Traditional vs. Modern Production Systems: Nonmarket and Price Considerations of Cacao Producers in Northern Ecuador

1. Introduction

The link between the price premiums paid by affluent consumers in the North and the sustainability of the production practices of farmers in the South has been tightened during the last decades. Increasing awareness of environmental degradation and socioeconomic inequality has impacted consumers throughout the world who desire to confront these challenges through their purchasing behavior. The demand for environmentally and socially differentiated products has led to the creation of organic and fair trade (FT) commodities (LeClair, 2002; Smith, 2009). Indeed, great complementarities of the social and environmental objectives linked to these markets has led to a growing integration of FT and other eco-labels through multiple-certification providers, which verify that a good is fair trade and meets strict environmental standards (de Janvry et al., 2010).

In the regions where alternative markets operate, smallholder producers have found renewed incentives to invest their time and effort in using sustainable production systems, which include many traditional farming practices, such as agroforestry systems. These production systems provide farmers with economic and non-economic benefits, such as food, medicine, and cultural rewards. Yet, the need for cash, education, and other investments benefits the adoption of modern, more productive and genetically uniform, high-yielding crops (Harlan, 1975; Brush et al., 1992). The perspective of selling in alternative markets may provide incentives to move away from modern production systems, yet the smallholders' decision about what type of system to prioritize goes beyond a plain comparison of economic benefits. Especially in areas with pervasive market imperfections, household preferences and endowments have a strong influence on production decisions (Eswaran and Kotwal, 1984; Carter and Yao, 2002; Key et al., 2000; Benjamin et al., 1993).

While many studies have tried to quantify the impact of participation in alternative markets on farmers' welfare, most of the focus has been on examining the price premium or additional income received by farmers, compared to income in regular markets (Giovannucci et al., 2010; Calo and Wise, 2005; de Janvry et al., 2010; Ruben et al., 2009; Ronchi, 2006; Wollni and Zeller, 2007). These studies ignore the environmental attributes associated with the production of these specialty products and their interaction with farm-households' decisions. A few authors have looked at a wider notion of living standards (Bacon, 2005) and the non-market benefits of participation (Bechetti and Constantino, 2008), but these works have been mostly descriptive and do not integrate their analyses into a broader conceptual framework of farmer decision making.

In this study, we develop a farm-household model to explain how environmental factors, such as biodiversity, interact with price premiums received in specialty markets to impact the allocation of labor of smallholder households across different productive activities. Building on the seminal work of Jacoby (1993) and Skoufias (1994), we develop a link between the marginal benefits that households receive from planned biodiversity (Vandermeer and Perfecto, 1995) and the effective remuneration that their members receive for their work. This leads to a nuanced explanation of why farmers may prefer to work on farm and not participate in the labor market—environmental non-market benefits—which goes beyond the standard logic of transaction costs and typical market imperfections. It also shows how farmers' valuation of environmental benefits influences their economic behavior and widens the spectrum of reasons for the strong influence of factor endowments on small producers' decisions (known in the development literature as lack of separability or recursivity of household models). We also find that the identification strategy proposed by Jacoby (1993) and Skoufias (1994) to enable estimation of the shadow wage for household members does not deliver point identification in a setting with positive environmental benefits derived from farm labor. However, the implications of the effect of these ecological and social nonmarket goods on producer behavior can be derived.

The issue is inherently a crosscutting one that thematically falls in the growing body of research that integrates development economics with environmental economics. Our effort to formally integrate a micro-household model with environmental questions contributes to two major fields of applied economics: (1) to the recent research in environmental and ecological economics that has put considerable emphasis on valuing biodiversity, but has not tended to root it in a deeper portrayal of the household's full resource allocation problem (Nunes and van den Bergh, 2001; Nijkamp et al., 2008) and (2) to the slowly growing body of work in development economics that addresses environmental questions. This work blends both lines of work in the context of biodiversity effects on household behavior. As such, it also provides the groundwork for analyzing other dimensions related to smallholder participation in alternative commodity markets than has previously been available in the literature.

