Courant Research Centre
'Poverty, Equity and Growth in Developing and Transition Countries: Statistical Methods and Empirical Analysis'

Georg-August-Universität Göttingen
(founded in 1737)

Discussion Papers

No. 13

Productive efficiency of specialty and conventional coffee farmers in Costa Rica: Accounting for technological heterogeneity and self-selection

Meike Wollni, Bernhard Brümmer

September 2009

Platz der Göttinger Sieben 3 · 37073 Goettingen · Germany
Phone: +49-(0)551-3914066 · Fax: +49-(0)551-3914059

Email: crc-peg@uni-goettingen.de Web: http://www.uni-goettingen.de/crc-peg

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Meike Wollni and Bernhard Brümmer
Department of Agricultural Economics and Rural Development
Georg-August University of Göttingen

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Abstract

A steep decline in coffee prices at the producer level led to considerable pressure for farmers in Costa Rica and producer countries all over the world. One possible reaction was moving to specialty markets, where price pressure was perceived to be lower. We use original survey data from 2002/03 and 2003/04 to analyze the factors influencing efficiency levels of conventional and specialty coffee farmers. Controlling for selectivity bias, we find that technical efficiency in the two subsamples is influenced by both identical and divergent factors. Among the former, additional income activities increase efficiency. Among the divergent factors, experience, bookkeeping, and the number of adult household members are found to have a significant impact in the specialty coffee model. In the case of conventional coffee farmers, membership in cooperatives leads to higher farm-level efficiency. Based on the results, we derive policy recommendations to improve farmers' production performance and ability to cope with the effects of the coffee crisis. These policy measures include the provision of extension services with respect to accounting methods, the creation of income opportunities in rural areas, and the support of farmer-owned cooperatives.

Key words: Coffee, Costa Rica, Stochastic frontier analysis, Sample Selectivity, Specialty markets, Technological heterogeneity

JEL classification: Q12, D24

Introduction

As a result of considerable oversupply of green coffee in international markets, world coffee prices dropped in 2001 to their lowest levels in 30 years giving rise to the most severe crisis experienced by the coffee sector (Ponte 2002, Lewin et al. 2004). In many countries, coffee prices fell below average production costs causing widespread financial and social hardships among producers (Varangis et al. 2003, Flores et al. 2002). Economic losses and the lack of viable income alternatives forced many farmers to abandon their coffee plantations and migrate to urban areas in search of employment. Overall, the effects of the crisis pose serious threats to the prospects for sustainable rural development (Chaveriat 2001, Damiani 2005, International Coffee Organization 2004).

In the face of this situation, policymakers and development agencies have shown their interest to assist farmers in improving their production performance. To avoid wasting scarce resources, policy actions must be tailored to the needs of farmers. On this account, the paper seeks to identify the factors that determine farmers' technical efficiency in coffee production. As inefficiency in production results in a failure to maximize profits at the farm level, increases in productive efficiency enhance farmers' competitiveness and could help them to confront the adverse economic conditions caused by the coffee crisis. An empirical evaluation of the factors determining efficiency is critical to identify the constraints faced by farmers and to derive adequate policy measures.

Coffee has traditionally been marketed through a commodity system, in which the lowest cost production of a standardized product is typically rewarded (Lewin et al. 2004). In this system, where high-quality coffee is not rewarded by a higher price, farmers do not have an incentive to spend extra efforts on improving product quality. During past years, an increasing number of specialty coffee marketing channels has emerged satisfying increasingly diversified consumer demand patterns (Ponte 2002, Giovannucci and Ponte 2005). Specialty coffee refers to coffee that is differentiated from the standard commodity either by its high quality (e.g., gourmet and estate coffee) or by its production process (e.g., organic, shade-grown and fair trade coffee) (Lewin et al. 2004). Consumers' willingness to pay price premiums for the added value of these product and process attributes provides the economic incentive to preserve the identity of differentiated coffee throughout all stages of the marketing chain. In order to supply these markets, farmers have to comply with process and product standards, which require the adoption of sustainable and/or quality-enhancing production technologies (Muradian and Pelupessy 2005).

Compared to other coffee producing countries, Costa Rica has favorable natural conditions for the production of high-quality coffee as well as a strong organizational structure throughout the production and marketing stages of the coffee sector. In light of the crisis, the Costa Rican Institute of Coffee has put emphasis on exploiting this competitive advantage and improving the country's position as a producer of specialty coffee in international markets. While total coffee production has declined from 3.6 million fanegas[1] in 1999/2000 to 2.5 million fanegas in 2004/2005 in response to the crisis, the share of first grade specialty coffee in total exports has increased from 39% in 2001/2002 to almost 50% in 2004/2005 (ICAFE 2005). This was at least partly achieved through a shift away from a pure commodity system to a marketing system that allows the differentiation of coffee based on quality attributes at the producer level. In order to create incentives for farmers to adopt quality-enhancing production practices, the

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[1] In Costa Rica, the coffee that farmers deliver to processors is measured in fanegas. One fanega is equal to 4 hectolitres, and results in approximately 100 lbs of green coffee after processing (before roasting) (González 1998).

Costa Rican Institute of Coffee authorized processors[2] in 2001/2002 to pay price differentials for coffee of high quality conditional on their ability to preserve the identity of this coffee throughout all processing, storage and marketing stages (ICAFE 2005). At the time of delivery to the processors, specialty coffee must meet certain quality standards in order to be classified as such. Evaluation is based on visual inspection of the coffee and relates to attributes such as size, color, maturity, and contamination with extraneous material. Regular tastings have been implemented at the processor level, but are not traced back to individual farms (only in the event of special competitive tastings[3]). For the first time, this opened up opportunities for coffee farmers to participate in new market segments and receive higher prices for high-quality coffee. Taking this important development into account, the household sample selected for the empirical analysis includes both farmers producing in the specialty segment as well as in the conventional segment. Farmers' efficiency levels and their determinants are then assessed respective to the possibly heterogeneous technology applied on the farm.

