TRADE-OFFS BETWEEN ECONOMIC EFFICIENCY AND CONTAMINATION BY COFFEE PROCESSING A BIOECONOMIC MODEL AT THE WATERSHED LEVEL IN HONDURAS

Bruno Barbier[1], [2]Robert R. Hearne, José Manuel Gonzalez [3 1], Andy Nelson[4] and Orlando Mejía Castañeda[5]

[1]Center for International Cooperation on Agricultural Research for Development (CIRAD)
73 rue Jean-François Breton TA 40/15. 34398 Montpellier France. E-mail: bbarbier@cirad.fr
[2]Department of Agribusiness and Applied Economics, North Dakota State University,
PO Box 5636, Fargo, N.D., 58105. E-mail: rhearne@ndsuext.nodak.edu
[3]Consultant. 7170 CATIE, Turrialba, Costa Rica. E-mail: magojose@yahoo.com
[4]School of Geography. University of Leeds. W. Yorks. LS2 9JT, UK
[5]GIS Analyst. Secretary of Agriculture and Livestock, Tegucilpa, Honduras

ABSTRACT

In Honduras, traditional coffee processing is the cause of two major problems: poor coffee quality and contaminated water. In this paper we present a method that determines the trade-off between economic efficiency and contamination in a Honduran sub-watershed. The method is a bioeconomic model based on mathematical programming that simulates the functioning of the interlinked economic and ecological processes in the sub-watershed. We compare various scenarii where the model is given the possibility of replacing traditional coffee processing plants with a network of improved ecological plants. For different levels of contamination the model determines the optimal location and size of new coffee processing plants along river streams by minimizing transport, variable and fixed costs. The restrictions of the system are the volume of wet coffee to be processed, the available stream water, and in the alternative scenarii, investment capital and contaminant concentration in the river. We apply the method to a typical sub-watershed in the hillsides of western Honduras and show that coffee quality can be improved and contamination can be reduced substantially at a relatively low cost.

Keywords: coffee, environment, water quality, mathematical programming, transport cost, spatial analysis, watershed, Honduras

THE PROBLEM

Honduras recently became the largest coffee producer of Central America and there is still good potential for further growth. Coffee is produced by 85,000 small-scale producers harvesting 250,000 hectares of coffee. Around 90% of producers own less than 7 hectares (Pineda, 1997b, IHcafe 1999, CIAT 1999). Expansion of coffee production among small farmers is a Honduran particularity compared to neighboring countries such as Guatemala, Salvador, Nicaragua and Costa Rica where a large landowners control most of the production. The Honduran model has helped reduce poverty and has been a key factor in diffusing potential social conflicts in the seventies and eighties. Coffee development in Honduras is also considered to be a success story in terms of sustainable development (Baumeister 1996) since most plantations are located under tree shade which is also considered by many as more ecological than the production system of neighboring countries. Because much of the coffee is grown on the hillsides in the upper watersheds, it utilizes land that would be otherwise unsuitable for production of the other major crops of Honduras.

[1] Field research was conducted while Hearne and Gonzalez were Assistant Professor and MS student respectively at CATIE, Turrialba, Costa Rica, and Barbier, Nelson and Castaneda were Research Fellow at CIAT, Tegucigalpa, Honduras.

However, coffee production in Honduras does come at an environmental cost because post harvest processing is done at the farm level, using water intensive technology with little environmental control. Around 300,000 metric tons of pulp and 140,000 metric tons of mucilage are produced as waste in the post-harvest processing. This waste is dumped into the waterways of the upper watersheds without control or treatment causing eutrofisation, with the subsequent loss of plant and fish life, strong odors, acidic water and an increased population of mosquitoes and other harmful insects (Gonzalez et al, 1994, Echeverría and Cleves 1998, González, et al 1994, Osorio,1997, Orozco et al. 1992, Cleves 1995, Jacquet, 1993). Wet processing requires 40 liters of water for each kilo of processed coffee (Bailly et al. 1992) and around 40% of the water used during the process is wasted. This extraction of river water occurs during the dry summer months in Honduras when rainfall is not expected and river levels are at their lowest point. It is precisely during these months when human consumption of water reaches its peak because a large population of migrant workers arrives for the coffee harvest (Bailly et al., 1992).