We apply this framework to the Ecuadorian case of cacao production, where two different farming systems for the production of cacao are utilized. One method raises a traditional variety of cacao, known locally as cacao Nacional, in an agroforestry system that can be sold in specialty markets for a premium because of its flavor characteristics that are demanded by gourmet chocolate makers. This cacao is often certified with FT, shade-grown, organic, and origin certifications in order to access these markets. The other method raises a modern, hybrid variety, referred to in Ecuador by the name CCN-51, in a shade-less, less diverse system. The latter is advertised as being more productive and profitable than the former. Yet, many smallholder producers continue to raise the former (El Cacao Volvió Ser la Pepa de Oro, 2007; Coporación de Promoción de Exportaciones e Inversiones, 2009; Bentley et al., 2004). This study found that the benefit of a diverse production system is an important component of the opportunity cost of time that families consider when they make decisions about how to allocate their labor to different production activities.

2. Agroforestry Systems and Farmers' Decisions

Traditional production systems in high biodiversity areas, such as the cacao agroforestry system in Ecuador, provide households economic, social, and cultural benefits (Bentley et al., 2004; Beer et al., 1998).These traditional cropping systems are more biodiverse than commercial systems and may reduce the need to apply agrochemicals, as they control the spread of pathogens (plagues that affect one crop are buffered from affecting other crops). The agroforesty system often mimics the planting structure of a native forest whose structure naturally prevents the spread of diseases through the spacing and random arrangement of diverse species (Reitsma et al., 2001). In addition, these intensive cropping systems provide shading that inhibits the growth of weeds and provide an abundance of organic matter that enhances the quality of the soil (Beer et al., 1998). Indeed, in many agroforestry systems, several varieties of leguminous plants are included in this system, which provides natural nitrogen to the system as well (Duguma, 2001).

There are two distinct components of biodiversity which can be recognized in agroecosystems (Vandermeer and Perfecto, 1995). The first component, planned biodiversity, is the biodiversity that is associated with the crops in the agroecosystem and varies depending on farmer management. The second component, associated biodiversity, includes all soil floras and faunas, as well as other living organisms that colonize the agroecosystem from surrounding environments. Planned biodiversity is managed by the farmers and has a dual function in the system. It directly promotes ecosystem functions, such as pest regulation and nutrient cycling, and indirectly creates conditions for the survival of associated biodiversity, such as insects and birds that are attracted to shade trees. Thus, cacao agroforesty systems create a synergy with the planned biodiversity, creating an environment welcoming to additional species.

In contrast, a principal cause of genetic erosion has been found to be the replacement by farmers of multiple local varieties and landraces for genetically uniform, high-yielding varieties (Harlan, 1975; Brush et al., 1992). While the adoption of these modern varieties has increased short-term crop productivity for some farmers, the consequent loss of genetic resources has increased the vulnerability of farmers to environmental changes, pests, and pathogens. These problems have exacerbated poverty and increased the level of food insecurity (Dasgupta, 1995). This phenomenon is also present in Ecuador, where farmers had been encouraged to replace their traditional agoforestry cacao fields with high yielding monoculture systems (Bentley et al., 2004). Indeed, the loss of diversity is an acute problem in Ecuador, which is one of the world's biodiversity hot spots due to its high concentration of threatened/endangered plants and species (Myers et al., 2000).

The additional food source provided by the intercropping of cash crops, such as cacao, with subsistence crops encourages the planting of various crops and agroforestry production systems as occurs in the traditional Ecuadorian cacao production system. In addition to food safety and environmental benefits, social and cultural benefits have shown to be important in the planting decisions of smallholder farmers (Becchetti and Costantino, 2008). Farmers recognize these benefits when choosing to invest in these cropping systems to maximize economic, social, and environmental benefits. This is the type of decision framework faced by Ecuadorian cacao farmers and other smallholder producers throughout the world.

Barnum and Squire (1979) developed the household model to show how all decisions of smallholder families are interrelated. Production and consumption decisions are not made independently. Agricultural production, education, migration, and household food allocation are thought to depend upon current or future opportunity costs of time (Rosenzweig and Evenson, 1977; Rosenzweig and Schultz, 1982; Jacoby, 1993; Skoufias, 1994; Le, 2010).