The main contribution of the paper is thus to analyze the adaptation of coffee farmers in Costa Rica to the worsening world coffee market situation. This main focus is augmented by

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[2] After harvesting, farmers have to deliver their coffee cherries within 24 hours to a processing plant to avoid post-harvest damage and decay. Processors maintain a dense network of collection stations located all over the coffee production area to facilitate daily coffee transactions during harvest time. Farmers deliver their coffee cherries to one of these collection stations or directly to the processing plant. Processing factories are responsible for washing, hulling, drying, and grading the coffee beans.

[3] Costa Rica hosts and participates in competitive tastings, such as the "Cosecha de Oro", as a way to promote Costa Rican coffee quality. While the tasting is anonymous, the selected coffees are identified by their origin and auctioned through the internet.

some methodological aspects which, if ignored, would confound the empirical analysis: First, the possibility that the reference technology might be different between farm groups and second, the necessity to account for sample selectivity. In order to shed light on these main questions, we start with a presentation of the basic stochastic frontier model in the next section. The following section then presents the additional methods employed for the empirical analysis. Section four describes the data, the empirical model specification and the explanatory variables included in the model. After results are presented in section five, section six discusses the main results in the wider context of the coffee crisis and derives policy recommendations. Finally, the last section provides a summary of the main findings and concludes the paper.

Measuring productive efficiency

Following Meeusen and van den Broeck (1977) and Aigner, Lovell and Schmidt (1977), the present study employs stochastic frontier analysis to estimate a production function[4] and to obtain farm-level technical efficiency estimates[5]. By means of a composed error structure, the stochastic frontier model distinguishes technical inefficiency from the effects of random shocks. The basic stochastic frontier model for panel data can be expressed as

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[4] The direct estimation of a production frontier is criticized for its susceptibility to simultaneous equation bias that results if farmers select the levels of input and output that maximize profits for given prices (Coelli et al. 1998: 54). In this matter, it is referred to Zellner et al. (1966), who show that the estimation of a production function does not suffer from simultaneous equation bias, if expected rather than actual profit is maximized.

[5] In this section, we provide a short introduction to stochastic frontier estimation. The method is presented in much more detail in Kumbhakar and Lovell (2000).

$$Y_{it} = f(X_{it};\alpha)exp(\varepsilon_{it}) \qquad (1)$$

where Y_{it} is scalar output of farmer i at time t, X_{it} is a vector of input quantities, α is a vector of unknown parameters that define the production technology, and ε_{it} is a random error term composed of two independent components such that $\varepsilon_{it} \equiv V_{it} - U_{it}$. The V's are assumed to be identical and independently distributed as $N(0, \sigma_V^2)$ and reflect measurement error, omitted variables and statistical noise. The U's are a one-sided random variable independent of the V's and truncated at zero such that $U_{it} \geq 0$. U_{it} is assumed to represent technical inefficiency.

The farmer-specific technical inefficiency is the ratio of the observed output and the farmer-specific stochastic frontier output (Battese 1992). Accordingly, technical efficiency of farmer i at time t can be expressed as $TE_{it} = exp(-U_{it})$. In order to identify the factors that explain differences in efficiency levels among farmers, the U's obtained from the stochastic frontier have to be related to farm-specific variables. Early approaches to the analysis of technical inefficiency effects have applied a two-step procedure. In the first step, a production frontier is estimated to obtain inefficiency estimates, and in the second step, these estimates are regressed on a range of exogenous farm-specific variables (e.g. Page 1984, Larson et al. 1999). However, this two-step procedure suffers from an inherent inconsistency since for the maximum likelihood (ML) estimation in the first step, the U's are assumed to be identical and independently distributed, while in the second step they are expected to depend on a number of farm-specific variables (Kumbhakar and Lovell 2000: 264). Wang and Schmidt (2002) illustrate that the two-step approach might lead to inconsistent results. Simultaneous estimation of the inefficiencies and the impact of farm-specific variables were proposed by Kumbhakar, Gosh, and McGuckin (1991), Reifschneider and Stevenson (1991), and Huang and Liu (1994). The latter authors derived a non-neutral frontier model in which the technical inefficiency effects are allowed to interact with the inputs.

Battese and Coelli (1993, 1995) expanded these models to panel data. More recently, Wang and Schmidt (2002), and Alvarez et al. (2006) discuss various alternatives for incorporating possible determinants of inefficiency differences in a simultaneous ML estimation of the frontier. For the present analysis, the model proposed by Battese and Coelli (1993, 1995) is used, which allows U_{it} to be a function of several exogenous variables. The basic stochastic frontier model is the same as in (1). The U's are defined as a non-negative truncated normal distribution with mean μ_{it} and variance parameter σ_u^2. Basically, the model allows μ_{it} to vary among farms by specifying that

$$\mu_{it} = \delta Z_{it} + W_{it} \tag{2}$$

where Z_{it} is a vector of farm-specific variables that are expected to influence efficiency, δ is a vector of parameters to be estimated, and W_{it} is an i.i.d. random error term. Maximizing the log likelihood function for the model in (1) and (2) yields parameter estimates of the production frontier, α, the technical inefficiency effects, δ, and the variance parameters $\gamma \equiv \sigma_u^2 / \sigma^2$ and $\sigma^2 \equiv \sigma_u^2 + \sigma_v^2$.

Controlling for self-selection

When estimating a production frontier the underlying assumption is that all farmers in the sample have access to the same production technology. In the present study, a sub-sample of farmers produces for specialty markets, which requires the adoption of quality-enhancing production techniques in order to increase coffee quality. To account for differences in the underlying technology separate production frontiers are estimated for each sub-sample of farmers. These subsamples, however, are unlikely to represent unbiased representations of the population. If farmers choose to participate in one group or the other based on their expected performance under the chosen technology, the two sub-samples will systematically differ with respect to certain farm and household characteristics. Consequently, if self-selection is ignored in the estimation of separate production frontiers, coefficient estimates will be biased (Heckman 1979). Heckman (1979) shows that self-selectivity bias can be controlled for by including an error correction term. Heckman proposes a two-step procedure to obtain the inverse Mill's ratio, which is then used as an additional regressor in the second-stage model. Similarly, Lee (1978) controls for selection bias in the framework of an endogenous switching regression model.