Because coffee processing in Honduras is decentralized, exporters are unable to guarantee a standardized product that meets the quality standards that the international market demands. International buyers apply a price penalty of US $12.00 for each 46 Kg bags of Honduran coffee except to a few Honduran cooperatives that can guarantee quality through centralized processing (Kotchen et al. 2000). Over 90% of Honduran coffee is processed by individual small-scale farmers using inefficient traditional technology. They do not have the financial capacity to improve their processing technologies, and banks are reluctant to lend to farmers with little collateral. Also the private sector has invested very little in coffee processing since the production is too scattered about on the hillsides. Only a few dozen large producers have constructed modern processing plants (Pineda, 1998). Previous efforts from the government to improve coffee processing have failed. In the 1970s, IHCAFE constructed 13 large processing plants but the choice of the location was motivated by politics more than by efficiency. Only three of those plants are still operating.

INPROVING COFFEE PROCESSING

To improve coffee quality, the Honduran Coffee Institute (IHCafe) is promoting the system adopted by most neighboring countries consisting of centralizing coffee processing in medium sized modern plants with pollution reducing technologies. IHCafe has proposed five types of regulated plants which feature water recycling, effluent treatment, composting of organic byproducts, rapid fermentation, improved depulping and low energy use (Urive et al., 1997, Jacquet, 1993, Barrios, 1995). The plants differ in their capacities from 25 to 5000 bags per year and their water requirements (Pineda, 1997a). The great majority of the plants are small-scale, requiring limited capital. The smaller processing plants are similar in size to those that are currently employed by individual farmers, but the larger plants are only appropriate for centralized production. These technologies rely on water power to reduce labor and utilize less water for each kilogram of processed coffee (Pineda 1997a, Baily et al. 1992). These processing plants would reduce water pollution, reduce water consumption during processing, improve the product quality and facilitate improved export prices.

A necessary condition for the success of this new system is that all participants, farmers, processors, and exporters remain at least financially neutral to the new system. With the possibility of improved export prices, it is possible that a centralized system of environmentally controlled processing plants is Pareto superior to the current system. This study does not address how this network of processing plants should be initiated nor who should own and operate these plants. Rather we concentrate on the determination of the best location and the most appropriate type of plant for different levels of contamination.

THE MODEL

We solved the problem with a bioeconomic model based on mathematical programming which consists in maximizing or minimizing an objective function under constraints. Much of the original development of mathematical programming by Nobel laureates Leonid Kantorovitch and Tjalling. Carl Koopmans but also by George Dantzig in the fifties dealt with minimizing transportation costs. Since then, mathematical programming has been widely used to optimize distribution of goods and services, especially by large industries. In natural resource management such models have been used to evaluate policies to reduce erosion costs (White 1988).

The novelty in our study is to apply an environmental constraint and to apply the model to a watershed with explicit water balance constraints and to draw the trade-off between economic efficiency and levels of contamination. Another novelty is that we used a non-linear algorithm that avoids the use of integer programming while taking explicitly into account fixed costs.

The model determines the minimum of the annualized fixed costs FC, variable costs VC of the plants, and transport costs of coffee TC in a sub watershed. The problem is to select the decision variable $X_{f,,r,l,,n,m}$ = where X is the volume of processed coffee; *f* = cluster of coffee plantation (1 to 17); *r* = river segments where plants are located (1 to 7), l = processing plant potential location along a river segment (1 to 6); *n* = number of plants per potential location; *m* = plant type (1 to 5) in order to minimize:

$$\sum_{f,r,l,n,m} (FC_m + FC_m (1 - X_{f,r,l,n,m} / cap_m) + VC_m + dis_{f,r,l} \cdot TC^{\gamma} + \sum_{e} dis_{r,l,e} \cdot TC^{\phi}) \cdot X_{f,r,l,n,m} \tag{1}$$

With FC_m = Annualized fixed cost per quintal for each plant of type *m* ; $X_{f,r,l,n,m}$ /cap_m , divides the processed quantity of coffee by the plant capacity to obtain the number of necessary plants. A constraint bellow binds the number of plant to 1. So 1 - $X_{f,r,l,n,m}$ /cap_m is always less than 1 and determines the fraction of the plant that is not used. Then FC_m . (1- $X_{f,r,l,n,m}$ /cap_m) is the fixed cost of the unused part of the plant. Added to FC_m we obtain the full fixed cost of each plant. This way the model behaves exactly like an integer program. We did not apply this rule to the traditional plants because there are too many. Instead the model produces the optimal quantity processed by the traditional small plants.

TC^{γ} = Transport cost per kilometer per quintal of wet bean from the coffee plantations to the plant; TC^{ϕ} = Transport cost per quintal per kilometer of dry bean from plant to exporter; VC_m = Variable cost for each type of plant *m*; $dis_{f,r,l}$ = Distance from the field to the plants; $dis_{r,l,e}$ = Distance from the plants to the exporter.