The opportunity cost of time or shadow wage is a key articulating variable that is able to capture both the market and non-market benefits of productive activities because it is a measure defined in terms of utility, not economic profits. This is relevant because smallholders' decisions in developing countries are equally affected by market and non-market factors. For example, Arslan and Taylor (2009) discovered that Mexican families choose to plant traditional maize instead of the hybrid variety because of the extra utility received from the taste of traditional maize, even though the hybrid variety was more productive and profitable. Furthermore, Indonesian farmers were found to be willing to accept a price lower than full compensation for lost profits when growing cacao in a traditional agroforestry system instead of the more productive modern system because of the additional nonmarket ecological services provided in agroforests (Steffan-Dewenter et al., 2007). Even in the United States, some Floridian ranchers also prefer agroforerstry practices in spite of lower returns, compared to more intensive agriculture systems (Shrestha and Alavalpati, 2003). Thus, to truly understand smallholder farmers' production decisions, nonmarket as well as market values must be integrated into the analysis.

3. Conceptual Framework

3.1. A Farm-Household Model with Nonmarket Benefits

Standard economic frameworks to analyze the benefits and costs of specialty crops generally include only monetary benefits. LeClair (2002, 2008) and Hayes (2008) base their analyses on standard consumer-worker utility models, which do not take into account that commodity producing households face multiple complex decisions in their producer-consumer-worker role. These complexities not only yield standard economic frameworks inadequate for estimating the price premium effects on producers' labor and production behavior, but also completely ignore the ecological externalities that arise from environmental standards.

To explain the impact environmental services provided by agroforestry systems have on the decisions of smallholder households, we propose a farm-household model that includes the production decisions of the household and the associated potential biodiversity nonmarket benefits linked to this production, in addition to the standard labor/consumption dimension. We focus on capturing the effect of *planned biodiversity*, which as we explained earlier is the component of biodiversity that the farmer manages and which provides direct and indirect benefits (see section two). We further allow for the presence of market imperfections, which are prevalent in rural economies. Consider a household which maximizes its utility by consuming market goods (C), home time (l), and non-market goods such as the benefits from planned biodiversity (V), which are the byproducts of cash crop production. Household characteristics, such as family size or ethnicity, influence household preferences and are included in vector D. The labor supply of the household (h) is the total stock of time for the household (T) minus home time (l) and is divided among three activities: market labor (M), farm labor for cultivation of a cash crop in a traditional agroforestry system (L_1), and farm labor for cultivation of the crop in a modern homogeneous system (L_2), so that $T - l = L_1 + L_2 + M = h$. This time constraint, together with the budget and other market constraints faced by the household, shape its decisions as follows:[i]

$$\text{Max}_{C, L1, L2, M, H,} U(C, l, V; D)$$

subject to:

$$p\, Q(L_1, L_2, H; A) - \omega H + \omega M + K = C \qquad (1)$$

$$V = V(L_1, L_2, H; A) \qquad (2)$$

$$T = L_1 + L_2 + M + l \qquad (3)$$

$$K \geq \omega H \qquad (4)$$

$$\overline{M} \geq M \geq 0 \text{ , } L_j > 0 \qquad \text{for } j=1,2 \qquad (5a,b)$$

Constraint (1) states that total expenditures on market goods cannot exceed total income, which is derived from both the value of the family's labor in the market at wages ω and the sales of farm output of cash crops $Q(L_1, L_2, H; A) = \sum_j Q_j(L_j, H; A)$ at prices p, plus liquidity (K) available to the farmer at the beginning of the period. The cash crop is produced with family (L) and hired labor, H. A is a vector of quasi fixed assets (e.g., land). Equation (2) defines additional benefits of on-farm labor, V, which are obtained by small producers who intercrop their cash crops with other crops and forest plants for self-consumption. Equation (3) is the time constraint mentioned above, (4) limits expenditures on hired labor to the value of the household's liquidity, (5a) allows for the possibility that farmers may face constraints in the labor market limiting the levels of labor that can be sold, and (5b) reflects the fact that farmers may choose to grow all of their cash crop in either the traditional or the modern system. We designate $\overline{M}$ as the upper limit of off-farm work that a farmer will find in the market. Also, the amount of labor sold cannot be negative, but

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[i] For better readability, we include below a table with all symbols used (Table 1).

may be zero. The production and utility function are assumed to be increasing, strictly concave and continuously differentiable in their arguments.[ii]

In sum, we assume that small cacao farmers face different constraints that limit the amount of utility they can receive and shape their production decisions. In particular, the standard logic that a price premium received for a product directly increases farmers' supply of labor to produce more of that good (LeClair, 2002) may not hold here since these households face constraints and have preferences that determine limitations to and trade-offs of increasing some product amount.