Following Heckman (1979) and Lee (1978), the probability that a household chooses to produce in the specialty segment is estimated by means of a probit model. The inverse Mill's ratio (IMR) is obtained from the linear prediction of the probit model. According to Heckman (1979), it is defined as:

$$IMR_{Sit} = -\frac{\phi(\beta' x_i)}{\Phi(\beta' x_i)} \quad \text{if the household produces in the specialty segment, and} \tag{3}$$

$$IMR_{Cit} = \frac{\phi(\beta' x_i)}{1-\Phi(\beta' x_i)} \quad \text{otherwise,} \tag{4}$$

where ϕ and Φ denote the normal density and the cumulative normal distributions, respectively. In the second step, the inverse Mill's ratio is included among the exogenous variables of the production frontiers to correct for possible selection bias.

In the context of efficiency studies, selection bias has often been neglected when estimating separate production frontiers for farmers using different technology sets. Empirical studies comparing efficiency levels of organic and conventional farms (Tzouvelekas et al. 2001, Oude Lansink et al. 2002) or between farms specializing in livestock and crop production respectively (Latruffe et al. 2005) often emphasize the variations in household and farm characteristics between the sub-samples, but do not control for the resulting bias in the analysis. Exemptions can be found in Sipiläinen and Oude Lansink (2005) and Curtiss et al. (2006). Brümmer et al. (2002) test for sample selectivity effects caused by balancing an initially unbalanced panel in the context of a distance function estimation for Polish dairy farmers, but do not find evidence for this specific kind of selectivity problems. These studies do not report adjusting standard errors, which is required in the context of two-step models (Lee 1978, Heckman 1979, Greene 2000: 135).

Data and model specification

The empirical analysis is based on a sample of 216 coffee producing households that were randomly chosen from within two of the main coffee regions in Costa Rica, namely the Western Central Valley and the Brunca region in the South. A standardized questionnaire was used to collect data on coffee production as well as on the socio-economic characteristics of household members. The information collected covers the production periods 2003/04 and 2002/03 partly including recall data. The percentage of farmers in the sample participating in the specialty segment increased from 31% in 2002/03 to 49% in 2003/04.

In the first step of the analysis, data from both production periods is pooled to estimate the probability of participation in the specialty segment and to derive the inverse Mill's ratio. In the second step, separate production frontier models are estimated for specialty coffee farmers and conventional coffee farmers to account for the use of different production technologies. Potential selectivity bias is controlled for by the inclusion of the inverse Mill's ratio obtained from the first-stage pooled probit model. The translog production function for the i-th farmer (i = 1,…, 216) and the t-th year (t = 1,2) is specified as:

$$\ln Y_{it} = \alpha_0 + \sum_{j=1}^{5} \alpha_j \ln X_{jit} + 0.5 \sum_{j=1}^{3} \sum_{k=1}^{3} \alpha_{jk} \ln X_{jit} \ln X_{kit} + \alpha_{IMR} IMR_{it} + \alpha_t t + \sum_{m=1}^{6} \alpha_{Dm} D_{mit} + V_{it} - U_{it} \qquad (5)$$

where Y is the amount of coffee cherries harvested in fanegas, X_j is a vector of observations on input j, *IMR* is the inverse Mill's ratio, t is a time dummy controlling for unobserved factors that differ between the two years, such as technical change or weather conditions[6], D_m is a vector of observations on dummy variable m characterizing the production process, the α's are unknown parameters to be estimated, V is a $N(0, \sigma_V^2)$ distributed random error term, and U is a non-negative random variable representing technical inefficiency.

Given the functional specifications presented above, the technical inefficiency effects model for farmer i at time t under production technology p ($p = S, C$) is defined as:

$$\mu_{pit} = \delta_{p0} + \sum_{j=1}^{12} \delta_{pj} Z_{pjit} + \delta_{pt} t + W_{pit} \tag{6}$$

where Z_j is a vector of observations on variable j that is expected to have an impact on the level of technical efficiency, t again denotes a time dummy that accounts for changes in average technical efficiency between the two years, the δ's are unknown parameters to be estimated, and W is a normally distributed random error term with mean zero and variance parameter σ_u^2 , truncated such that $U_{it} \geq 0$. In the second step, the usual procedure to obtain standard errors is incorrect, if selection bias is present (Heckman 1979). Therefore, standard errors of the production frontiers are adjusted using the Murphy-Topel estimate of variance (Murphy and Topel 1985)[7].

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[6] As the data for 2002/03 was obtained by recall, the dummy variable also reflects the measurement error that is likely to be higher for 2002/03 as compared to 2003/04.

[7] Asymptotically, the Murphy-Topel estimate gives the same results as the Heckman correction (see Greene 2000: 933).

Potential explanatory variables in the production frontier and inefficiency effects model

Given the technology choice of the farmer, output can be explained as a function of land, labor, and other input factors as well as farmers' management capabilities. The input vectors in the production frontier model are the classical production factors land (X_1), labor (X_2), and intermediate inputs (X_3). Land refers to the area planted with coffee trees and is measured in hectares. Labor is measured in hours and includes all maintenance activities realized on the coffee plantation[8]. Intermediate inputs are measured as the value of materials including chemical and organic fertilizers, pesticides and herbicides in Costa Rican Colones. Due to different concentrations of nutrients and active components, quantity is not a meaningful indicator, but the value of material inputs is assumed to reflect concentration and quality of the input. In order to control for potential heterogeneity of family and hired labor we follow Bardhan (1973) and include a variable that reflects the share of total labor used on the plantation that is hired. Bardhan (1973) and Deolalikar and Vijverberg (1987) discuss a number of arguments that explain heterogeneity of family and hired labor. On the one hand, qualitative differences in labor productivity can result from the composition of hired labor as compared to family labor and the fact that hired labor may be more specialized to perform specific agricultural operations (Deolalikar and Vijverberg 1987). On the other hand, hired laborers have an incentive to shirk as they are not the residual claimants of farm profits resulting in moral hazard problems associated with hired labor (Eswaran and Kotwal 1986). Moreover the literature on agricultural dualism in developing countries argues that in the

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[8] Labor input used for the application of fertilizers and agro-chemicals has been excluded as it is correlated with the amount of these materials applied. Harvesting is also excluded as workers are hired under a piece-rate payment scheme, so that expenditures on harvest labor are highly correlated with total output.

presence of imperfect labor markets and limited alternative income opportunities, family labor faces lower shadow wages and as a result will be used on the plantation to a larger extent so that the marginal product of family labor tends to be lower than in the case of hired labor (Sen 1966). Finally, we add the average age of the coffee trees (X_4) to the exogenous variables in the production function, which is assumed to reflect the farmer's investment in the renovation of the plantation. After coffee trees reach peak production levels, their productivity declines with their age[9]. In addition, a younger plantation is likely to consist of more modern varieties developed and distributed by the Costa Rican Institute of Coffee, which are characterized by their suitability to agro-ecological conditions, resistance to pests and diseases, and higher yields (ICAFE 1998).