Subject to the following 5 restrictions:

The processing capacity of the proposed plants in the river segment is larger than the wet bean production of the watershed.

$$\sum_{f} prod_f \leq \sum_{f,r,l,n,m} cap_m \cdot X_{f,r,l,n,m} \tag{2}$$

Processed quantity by one plant is less than the capacity of the plant.

$$X_{f,r,l,n,m} \leq cap_m \tag{3}$$

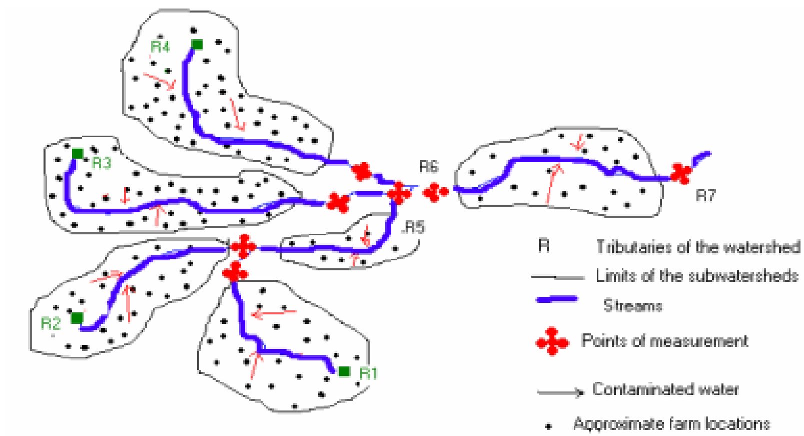

Figure 1. Río Frío watershed and subwatersheds where the stream flows were measured.

In equation 4 water available to a given potential plant location within a river segment is the result of water produced by the springs located between this location and the upstream next plant location, plus the water coming from the various upstream river segments minus the water consumed in coffee processing during the peak period (see Figure 1).

$$WATER_{r,l} = springs_{r,l} + WATER_{r,l-1} + WATER_{r-1,l6} + WATER_{r-2,l6} - \sum_{l,n,m} water_m \cdot X_{f,r,l,n,m} \tag{4}$$

The sum of effluents rejected by all plants is less than a predetermined maximum effluent concentration per cubic meter of water at the outlet of watershed (only in some scenarios).

$$\sum_{\mathrm{f,r,l,n,m}} cont_m \cdot X_{\mathrm{f,r,l,n,m}} \le Contm \cdot WATER_{r,l7} \tag{5}$$

Total investment is less than a predetermined maximum (only in some scenarios)

$$\sum_{\mathrm{f,r,l,n,m}} inv_m \cdot X_{\mathrm{f,r,l,n,m}} \le Inv \tag{6}$$

STUDY AREA

We applied the model to the Río Frio sub-watershed in western Honduras. The watershed covers an area of 86 km^2 between 550 and 1600 meters above sea level. Coffee plantations are located in the upper part of the watershed and represent the main economic activity for the 1137 families living in the watershed. Around 40,000 quintals of coffee is grown on 2527 hectares, thus a yield of 16 quintals per hectare.

In this area, recent studies of river flows and water quality complement the data collected by IHCafe on farm locations, costs and output. Data on water availability is based on measurement of the stream flows by Pineda et al.(1998). The Rio Frio subwatershed can be divided into 7 river sections (see figure 1). Outflows are measured at seven points of the watershed. Stream flow is 2.5 m^3 /s at the end of the rainy season but goes down to 1.4 m^3 /s in December, and down to 0.4 m^3/s at the end of the dry season in March.
Figure 1

The processing capacity needs to be sufficient to receive all of the coffee harvested during any day. Thus the peak period determines all the estimates for the processing: size of the installation, type of plant to construct and demand for water. In the sub-watershed 70% of the production is harvested in 30 days between January and February. During this period, all fixed inputs and variable inputs are fully employed in harvesting and processing. Processing capacity must be sufficient to receive 1381 quintals per day. Distances from plantation to the plants and from the plants to the exporter were calculated using a Geographical Information System and maps produced by CIAT (1999).