The Lagrangean function associated with this model is:

$$L = U(C, T - L_1 - L_2 - M,\ V(L_1, L_2, H; A); D) + \lambda[p \textstyle\sum_j Q_j(L_j, H; A) - \omega H + \omega M + K - C]$$
$$+ \mu_K(K - \omega H) + \mu_0 M + \mu_M(\overline{M} - M)$$

Examining the first order optimality conditions (FOCS)[iii] allows us to derive several important implications for the economic decisions taken by small producers described by the optimization problem. First, in a context of perfect markets and zero biodiversity benefits, agricultural households will choose to work and purchase inputs and consumption goods until the marginal product or utility of these equals their market price as follows:

$$\partial U/\partial l \,/\, \partial U/\partial C \equiv w_j^* = p\partial Q_j/\partial L_j = \omega \qquad (6)$$

$$p\partial Q_j/\partial H = \omega \qquad (7)$$

As it is standard, optimality conditions require that the marginal value product of on-farm labor ($MPL_j = p\partial Q_j/\partial L_j$) be equated to the marginal rate of substitution between home time and

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[ii] Family labor is assumed to be strictly positive and the household not constrained in inputs markets.

[iii] The derivation of the first order conditions is shown in the appendix section, along with the Kuhn-Tucker conditions for variables that can have corner solutions. The Kuhn-Tucker conditions identify a candidate for optimality. We ensure that this candidate is a global optimum by the previously made concavity assumptions and by imposing the constraint qualification that the constraints form a convex set and a feasible interior point can be found (Bazaraa and Shetty 1979).

consumption (MRS= (∂U/∂L)/(∂U/∂C)) and to the marginal cost of labor or market wage ω. The MRS defines the opportunity cost of time or shadow wage for household members, w^*, (*shadow* because it is generally not observable from production or consumption data, since it involves marginal utility terms). This key variable articulates the decisions of pluriactivity households, considering the interaction between the preferences of farmers and their families and the overall economic environment in which they operate. While not directly observable, this marginal cost of time can be identified, as it is equated to the marginal productivity of labor, is observable, and under perfect labor markets is also equated to the market wage. Similarly, the marginal productivity of hired labor is equated the market wage in (7).

The presence of non-market environmental and self-consumption benefits associated with on-farm labor and labor market imperfections changes the former condition to:

$$\partial U/\partial l \,/\, \partial U/\partial C \equiv w_j^* = p\partial Q_j/\partial L_j + \gamma_i^* \partial V/\partial L_j = \omega + \mu_0/\lambda - \mu_M/\lambda \qquad (8)$$

where $\gamma = (\partial U/\partial V)/(\partial U/\partial C) > 0$ and λ, μ_0, μ_M are non-negative shadow values for income and for participation in and for access to the labor market, respectively.

The first two terms of this equation reflect the fact that with planned biodiversity benefits, the mere productivity of labor in terms of the cash crop will not reflect the full opportunity cost of time. Additional to MPL, important components of w^* are the utility or disutility received from these non-market byproducts of labor (MPV=$\partial V/\partial L$) and the household's subjective valuation of these benefits ($\gamma = (\partial U/\partial V)/(\partial U/\partial C)$). The fact that these two terms influence the rewards to on-farm labor has important consequences, as it makes evident that it is not only the price premiums in specialty markets that may influence farmers decisions to work and produce more of these products, but also the environmental standards and the farmers' valuation of the environment. However, these terms are not observable from standard production and consumption data. Furthermore, estimating MPV has proven to be a daunting task when it is associated with biodiversity, as it is almost impossible to consider the entire range of biodiversity benefits. Therefore, available estimates generally provide at best lower bounds to the unknown value of biodiversity changes (Nunes and van den Berg, 2001).

