputs, producing the same output and moving toward the production frontier.

One area of interest for future research will be to study in more detail some of the findings in this study, for example the negative contribution of organic fertilizer to yield. This finding might suggest that some other important variables are omitted in the production equation, such as differences in soil among farms, labor quality, etc. Including such other variables in the model will be interesting and might also help to explain efficiency patterns.

Another area of interest for further research will be to construct panel data. With this information we will be able to compare coffee production results for several years taking into account favorable or poor environmental conditions for a specific year. We will be able to find out whether the year 2003 was just a good a year (weather-wise) for Vietnam and Guatemala, but a bad year for Honduras and Nicaragua.

Another important subject for further research will be to obtain more detailed information for Robusta, Arabica, organic and conventional coffee (prices, inputs, yield, etc.) in the countries of interest. With this information, one could learn whether differences in coffee yield among these countries are caused by the variety of coffee (Robusta and Arabica) or because there are differences in technical efficiency among Vietnam and Central America farmers. This will allow one to make a more comparable study between Robusta and Arabica coffee.

Future analysis might also aim to use different methods to study efficiency. For example, non-parametric analysis could be employed. This would help us compare results from different approaches and see how the results differ from one method to another. In addition, with better data on input and output prices one could undertake an allocative efficiency study to measure efficiency in terms of cost minimization, revenue maximization and profit maximization.

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Appendix A

Assumptions for the Composed Error with an Exponential Distribution

Following Meeusen and van den Broeck (1977) approach, the assumptions for the composed error with an exponential distribution in the stochastic frontier production function are the following:

(i) $v_i \sim$ i.i.d. $N(0, \sigma^2_v)$

(ii) $\mu_i \sim$ i.i.d. exponential

(iii) μ_i and v_i are distributed independently of each other, and of the regressors.

The exponential distribution has one parameter, σ_μ, where $\mu_i \geq 0$ follow an exponential distribution and its density is given by:

$$f(\mu) = \frac{1}{\sigma_\mu} \exp\left\{-\frac{\mu}{2\sigma_\mu}\right\}.$$

It is assumed that v follow a normal distribution. Its density is given by:

$$f(v) = \frac{1}{\sqrt{2\pi\sigma_v}} \exp\left\{-\frac{v^2}{2\sigma^2_v}\right\}.$$

The joint density functions of μ and v is the product of their individual density function given by the independence assumption:

$$f(\mu, v) = \frac{1}{\sqrt{2\pi\sigma_v\sigma_\mu}} \exp\left\{-\frac{\mu}{\sigma_\mu} - \frac{v^2}{2\sigma^2_v}\right\}.$$

Because $\varepsilon = v - \mu$, the joint density function of μ and ε is

$$f(\mu,\varepsilon)=\frac{1}{\sqrt{2\pi\sigma_{v}\sigma_{\mu}}}\exp\left\{-\frac{\mu}{\sigma_{\mu}}-\frac{(\varepsilon+\mu)^{2}}{2\sigma_{v}^{2}}\right\} .$$

The marginal density of ε is obtained by integrating μ out of $f(\mu,\varepsilon)$:

$$f(\varepsilon)=\int_{0}^{\infty}f(\mu,\varepsilon)d\mu=\frac{2}{\sigma}\phi\left(\frac{\varepsilon}{\sigma}\right)\Phi\left(-\frac{\varepsilon\lambda}{\sigma}\right) .$$

Appendix B

Chow Test

This Appendix presents the Chow test results where *N*, *M*, and *k* are the number of observations for Central America, number of observations for Vietnam and number of restrictions in the model, respectively. The ESS_R is the restricted residual sum of squares obtained from the pooled regression analysis and the ESS_{UR} are the unrestricted residual sum of squares obtained for country-specific regression analysis.

The Chow test is:

ESS_{UR} = ESS1 + ESS2 = 57.4096802 + 38.9909241 = 96.40

N – M – 2k = 209 + 129 – 2 (5) = 328

ESS_R = 102.4229

$$\text{F-statistic} = \frac{(102.4229 - 96.40)/5}{(96.40/328)} = \frac{1.20458}{0.2939} = 4.09$$

F-critical= 2.21 at 5%

Because F-statistic is greater than the F-critical, we can reject the null hypothesis of equal coefficients.

Appendix C

Table C.1 Summary of the Regression Results (Central America) Coffee Yield

Type of Regression	Cobb Douglas	Quadratic	Frontier (Cobb Douglas)	Frontier (Cobb Douglas)
Intercept	3.49 (5.05)	210.04 (0.77)	3.72 (6.25)	3.66 (6.13)
Labor (days/ha)	0.44 (3.89)	1.14 (0.66)	0.49 (4.99)	0.50 (5.08)
Labor-Squared (days/ha)	---	0.00 (0.54)	---	---
TreeAge (years)	0.12 (0.80)	2.66 (0.11)	0.09 (0.72)	0.09 (0.76)
TreeAge-Squared (years)	---	-0.14 (-0.20)	---	---
Pesticide (kg/ha)	0.12 (1.87)	16.17 (0.88)	0.14 (2.26)	0.13 (2.18)
Pesticide-Squared (kg/ha)	---	-0.07 (0.08)	---	---
Chemical (kg/ha)	0.02 (1.17)	0.47 (1.93)	0.02 (0.66)	0.02 (0.88)
Chemical-Squared (kg/ha)	---	-0.00 (-2.29)	---	---
Organic Fertilizer (kg/ha)	-0.04 (-2.88)	-0.03 (1.02)	-0.04 (-2.45)	-0.04 (-2.34)
Organic-Squared (kg/ha)	---	-5.32e-07 (-0.22)	---	---
Guatemala	0.92 (5.49)	554.31 (4.80)	0.96 (5.26)	0.91 (4.87)
Honduras	0.17 (0.95)	8.86 (0.10)	0.26 (1.56)	2.29 (1.71)
lnsig2u				
Lnsize	---	---	---	0.23 (1.07)
Const	---	---	---	-1.83 (-3.36)
R-squared	0.33	0.61	---	---
F-statistic	10.08	61.00	---	---
Log-likelihood	---	---	-124.82	-124.23
N	129	129	129	129