The basic production frontier is augmented by a range of dummy variables in order to characterize the production system more precisely. According to Battese (1997), zero values in input variables can lead to biased estimates. He suggests the inclusion of a dummy variable that assumes one if the input variable equals zero. In the present data set, there are 40 observations that do not apply any intermediate inputs and seven observations that do not use any maintenance labor. A dummy variable is included that assumes one if labor or intermediate inputs equal zero. Including separate dummies for each of the input variables leads to near-perfect multicollinearity as the non-use of maintenance labor is highly correlated with the non-use of intermediate inputs. The second dummy variable equals one if the farmer uses motorized equipment for plantation maintenance. This variable acts as a technology shifter moving the frontier up if a higher level of mechanization is achieved on the farm. Therefore, the expected sign of this variable is

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[9] The squared term of average age of coffee trees was included in an earlier version of the model, but excluded due to insignificance.

positive. Furthermore, a dummy that takes on the value one if the coffee varieties *Caturra* or *Catuai* are planted on the farm is included. Due to higher performance levels and better suitability for local agro-ecological conditions, the use of these plant varieties is expected to result in higher output levels. The pruning of coffee trees, while ensuring plant productivity in the long run, is expected to reduce output levels in the following years. Two dummy variables – one for pruning in the current and one for pruning in the previous year – are included in the model. Additionally, a regional dummy for farms located in the Western Valley is used to reflect regional differences in production systems and natural conditions between the two coffee regions.

The explanatory variables included in the vector Z in the inefficiency effects equation are chosen to reflect farmers' management capabilities, and their access to knowledge as well as to productive resources. The first two explanatory variables refer to education and experience in coffee farming. EDUCSEC is a dummy variable equal to one if the household head completed secondary school; EXPER reflects the farmer's experience in coffee growing measured in years. Both education and experience are expected to have a positive effect on farmers' management skills and thus on efficiency (e.g. Lockheed et al. 1980, Phillips 1994, Rahman 2003, Coelli and Fleming 2004). The variable BOOK indicates whether the farmer keeps an account of the expenditures and labor activities related to the coffee plantation. Allowing for closer monitoring of input use and timing, this should increase the efficiency level of farmers. Similarly, the number of extension visits received by the farmer (ASSIST) is expected to positively contribute to productive efficiency (Rahman 2003, Dinar et al. 2004).

The variables ADULTS, FEMALE and AGE reflect the structure of the household. The number of adult household members represents the household's access to family labor. As discussed above, the availability of family labor can improve efficiency if moral hazard problems related to hired labor are significant. On the other hand, if in the presence of imperfect labor markets family workers fail to find off-farm employment, their time might be reallocated to do maintenance activities on the coffee plantation up to the point where the marginal utility of production equals the marginal utility of leisure (Barrett 1996, Binswanger and Rosenzweig 1986). Thus, if the coffee plantation is used to absorb excess family labor, and the additional family members employed are less specialized or motivated to work on the coffee plantation, the impact on technical efficiency could be negative. Female-headed households are expected to face more difficulties in accessing markets and as a result display lower levels of efficiency. Similarly, the age of the household head, is expected to negatively influence efficiency levels.

Reflecting households' endowments, total farm size in hectares is included in the inefficiency effects model. The hypothesized effect of farm size on efficiency is ambiguous. If larger farms are less specialized in coffee production, farm size might have a negative effect on efficiency. On the other hand, if financial markets are constrained, farm size as a proxy for overall wealth and credit access (Binswanger and Sillers 1983) is expected to be positively related to efficiency. The variable ACT, indicating whether a household pursues other income-generating activities than coffee, might also have an ambiguous effect on efficiency. The effect is likely to be negative, if the diversion of labor from coffee cultivation to other activities results in maintenance activities being delayed or ignored (e.g. Fleming and Lummani 2001). On the other hand, farmers working off-farm often have better access to information (Mathijs and Vranken 2001). Furthermore, additional income can help farmers to overcome liquidity constraints and thus to buy inputs in a timely manner, even if income from coffee is low (Kalirajan 1990, Ali 1995, Abdulai and Huffman 2000).

Finally, a binary variable for membership in a coffee cooperative is included. It is hypothesized that cooperatives help farmers to reduce transaction costs, thereby increasing their access to resources and improving their productive efficiency (Shaffer 1987, Deininger 1995, Binam et al. 2004). The last variable included among the possible determinants of technical inefficiency is again the regional dummy for farms from the Western Valley. Regional heterogeneity might influence the level of technical efficiency via differences in the agro-ecological environment, institutional settings, or the intensity of local competition. The ultimate effect of the regional dummy depends on which factors predominate. Summary statistics for the dependent and independent variables included in the production frontier and in the inefficiency effects models are given in Table 1.