The second equality reflects the fact that, in the presence of market imperfections, the market wage is not a good indicator of the value of time for an average household. For example, household members may face limitations to labor market participation that deter them from supplying the desired amount of labor to the market (M= $\bar{M}$). In that case, $\mu_M \geq 0$ and $\mu_0 = 0$, and the market wage is far above their reservation or shadow wage ($w^* \leq \omega$). Alternatively, some household members may not participate in the market (M=0) when the market underestimates the opportunity cost of labor time. This may be the case when some goods produced on-farm or at home are not traded in the market. In this case, $\mu_0 \geq 0$, $\mu_M = 0$ and $w^* > \omega$. Thus, only when labor markets are perfect, and condition (4) is not binding for M, is the market wage a good measure of the opportunity cost of time for families ($w^* = \omega$).[iv]

Further market limitations resulting in lack of liquidity at planting time will change the equilibrium condition for purchased labor in equation (7) to:

$$\gamma^* \partial V/\partial H + p \textstyle\sum_j \partial Q_j/\partial H = \omega(1+\mu_K/\lambda) \qquad \text{for } j=1,2 \qquad (9)$$

where γ and λ are as in (8) and μ_K is the non-negative marginal utility of liquidity. The latter optimality condition reflects the fact that liquidity constrained households make hiring decisions using higher than market wage values. Thus, this constraint induces liquidity constrained households to use less purchased inputs than is optimal at market price (Vakis et al., 2004).

[iv]The fact that a producer's optimal choice of on farm labor does not need to equate w^* with the market wage when there are market imperfections has previously been shown in the literature of farm-household models (Jacoby, 1993; Arslan and Taylor, 2009; Le, 2009).

Manipulating the first order conditions of the model yields optimal supply and demand equations for production and inputs in terms of the product price *p*, the shadow prices for the inputs (w_j*, p_z*), and the quasi-fixed production factors *A.* These shadow prices are in turn functions of household environmental preferences γ and liquidity constraints μ_K. This implies that production is not independent of household preferences and endowments—as can be seen by substituting these optimal functions into the production equation:

$$Q^o_j = Q^o_j\,(L^o_j(p, w_j^*(w, \gamma , A), H^o(p, w, \mu_K ; A) \qquad (10)$$

In order to estimate a measure of w*, previous studies calculate the marginal productivity of labor by estimating production in terms of optimal input levels. Because the latter are endogenous, as shown above, researchers have used instrumental variables or predicted measures of input use (see, e.g., Skoufias, 1994; Le, 2010), yet they have not accounted for the influence of variables related to environmental valuation or liquidity constraints. Failing to do so will generate omitted variable biases, which in turn will bias MPL estimates.

In sum, existing methodologies to estimate households' shadow wages are inappropriate for developing country contexts where market imperfections prevail and where the type of environmental nonmarket goods described in this model are present. In particular, previous studies analyzing developing country contexts have relied on the equalization of the shadow wage with the MPL to identify the cost of time for households that do not participate in the market, yet none of these models has analyzed environmental effects of production. Our model explains why economic models neglect the analysis of the environmental component: it is an impediment to point-identify the shadow wage estimates and to perform labor supply estimations. In the next sections, we estimate a lower bound of the shadow wage of labor in our empirical application.

3.2. Countervailing Market Imperfections

As seen by examining the first order conditions of the model, the relative size of the shadow wage with respect to the market wage determines whether and what type of constraints households face in allocating their time as they wish.[v] Even though the total value of the shadow wage cannot be determined exactly, we can derive important implications about the effect of planned biodiversity on farmers' labor supply behavior based on the observable market wage and marginal value product of labor for the cash crop, MPL. We examine the case, without loss of generality, where $\partial V/\partial L$ is positive—one can always redefine the negative environmental effect of an activity as the positive effect of not doing this activity. Furthermore, the sign of $\partial V/\partial L$ for specific production activities can be empirically tested, as will be shown later.

Analyzing the first equality in equation (8), we find that MPL bounds w* from below (MPL ≤ w*). Thus, when MPL is observed to be greater than ω, one can deduce with certainty that $w^* > \omega$. This indicates that households' time value is underestimated by the market, regardless of environmental externalities. Thus, this case is unambiguous and observable. To the contrary, the case where MPL is observed to be lower than the market wage (which has been the case in most applied studies reviewed) calls for additional information about the size of the non-market benefits from on-farm labor and the valuation by households of these benefits, in order to know whether or not a household is constrained in the labor market. Specifically, we can separate two different cases:

i. $\gamma^*\partial V/\partial L > (\omega - MVP_L) \Rightarrow w^* > \omega$

 The market undervalues the opportunity cost of time

[v] For example, a market wage higher than the time allocated to work on the farm-household, $w^* < \omega$, indicates that households would be better off if they allocated more time to work off-farm. Doing so would raise the marginal opportunity cost of time until $w^* = \omega$. Yet, the unavailability of employment prevents them from reaching such an equilibrium.