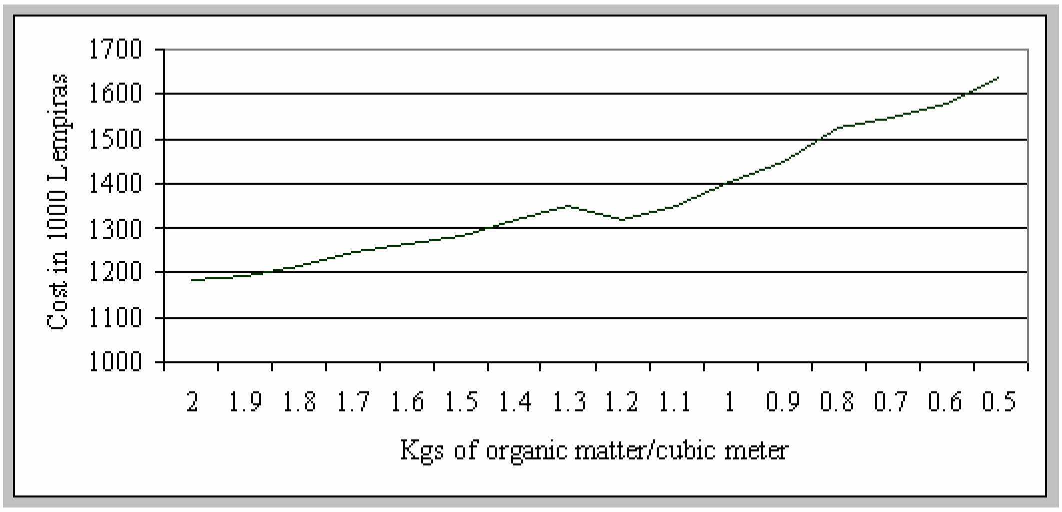

Figure 2. Trade-off between water contamination and processing costs.

SIMULATION RESULTS

In the first scenario, we apply to the model an increasing upper limit of contamination in the water, using concentration of organic matter in the water as an indicator of contamination. Figure 2 shows the trade-off between contamination and total processing and transport costs.

As contamination decreases, the cost increases until it reaches a limit of 0.4 kgs of organic matter per cubic meter of water below which reducing contamination becomes impossible. The curb is almost linear and relatively flat meaning that reducing substantially contamination does not come at a high cost per quintal.

Figure 3 shows which type of plant should process wet coffee in which segment of the river at various concentrations of contaminant. When contamination is not restricted, traditional coffee plantations are most cost effective. Only two modern plants of type 4 and 5 in the segment 3 of the river are cost effective, the rest remaining into traditional coffee processing. But below 2 kilos of contaminant, traditional plants have to be progressively replaced by type 4 and 5 plants. The types 1, 2 and 3 are never competitive. At the lower possible level of contamination (0.5 kilos), traditional plants have disappeared.

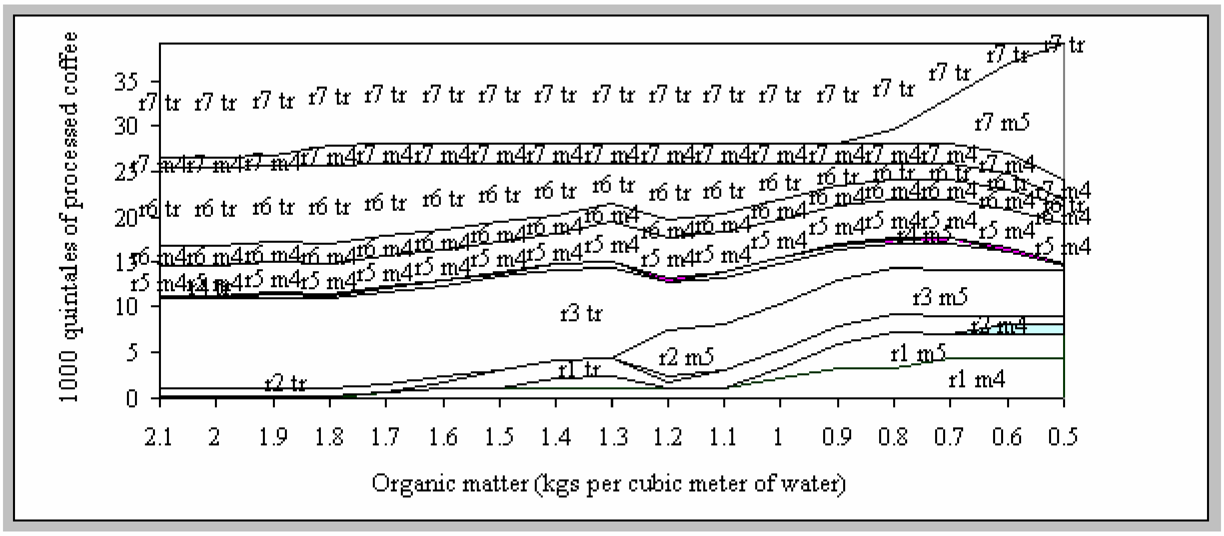

Figure 3. Processed coffee by plant type, river segment and contamination level.