Table 1: Summary statistics for the variables included in the analysis

Variable	Description	Specialty coffee			Conventional coffee		
		N	Mean	Std. Dev.	N	Mean	Std. Dev.
Dependent variable							
Coffee	Total amount of coffee cherries harvested (in fanegas)	173	203.6	319.1	258	89.3	107.6
Input variables							
Land	Total area cultivated with coffee (in ha)	173	7.7	9.2	258	4.0	4.1
Labor	Total labor hours used for the maintenance of coffee plantations	173	926.8	1823.9	258	478.9	543.9
Capital	Total value of fertilizers and agrochemicals (in Costa Rican Colones)	173	763220	1232442	258	287667	475736
Agetree	Average age of the coffee trees	171	11.7	7.9	258	13.2	7.4
Dummy variables							
Inp_d	Dummy that assumes 1 if capital = 0 or labor = 0	173	0.04	0.2	258	0.07	0.3
Motor	Dummy that assumes 1 if household uses motorized equipment	173	0.8	0.4	258	0.6	0.5
Prune	Dummy that assumes 1 if household pruned in current year	173	0.2	0.4	258	0.3	0.5

Variable	Description	Specialty coffee			Conventional coffee		
L_prune	Dummy that assumes 1 if household pruned in previous year	173	0.3	0.4	258	0.2	0.4
Superior	Dummy that assumes 1 if household has superior coffee varieties	173	0.9	0.3	258	0.9	0.3
Hired	Hired labor as a share of total labor	173	0.4	0.4	258	0.3	0.4
Region	Dummy that assumes 1 if household is located in Western Valley (0 = Brunca)	173	0.98	0.1	258	0.45	0.5
Time	Time dummy (1 = 2003)	173	0.6	0.5	258	0.4	0.5
IMR	Inverse Mill's Ratio	173	0.6	0.4	258	0.4	0.4
Inefficiency effects							
Educsec	Household head completed secondary school (1 = yes)	173	0.2	0.4	258	0.1	0.2
Exper	Experience in coffee cultivation (in years)	173	39.6	14.1	258	34.3	15.5
Age	Age of the household head	173	56.1	12.5	258	54.9	14.0
Female	Household is female-headed (1 = yes)	173	0.1	0.2	258	0.1	0.3
Adults	Number of adult family members	173	1.8	1.0	258	3.3	1.3
Book	Household keeps book about the coffee activity (1 = yes)	170	0.4	0.5	257	0.2	0.4
Comem	Household is member of coffee cooperative (1 = yes)	173	0.9	0.3	258	0.8	0.4
Act	Household has income from other activities (1 = yes)	173	0.8	0.4	258	0.8	0.4
Size	Total farm size (in ha)	173	17.9	34.5	258	8.6	16.8
Assist	Number of extension visits received during the last year	173	1.3	0.9	258	0.9	1.2

Results of the efficiency estimation

The results of the probit model indicate that the probability of participation in specialty markets increases with farmers' experience in coffee cultivation, education, farm size, and membership in coffee cooperatives (see annex Table 1). Furthermore, farmers who have received extension in quality-enhancing cultivation practices are more likely to produce in the specialty segment. In contrast, if farmers dedicate their time to other income-generating activities, the probability of participation decreases. It is apparent that some significant differences exist in terms of farm and household characteristics between specialty and conventional farmers[10]. In the following sections, the results of the efficiency analysis are presented for each sub-group of farmers, while controlling for potential selection bias.

Model specification tests

In order to select the statistically preferred model specifications, a number of hypotheses were tested using the generalized likelihood ratio test[11] (see Table 2). The first null hypothesis assumes that the Cobb-Douglas functional form is an adequate simplification against the alternative of a translog. In the case of specialty coffee farmers, the null-hypothesis cannot be rejected, while for the conventional coffee farmers the null-hypothesis is rejected at 5% error probability. The next three tests refer to various inefficiency effects. The first test assesses the null that the inefficiency effects are absent from the model, that is, an average response function would fit the model. However, the null is rejected for both models at the 1% probability of error, indicating that the stochastic frontier model is a more appropriate representation of the data than OLS. The following test assumes under the null that the inefficiency effects are not stochastic, which would imply that they should be included as additional inputs in the frontier model while γ would equal zero. The null is also rejected in both cases at the 1% probability of error. Finally, a test for the significance of the variables in the inefficiency effects model is conducted. The null that all va-

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[10] For a more detailed discussion of the factors influencing participation in specialty markets see Wollni and Zeller (2007).

[11] Coelli (1995) showed that this test performs superior to a range of other tests when investigating the existence of inefficiency effects.

riables in the Z-vector are insignificant is rejected at the 5% (1%) level in the case of specialty (conventional) coffee farmers.

Table 2: Hypotheses tests for the efficiency model specification

		Specialty coffee			Conventional coffee		
Null hypothesis	Restrictions	Critical χ^2 value	Test value λ		Critical χ^2 value	Test value λ	
H_0: $\beta_{ij} = 0$, $i \le j = 1...3$	6	10.64	5.15		12.59	13.96	**
H_0: $\gamma = \delta_0 = \ldots = \delta_s = 0$	14	28.49[a]	43.05	***	28.49[a]	48.29	***
H_0: $\gamma = 0$	4	12.48[a]	29.55	***	12.48[a]	34.58	***
H_0: $\delta_0 = \ldots = \delta_s = 0$	13	22.36	25.56	**	27.69	28.65	***

**(***) The null-hypothesis is rejected at a level of significance of p=0.05 (0.01).

a) Critical values are obtained from the mixed χ^2 distribution (see Kodde and Palm 1986).

Stochastic production frontiers

Table 3 presents parameter estimates from the two production frontier models. Additionally, partial production elasticities of land, labor and intermediate inputs together with their standard errors are reported in Table 3. In the case of the Cobb-Douglas form, production elasticities can be directly inferred from the estimated coefficients. For specialty coffee farmers, partial production elasticities of land, labor, and intermediate inputs are 0.535, 0.137, and 0.243, respectively. In the case of the translog functional form, production elasticities are computed at the sample mean[12] and approximate standard errors are calculated based on the adjusted variance-covariance matrix. In the case of conventional coffee farmers, partial production elasticities are also positive and significant. Furthermore, scale elasticities are calculated for both groups of farmers. The null hypothesis of non-decreasing returns to scale is rejected in both cases indicating that farmers operate under decreasing returns to scale.

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[12] Partial production elasticities are derived from the first order and second order terms of the inputs and calculated at the sample mean (see Greene 2000: 286).

The Cobb-Douglas preferred for the specialty farmers is globally monotone because of the positive elasticities. For the translog functional form, which is preferred in the case of conventional coffee farmers, monotonicity is not necessarily fulfilled and has to be tested a posteriori at each point. Hence, production elasticities of land, labor and intermediate inputs were calculated for each individual farm household and t-tests were conducted to test whether these elasticities differ significantly from zero. Results indicate that partial production elasticities for land and labor are non-negative for all farmers in the sample. Of those farmers that use fertilizers or other agro-chemicals, one farmer displays negative production elasticity with respect to this input variable. Although it is inconsistent with theory that a farmer uses additional inputs if these reduce output, Chambers (1988) points out that this behavior may be observed in practice as a result of uncertainties faced in agricultural decision-making.