ii. $\gamma^* \partial V/\partial L < (\omega - MVP_L) => w^* < \omega$

Household faces under- or unemployment

These equations show that the value of environmental benefits associated with planned biodiversity can be seen as a countervailing effect to labor market constraints. These non-market benefits help offset the difference between market and shadow wages, and if large enough may fully change the relative value of the opportunity cost of on-farm work. In other words, lack of labor market participation could be explained by a growth in productivity due to biodiversity, which increases the shadow wage high enough so that the higher benefits of on farm work exist relative to market work.

The work regime to which the households in a specific context belong can then be explored in the estimation. Although the term reflecting marginal side products of the labor used in production, $\partial V/\partial L$, is difficult to measure because of both the multidimensionality of V (composed of self-consumption, medicinal plants, shade for the cacao, education of children, continuation of cultural identity) and the missing markets for some of its components (such as cultural or traditional values), we use a proxy measure (see the estimation section below), which allows for the estimation of a lower bound for the shadow wage and lies between MPL and w*.

4. Application to the Ecuadorian Cacao Market

The production of cacao in Ecuador provides a particularly relevant example of how differences in the cacao production systems allow for differences in the shadow wage for traditional and modern production methods. Examining the terms that enter the calculation of w^* in (8), $(p\partial Q/\partial L + \gamma_i^* \partial V/\partial L)$, shows that the labor invested in different types of crops or crop varieties may have systematically different shadow wages when (1) farmers sell in different markets or at different prices, (2) the marginal cash-crop productivity of labor differs consistently across the crops or crop varieties, (3) the marginal productivity of planned biodiversity or degree to which crops are intercropped differ systematically, and (4) the valuation of these benefits differ across households.

As noted earlier, the Ecuadorian cacao industry consists of two varieties; cacao Nacional (raised traditionally in agroforestry systems) and cacao CCN-51 (a modern variety grown using less intercropping). In addition, there are two principal markets for cacao in Ecuador: the commercial market, where cacao Nacional and cacao CCN-51 can be sold, and the specialty market, which pays a premium for cacao Nacional because of its flavor characteristics. Thus, Ecuadorian cacao production can be described using three distinct shadow wages. The shadow wage for each market can be written using the following equations earned for cacao Nacional:

Conventional market for cacao Nacional: $w_1^* = p_c \partial Q_1/\partial L_1 + \gamma^* \partial V/\partial L_1$

Conventional market for cacaco CCN-51: $w_2^* = p_c \partial Q_2/\partial L_2 + \gamma^* \partial V/\partial L_2$

Specialty market for cacao Nacional: $w_3^* = (p_c + a)\, \partial Q_1/\partial L_1 + \gamma^* \partial V/\partial L_1$

where Q_2 represents the quantity produced using the modern CCN-51 production, p_c stands for the selling price in the conventional market, and $p_S = (p_c + a)$ for the price in the specialty market with the premium a.

The first observation that can be made based on the above equations is that, on the grounds of time rewards, farmers growing cacao Nacional will prefer to switch to the specialty market if selling in that market does not imply changes in the marginal productivity of labor (comparing w_1^* with w_3^*). In this case, they will always be better off with a price premium. This is not the case for farmers who grow cacao CCN-51. First, when alternative markets are unavailable, CCN farmers compare w_2^* and w_1^* to decide on their labor allocation. Thus, farmers grow CCN-51 only if the difference in marginal value product of labor in CCN versus

Nacional exceeds the difference in the value to them of biodiversity benefits from Nacional versus CCN: $\gamma*(\partial V/\partial L_1 - \partial V/\partial L_2) < p_c* (\partial Q_2/\partial L_2 - \partial \boldsymbol{Q_1}/\partial \boldsymbol{L_1})$. Indeed, based on our literature review of modern versus traditional systems, we hypothesize that the marginal productivity of labor used in the modern system, in terms of the cash crop, may be larger than in the traditional system, yet the marginal productivity in terms of biodiversity is higher for the traditional system ($Q_2/\partial L \geq \partial Q_1/\partial L$ and $\partial V_2/\partial L \leq \partial V_1/\partial L$). With the price premiums offered in specialty markets, the productivity difference using CCN has to be even larger (by the amount of $a* \partial Q_1/\partial L_1$) for farmers to be willing to grow CCN instead of Nacional.