Note: Standard Errors are in parenthesis

Table C.2 Summary of the Regression Results (Vietnam) Coffee Yield

Type of Regression	**Cobb Douglas**	**Quadratic**	**Frontier (Cobb Douglas)**	**Frontier (Cobb Douglas)**
Intercept	5.25 (8.81)	242.67 (0.34)	5.86 (10.23)	5.84 (10.12)
Labor (days/ha)	0.21 (2.30)	5.67 (1.10)	0.17 (1.94)	0.17 (1.93)
Labor-Squared (days/ha)	---	-0.01 (-0.83)		---
TreeAge (years)	0.01 (0.14)	128.13 (1.44)	0.00 (0.02)	-0.00 (-0.00)
TreeAge-Squared (years)	---	-4.64 (-1.54)		---
Pesticide (kg/ha)	0.02 (0.50)	-23.83 (-0.59)	0.02 (0.52)	0.02 (0.45)
Pesticide-Squared (kg/ha)	---	2.13 (1.30)		---
Chemical (kg/ha)	0.18 (4.62)	0.53 (4.03)	0.17 (6.76)	0.17 (6.81)
Chemical-Squared (kg/ha)	---	-0.00 (-2.12)		---
Organic Fertilizer (kg/ha)	0.02 (1.78)	-0.37 (-1.27)	0.02 (1.46)	0.02 (1.43)
Organic-Squared (kg/ha)	---	0.00 (2.68)		---
lnsig2u				
Lnsize	---	---	---	-0.26 (-0.85)
Const	---	---	---	-2.48 (-5.67)
R-squared	0.23	0.27	---	---
F-statistic	8.18	10.12	---	---
Log-likelihood	---	---	-118.48	-118.10
N	209	209	209	209

Note: Standard Errors are in parenthesis

Table C.3 Profit from Country-Specific Regressions

	Observed	Cobb Douglas	Frontier
Guatemala	1014	6542	37629
Honduras	547	980	6072
Nicaragua	143	327	1202
Vietnam	920	781	1231

Table C.4 Profit Maximization Results for Guatemala (Separate Regressions)

		Cobb Douglas	Frontier
	Observed	Optimal	Optimal
Labor (Days/ha)	105.32	2071.21	16114.56
Chemical Fertilizer (Kgs/ha)	322.02	1699.36	10886.18
Organic Fertilizer (Kgs/ha)	4046.05	1.00	1.00
Pesticide (Kgs/ha)	0.00	217.48	1589.86
Yield (Kgs/ha)	896.16	7266.00	49729.11
Profit (Dollars/ha)	1014.31	6541.71	37628.50

Table C.5 Profit Maximization Results for Honduras (Separate Regressions)

		Cobb Douglas	Frontier
	Observed	**Optimal**	**Optimal**
Labor (Days/ha)	130.86	399.99	3352.07
Chemical Fertilizer (Kgs/ha)	313.34	848.63	5855.76
Organic Fertilizer (Kgs/ha)	1129.81	1.00	1.00
Pesticide (Kgs/ha)	1.07	42.03	330.96
Yield (Kgs/ha)	448.00	1299.05	9576.49
Profit (Dollars/ha)	546.95	980.02	6072.07

Table C.6 Profit Maximization Results for Nicaragua (Separate Regressions)

		Cobb Douglas	Frontier
	Observed	**Optimal**	**Optimal**
Labor (Days/ha)	210.72	176.03	875.33
Chemical Fertilizer (Kgs/ha)	9.74	889.50	3641.86
Organic Fertilizer (Kgs/ha)	4967.25	1.00	1.00
Pesticide (Kgs/ha)	7.32	18.47	86.29
Yield (Kgs/ha)	524.41	719.43	3146.85
Profit (Dollars/ha)	143.26	326.78	1201.52

Table C.7 Profit Maximization Results for Vietnam (Separate Regressions)

		Cobb Douglas	**Frontier**
	Observed	**Optimal**	**Optimal**
Labor (Days/ha)	223.68	189.98	225.53
Chemical Fertilizer (Kgs/ha)	2194.08	568.16	775.69
Organic Fertilizer (Kgs/ha)	191.15	698.87	850.42
Pesticide (Kgs/ha)	4.67	9.55	10.99
Yield (Kgs/ha)	2733.71	2255.62	3247.99
Profit (Dollars/ha)	919.83	781.44	1231.08