In addition to the labor input variable, we included a variable for the share of total labor that is hired to control for heterogeneity of family and hired labor. In case of the specialty coffee model, the variable is positive and significant at the 5% probability of error indicating higher productivity of hired labor in the specialty segment. This finding supports the hypothesis that family labor faces lower shadow wages compared to market wages paid to hired laborers and is thus used on the plantation to a larger extent.

Furthermore, a range of dummy variables is included in the models to characterize the production process. In the case of specialty coffee farmers, the variable MOTOR is positive and significant at the 5% probability of error. As expected, output is higher for farmers who use motorized equipment. The variable SUPERIOR shows the tendency that farmers who have superior plant varieties on their farm achieve higher output levels. The negative sign on the regional dummy shows that output is lower in the Western Valley as compared to the Brunca region, with all other factors held constant. Finally, the time dummy has a negative sign reflecting decreased output levels in 2003 as compared to the previous year. This is a result of farmers' reduced input use in response to the crisis. Overall, production levels in Costa Rica decreased from 3.2 million fanegas in 2002 to 2.9 million fanegas in 2003, and average yields decreased from 27.8 fan/ha to 25.8 fan/ha during the same time period (ICAFE 2005).

As regards the model of conventional coffee farmers, the variables MOTOR, L_PRUNE, and the time dummy are significant. As in the specialty coffee model, farmers who use motorized equipment achieve higher output levels. Also, output decreased in 2003 as compared to the previous year. Furthermore, if farmers pruned their coffee trees in the previous year, output levels are lower. Pruning in the same year also has a negative effect on output, but is not significant.

Finally, the inverse Mill's ratio (IMR) is significant in both models indicating that selection bias is indeed present. The negative sign of the IMR in the specialty coffee model indicates that the average output of specialty farmers is larger than it would be if all farmers cultivated specialty coffee. In contrast, the negative sign of the IMR in the model for conventional farmers indicates that average output of conventional farmers is smaller than it would be if all farmers were using that technology. This bias might result from various factors: specialty coffee farmers having larger plantations, using inputs more intensively, or achieving higher levels of efficiency than conventional farmers. These results emphasize the importance of testing and controlling for selection bias when estimating separate production frontiers.

Table 3: Parameter estimates from the production frontier

		Specialty coffee			Conventional coffee		
Production elasticities							
Land		0.535	(0.077)	***	0.473	(0.082)	***
Labor		0.137	(0.059)	**	0.113	(0.052)	**
Inputs		0.243	(0.041)	***	0.284	(0.045)	***
Scale Elast.		0.915	(0.050)	*	0.870	(0.048)	***
Variable	Parameter	ML estimate			ML estimate		
Land	α_1	0.535	(0.077)	***	1.108	(0.182)	***
Labor	α_2	0.137	(0.059)	**	0.026	(0.160)	
Inputs	α_3	0.243	(0.041)	***	-0.979	(0.365)	***
0.5*Land^2	α_{11}				0.236	(0.085)	***
0.5*Labor^2	α_{22}				0.081	(0.066)	
0.5*Capital^2	α_{33}				0.117	(0.033)	***
Land*Labor	α_{12}				-0.136	(0.061)	**
Land*Capital	α_{13}				-0.009	(0.031)	
Labor*Capital	α_{23}				-0.020	(0.018)	
Agetree	α_4	0.014	(0.074)		-0.018	(0.063)	
Hired	α_5	0.221	(0.100)	**	0.024	(0.088)	
Linp_d	α_{D1}	2.745	(0.513)	***	-4.555	(2.055)	**
Motor	α_{D2}	0.236	(0.095)	**	0.170	(0.075)	**
Prune	α_{D3}	-0.133	(0.085)		-0.096	(0.067)	
Lag_prune	α_{D4}	-0.033	(0.077)		-0.152	(0.077)	**
Superior	α_{D5}	0.265	(0.137)	*	0.008	(0.111)	
Time	α_t	-0.232	(0.095)	**	-0.154	(0.091)	*
Region	α_{D6}	-0.948	(0.442)	**	-0.030	(0.100)	
IMR	α_{IMR}	-0.303	(0.095)	***	-0.227	(0.092)	**
Constant	α_0	0.880	(0.634)		7.439	(2.039)	***

*(**)[***] The null is rejected at a level of significance of p=0.10 (0.05) [0.01].

Note: Standard errors are in brackets and are based on the Murphy-Topel variance estimate (Murphy and Topel 1985).

Inefficiency effects

Table 4 presents the results of the two inefficiency effects models together with the marginal effects on efficiency. Marginal effects are calculated at the mean for continuous variables and for a discrete change from zero to one for dummy variables. Several factors were identified to have an influence on farm-specific technical efficiency levels in the case of specialty and conventional coffee farmers, respectively. It is important to note that a negative sign on a coefficient means that the predicted effect on inefficiency is negative, i.e. the variable has a positive effect on technical efficiency.

In the case of specialty coffee, the experience and age of the household head are significant factors. As expected, efficiency increases with experience in coffee cultivation and decreases with age. The number of adult household members has a significantly negative effect on efficiency. In accordance with the variable HIRED in the production function, this suggests that available family labor is used on the plantation more extensively than if the labor is hired. An additional family member decreases efficiency by 1.3 percentage points at the margin. Furthermore, book-keeping has an efficiency-enhancing effect increasing efficiency by 5.4 percentage points and thus emphasizing the importance of accounting methods for the efficient management of production. Households pursuing other income-generating activities besides coffee also display higher efficiency levels. Income from other activities allows farmers to realize timely and adequate input applications even when coffee incomes are low. Also, farmers working off-farm have better access to relevant information. Furthermore, if family members are engaged in other activities besides coffee, underemployment on the coffee plantation is less likely to occur. On the average, efficiency levels of households with additional income-generating activities are 6.5 percent higher. Finally, specialty coffee farmers located in the Western Valley display higher efficiency levels than those located in the Brunca region.