5. Empirical Implementation

In order to estimate the marginal productivity of labor and the shadow wage of agricultural households, we build on the approach that was first implemented by Jacoby (1993), which allows estimation of the shadow wage under market imperfections. Jacoby's method consists of two main steps. First, the cash crop production function, Q, is estimated in terms of inputs using instrumental variables to predict labor and other inputs. This yields an estimate of the labor elasticity of production (α), which is used in the second stage. This second stage consists of calculating MPL = $p\ \alpha\ \hat{Q}/L$, where $\hat{Q}$ is the predicted output from the first estimation.[vi]

Our approach differs from Jacoby's in several aspects. First, instead of only estimating cash crop production, we jointly estimate cash crop and production of *planned biodiversity*, V.[vii] This allows us to recover the marginal effect of labor on both Q and V and to determine the significance and sign of $\partial V/\partial L$ to confirm whether significant positive marginal benefits exist in cacao production. Second, we allow for different marginal returns across production systems and test for their significance. We can then calculate the relative magnitudes of $\partial Q_2/\partial L$ and $\partial Q_1/\partial L$,

[vi] Recall that elasticity α can be expressed as α = log(Q)/log(L)= $\partial Q/\partial L*L/Q$. Thus, $\partial Q/\partial L$= α*(Q/L).
[vii] We use the total number of plant species in all parcels of the farm as a proxy, including plants and trees used as shade providers and windbreakers, and for ritual, medicinal, or ornamental purposes.

as well as $\partial V_2/\partial L$ and $\partial V_1/\partial L$, providing an idea of the relative incentives to invest labor in the different cacao production systems of Ecuadorian farmers.[viii] Third, we compare MPL and ω to find out whether the labor-constraint regime faced by households is identifiable. Finally, we assign market values for different plant species grown as a way to use a measure of γ, capturing some of the economic benefits of these species, yet not including multiple non-pecuniary benefits mentioned above. The latter four steps allow us to calculate a lower bound measure for the shadow wage of labor in the different activities.

Another important difference in our approach with the traditional one is that, as explained conceptually, our model calls for inclusion of liquidity-constraint and environmental valuation related variables as part of the instruments explaining optimal input quantities. This stands in contrast to the standard applications of Jacoby's method, which generally only include household composition and price variables. Another practice that is used in the literature to simplify the method is to normalize all prices by the market price of the cash crop p. The problem with this strategy in a setting of imperfect or segmented markets is that farmers often face heterogeneous markets/prices. In our specific case, this type of imperfection arises because of the existence of specialty markets with limited demand. Thus, separate shadow wages are estimated depending on whether farmers have access to specialty markets or not.

5.1. Data

We examine production data at the parcel level from 69 parcels of cacao in northwestern Ecuador belonging to 50 smallholder households for whom cacao raising is their main economic activity. Extensive data were collected from these randomly selected households in July and August of 2009 in the rural region where the provinces of Santo Domingo, Esmeraldas, and Pichincha intersect. The survey consisted of three main sections, each with a different unit level: first, an

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[viii] We follow the literature in using Cobb Douglas production forms and estimating them in log terms.

individual level section that registered basic demographics for each household member, such as gender, ethnicity, age, education, occupation, employment, income, asset ownership; second, a parcel level section that included data, for each parcel farmed, on size, way of acquisition, years since it was acquired, the type of crops, plants and trees grown, their density and age, the slope of the land, amount and value of inputs used for production in different faces, the time required for their application and other labor required, amounts of production, sales and sale prices; barriers to market access. A final section at the household level inquired about home characteristics, farm characterization, farm and non-farm activities, levels of soil fertility and biodiversity over the past six years and expectations for the future, perceptions of water quality and health.