At low ecological standards the model places the plants in the upper part of the watershed because distances to plantations are shorter. Only with higher ecological standards, does constructing new plants become cost effective in the lower part of the watershed, but with a much higher transport cost.

In the second scenario we apply an increasing premium for the coffee processed in modern plants and without ecological restriction. Figure 4 shows that with a premium of 26 lps per quintal (around $3 at the time of the study) all traditional plants are replaced with new plants. This premium is much lower than the $17 dollar premium that some modern plants obtain in Honduras. It suggests that new plants would be highly cost-effective in this region but only if coffee quality is improved.

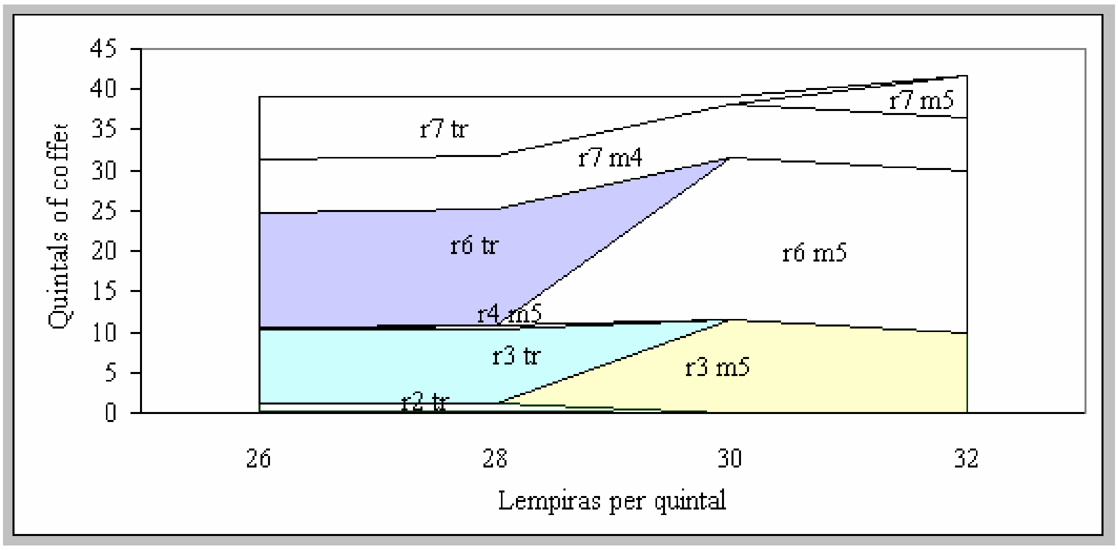

Figure 4. Effect of various price premium on coffee processing.

CONCLUSIONS

The analysis shows that it is cost effective for Honduras to improve the quality of both water and coffee bean through improved ecological plants. Since the private sector does not seem interested in investing in coffee processing and the government is reducing its intervention in such activities, farmers' organizations are the most likely to do it. The Honduran Coffee Producer association does have financial resources to start such program since they collect a relatively comfortable tax on coffee exports.

Cost minimization for the whole watershed addresses one of several necessary conditions for the success of centralized processing. Another necessary condition for the successful implementation of a centralized coffee processing system with environmental controls is sufficient financial incentive for all of the participants. Theoretically, the increased costs of pollution mitigation can be covered by an increase in the export price that producers receive. If this is so then a Pareto Superior solution is reached, and Honduras can improve its river water quality without risking the viability of small-scale coffee production.

Another condition is farmers' willingness to give up home processing. Not enough is known about the likely impacts of the loss of coffee processing on the household production system. Further research on the role of coffee processing within the household, and the alternative uses for household labor and capital should be explored.

The institutional setting of the coffee processing also needs to be determined. It is doubtful that the state will take charge of administrating new plants but there is a strong tradition of coffee cooperatives in the region, which might be capable of operating the processing plants. Alternatively private sector investors might enter into this enterprise through a concessionary system or full competitive one. If plant locations are determined by the market, the current tool will lose some of its relevance but still can help the private sector to compare different strategies. In case the location will be determined by a consensus between farmers' organizations and the private sector, the tool would be useful in order to take a more informed decision.

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