With respect to conventional coffee farmers, the availability of other income-generating activities is also significant at the 5% level and has the same sign as in the specialty coffee model. The marginal effect is not as high as in the specialty model, but nonetheless significant with 3.2 percent. Contrary to the case of specialty coffee farmers, conventional coffee farmers display higher levels of efficiency if they are member of a coffee cooperative, which increases their performance by 2.7 percent on the average. Applying a more standard production technology, experience and book-keeping are not found to be significant factors in the model of conventional coffee cultivation.

Table 4: Results of the inefficiency effects model

		Specialty coffee			Conventional coffee		
Variable	Para-meter	ML estimate		Marginal effects	ML estimate		Marginal effects
Educsec	δ_1	0.573 (0.545)		-0.0119	0.654 (0.533)		-0.0209
Exper	δ_2	-0.147 (0.053)	***	0.0030	-0.003 (0.012)		0.0001
Age	δ_3	0.083 (0.032)	***	-0.0017	0.020 (0.014)		-0.0006
Female	δ_4	-1.189 (1.027)		0.0229	0.449 (0.477)		-0.0144
Book	δ_5	-2.730 (1.378)	**	0.0541	-0.479 (0.423)		0.0154
Comem	δ_6	-0.347 (0.943)		0.0072	-0.833 (0.391)	**	0.0266
Time	δ_t	0.240 (0.542)		-0.0049	-0.336 (0.370)		0.0108
Region	δ_7	-2.860 (1.208)	**	0.0686	0.700 (0.441)		-0.0225
Act	δ_8	-2.865 (1.100)	***	0.0649	-1.005 (0.467)	**	0.0321
Size	δ_9	0.008 (0.005)		-0.0002	-0.013 (0.012)		0.0004
Assist	δ_{10}	-0.304 (0.252)		0.0062	-0.155 (0.160)		0.0050
Adults	δ_{11}	0.626 (0.293)	**	-0.0128	0.182 (0.121)		-0.0058
Constant	δ_0	0.519 (0.966)			-0.720 (1.058)		
Variance parameters							
	σ^2	1.441 (0.308)	***		0.954 (0.373)	**	
	γ	0.922 (0.017)	***		0.942 (0.300)	***	
Log likelihood		-97.515			-186.081		

*(**)[***] The null-hypothesis is rejected at a level of significance of p=0.10 (0.05) [0.01].
Note: Standard errors are in brackets.

Technical efficiency estimates

Mean technical efficiency of specialty farmers is estimated at 79%, and of conventional coffee farmers at 61% (see Table 5). These percentages represent relative measures of technical efficiency in comparison to the most efficient farmers in the respective sub-sample. Accordingly, specialty farmers achieve higher levels of efficiency relative to the best-practice farmers producing in the specialty segment. In contrast, there are more conventional coffee farmers that operate with lower efficiency levels compared to their technology-specific standard.

Table 5 shows the frequency distribution of farmers in each sub-sample across efficiency levels. Farmers were assigned to ten levels of efficiency according to their farm-specific technical efficiency score. Comparing the two distributions, it can be seen that in the case of specialty coffee farmers, 86% of households achieve technical efficiency levels of 70% or higher. In contrast, in the case of conventional coffee farmers, only 46% of farmers achieve efficiency levels of equal to or above 70%. A considerable share of conventional farmers of 32% operates under technical efficiency levels below 50%.

Table 5: Frequency distribution of technical efficiency scores

	Specialty coffee farmers		Conventional coffee farmers	
Efficiency (percent)	frequency	percent	frequency	percent
< 10%	1	0.58	4	1.55
10-20%	1	0.58	7	2.71
20-30%	2	1.16	20	7.75
30-40%	0	0	22	8.53
40-50%	3	1.73	28	10.85
50-60%	8	4.62	28	10.85
60-70%	14	8.09	31	12.02
70-80%	38	21.97	59	22.87
80-90%	92	53.18	53	20.54
90-100%	14	8.09	6	2.33
Total	173	100.00	258	100.00
Mean efficiency	78.61		60.88	
Standard deviation	13.68		22.23	
Min.	5.10		7.34	
Max.	94.30		92.49	

Intuitively, one would expect to find lower efficiency levels in the new market segment, where farmers are in a process of learning about the new technology. Yet, as revealed by the probit analysis, farmers with higher levels of education and more experience in coffee cultivation are more likely to participate in the specialty segment. This correlation between education and experience and the adoption of the new technology explains at least to some extent the higher efficiency levels observed in the sub-sample of specialty coffee farmers.

Discussion of results and policy implications

This section discusses the results of the analysis of technical efficiency in the wider context of the coffee crisis and derives policy recommendations on how to improve farmers' production performance. As a response to the crisis, the Costa Rican coffee sector launched initiatives to increase coffee quality. The success of these efforts is reflected in an increasing share of high-quality coffee in total exports. Those farmers that responded to the incentives and adopted quality-enhancing production technologies were generally more experienced in coffee cultivation, more educated, had larger farms and were associated with a coffee cooperative (as revealed by the probit analysis). In line with these findings, specialty coffee farmers achieve higher efficiency levels than conventional coffee farmers. Accordingly, the more successful farmers were more likely to switch to high-value production.

The higher requirements of the new production technology on farm management is reflected by the finding that within the specialty segment farmers who are more experienced and keep book of their activities and expenditures achieve higher efficiency levels. This has important implications for future extension activities which should focus on providing farmers with farm management skills in order to improve their performance. Especially in the context of more sophisticated production techniques accounting methods are promising tools to increase farmers' awareness of actual input use in relation to output levels, and thus their technical efficiency.

An important factor that deters farmers in the specialty segment from reaching higher efficiency levels is the amount of family labor available to the household. Lacking other income activities family workers face lower shadow wages than the wage rate paid for hired labor, and are thus used on the plantation to a larger extent. In line with this, the analysis provides evidence that in the specialty segment family labor productivity is lower than that of hired labor. We use our data to calculate the marginal product of family and hired labor respectively. Results of a t-test show that on average the marginal product of labor is indeed significantly lower for family labor as compared to hired labor supporting the hypothesis of lower shadow wages. These findings have to be evaluated in the wider context of the sharp decline in international coffee prices that jeopardized the profitability of coffee cultivation. As a response to the price decline, many farmers reduced the use of hired labor and intermediate inputs to adjust production levels. Fewer employment opportunities in the coffee sector as well as lower coffee incomes for farmers also had repercussions on other economic sectors resulting in higher rates of unemployment in rural areas (Damiani 2005). While the use of hired labor was reduced across the sample of coffee farmers, the use of family labor remained largely unchanged. Farmers can relatively easily adjust the amount of hired labor used on the plantation, whereas family workers cannot be dismissed, and in lack of other employment opportunities, are employed on the coffee plantation to perform regular maintenance activities. In addition, many family members who worked part-time as day-laborers on other coffee plantations lost their employment as a result of the price decline and were thus available to work full-time on the family-owned plantation. As a consequence, the economic downturn caused by the coffee crisis resulted in coffee plantations absorbing considerable amounts of excess family labor. In this way, coffee cultivation had a buffer function for the labor market during the crisis.

The creation of alternative job opportunities in coffee production regions is therefore essential in order to alleviate the effects of the crisis and also to enhance the competitiveness of coffee production. The analysis shows that in both models households with off-farm employment achieve higher efficiency levels. This underscores the need for the creation of employment opportunities in rural areas not only for providing farmers with additional income in periods of low coffee prices, but also for absorbing family labor that is otherwise underemployed on the farm and thereby increasing efficiency in coffee production. Policymakers can play an important role in fostering the creation of feasible income opportunities by supporting market research and facilitating the development of small and medium enterprises in rural areas. Examples of diversification efforts can be found for example in the southern coffee region of Costa Rica, where cooperatives engage in assisting farmers on how to grow ornamental plants and mushrooms. The public extension service in Costa Rica has also increasingly shifted its focus from traditional to non-traditional, high-value products including flowers. However, the limiting factor is often the lack of market outlets and trading partners that are well established for coffee but still need to be developed for many alternative high-value products. The government therefore should support existing forms of collective action (such as cooperatives and farmers' associations) that engage in exploring marketing opportunities and building trade relationships.

In addition to their marketing and diversification efforts, cooperatives play an important role in enhancing efficiency of conventional coffee farmers. The insignificance of the same variable in the specialty coffee model might wrongly lead to the conclusion that cooperative membership has negligible effects on specialty farmers' efficiency. In fact, cooperatives are crucial to link farmers to high-value markets, as reflected by the results of the probit analysis and the fact that 92 percent of the specialty farmers are members of a coffee cooperative (as opposed to 79 percent of the conventional coffee farmers). Therefore, the insignificance of cooperative membership in the specialty coffee model can rather be attributed to the low variability of the indicator given that the vast majority of farmers are actually members of a cooperative. Thus, for policymakers it is interesting to note that fostering coffee cooperatives can help to achieve multiple objectives as shown in the analysis. In Costa Rica, coffee cooperatives play an important role in connecting farmers with specialty markets and in helping farmers to organize their production process more efficiently. Additionally, through the provision of production and marketing assistance they can facilitate the diversification into alternative high-value (agricultural) activities.

Conclusions

We have analyzed the determinants of farm-level technical efficiency in coffee production for a sample of 216 conventional and specialty coffee farmers in Costa Rica by simultaneously estimating a stochastic frontier model and the effects of a range of farm-specific variables on technical efficiency levels. Given that farmers in the sample use different sets of technologies, two separate production frontiers are estimated for farmers in each sub-sample. We add to the existing methods of stochastic frontier analysis by controlling for potential selectivity bias when estimating separate production frontiers. The results indicate that self-selection is present emphasizing the importance of taking selectivity bias into account when estimating different production functions for sample subsets.

The paper presents an empirical investigation of the factors that determine productive efficiency in coffee cultivation. The main results in the case of specialty coffee farmers show that efficiency increases with experience and is higher for farmers that keep book of their activities and expenditures. These findings confirm the importance of management skills and methods for improving performance especially in the case of more sophisticated production technologies. Furthermore, efficiency decreases with the number of adult family members living in the household. In the context of the coffee crisis, coffee plantations often had to absorb excess family labor that could not find off-farm employment resulting in lower efficiency scores for these households. In the case of conventional farmers, model results reveal that membership in cooperatives significantly contributes to the achievement of technical efficiency at the farm level. In both models, the effect of other income-generating activities on efficiency is positive, which is partly a result of less family labor being underemployed on the coffee plantation, and also of better access to liquidity and information.

The results allow for the derivation of adequate policy measures that can help farmers to improve their competitiveness in coffee production and to confront the adverse economic conditions caused by the coffee crisis. These policy measures include the provision of extension services, especially in the field of management skills and accounting techniques, the creation of income opportunities through marketing research and small enterprise development, and the support of cooperatives that help farmers to explore new market opportunities and organize their production process efficiently.

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Annex

Annex Table 1: Results of the pooled probit model on participation in specialty markets

Variables	Description	Coefficient	Robust standard errors
EXPER	Experience in coffee cultivation (in years)	0.021 ***	0.006
EDUC	Level of education of the household head (1=no formal education, 6= university degree)	0.319 ***	0.077
LAND	Total area of land cultivated with coffee (in ha.)	0.045 ***	0.019
COMEM	Household is member of coffee cooperative (0/1)	0.413 **	0.206
ALT	Altitude of the coffee plantation (in meters)	0.006 ***	0.001
QUAL	Whether household received training in quality enhancing practices (0/1)	0.861 ***	0.263
NONAG	Number of non-agricultural income-generating activities household members are engaged in	-0.266 ***	0.085
MEN	Number of male adults in the household (>= 14 years)	-0.095	0.089
WOMEN	Number of female adults in the household (>= 14 years)	0.034	0.083
CHILD	Number of children in the household (age below 14)	-0.081	0.065
TIME	time dummy (0 = 2002, 1 = 2003)	0.670 ***	0.149
CONST	Constant	-8.585 ***	0.863
N		431	
Log pseudo-likelihood		-193.851	
Wald chi² (11)		122.590 ***	
Pseudo R²		0.332	

**(***) significant at p=0.05 (0.01)