A large part of the survey region was originally inhabited by the indigenous Tsa’chila nation that currently lives in seven communities around the city of Santo Domingo. Thus, 32% of the households in our sample are indigenous, and 68% are Afro-Ecuadorian and Mestizo families (See Table 2). Also, the fact that most cacao production in Ecuador is in the hands of small holders is reflected in our sample, where the majority of the farmers operate on less than 10 hectares of land.

These farmers have in their parcels, on average, 554 trees of cacao per hectare. Of these farmers, 92% have an average of 4.1 different types of intercropped perennials (the majority having plantain trees mixed with a few fruit trees), 66% have an average of 3 intercropped native tree types (such as Cascarilla, Arrayan, Bolsa, or Teak), and 14% of them also have 2.8 different types of intercropped annual plants (crops, legumes, and medicinal). Of these farmers, 76% grow cacao Nacional on the majority of their land and 24% have a majority of CCN. They produce on average 8.8 quintals of cacao per hectare in parcels that range from 0.5 to 30 hectares.

Because of the extensive focus on cacao production, this region has been the target of organizations seeking to purchase high quality cacao from farmers in order to make cacao paste, which is then exported to high quality chocolate producers in Europe. In our sample, 32% of the farmers have access to a processing center run by Fundación Acción Social Caritas (FASCA), a local nongovernmental organization, which purchases cacao in wet form, before it is fermented or dried, so that it can complete the processing stages to highest standards. These farmers receive a better price for their cacao from FASCA, which also pays for organic and other certification costs for the farmers if their cacao qualifies, and then pays a higher premium for this certified cacao.

5.2. Empirical Model

To determine the MPL and the MPV in cacao production, we simultaneously regress two equations, one for cacao production and the other for planned biodiversity, in terms of inputs, quasi-fixed production factors (land area and land characteristics that influence production), and other factors that may influence production or production techniques. Specifically, we use maximum likelihood estimation to fit a seemingly unrelated regression model of cacao and planned biodiversity production at the parcel level, adjusting the standard errors for intra-household correlation using the method explained by Gould et al. (2006). The estimated equations are:

$\log(Q)$ =, $\alpha_0 + \alpha_1 \log\widehat{L_f} + \alpha_2 \widehat{Nal} * {*}\log\widehat{L_f} + \alpha_3 \log\widehat{L_h} + \alpha_4 \log\hat{Z} + \alpha_5$ Flat + α_6 Hilly + α_7 Area + α_8 Insecure land + α_9 Tree density + α_{10}Tree age + α_{11} Ethnicity + ε

$\log(V) = \beta_0 + \beta_1 \log\widehat{L_f} + \beta_2 \widehat{Nal} * \log\widehat{L_f} + \beta_3 \log\widehat{L_h} + \beta_4 \log\hat{Z} + \beta_5$ Flat + β_6 Hilly + β_7 Area + β_8 Insecure land + β_9 Years parcel owned + β_{10} Ethnicity + ε

These equations share some of the explanatory factors, such as family and hired labor (L_f, L_h), other inputs Z (organic and inorganic fertilizer, pesticide, insecticide, seed), and characteristics and extension of the parcel (flat, hilly, or steep slope; area in hectares; whether household has secure ownership of the parcel, depending on the type of acquisition). Additionally, for cacao production, we include the age and density of the trees, as well as the ethnicity of the decision maker. For planned biodiversity, we take into account how long the household has owned the worked land and the ethnicity. The reasoning for the inclusion of these controls is explained below. The factor coefficients are interpreted as elasticities.

For family labor, we include an interaction term that allows the marginal productivity of labor to vary depending on the type of cacao variety used (Nacional versus CCN). In particular, while the family labor elasticity of production and biodiversity in the CCN system is displayed by α_1 and β_1, respectively, this same effect on production and biodiversity in the Nacional system is ($\alpha_1 + \alpha_2$) and ($\beta_1 + \beta_2$). In order to avoid endogeneity issues, we predict the probability that a household will grow Nacional versus CCN and interact it with the family labor variable. All variables with an emphasis represent predicted measures. Table 2 presents the detailed description of all the explanatory variables, as well as the instruments used for each equation. As we explained earlier, we include household composition variables, prices, and wages as explanatory variables of potentially endogenous regressors, as well as variables related to liquidity constraints (such as whether the household owns a car or motorcycle) and preferences for biodiversity (ethnicity, quality of land, water, and biodiversity in own farm three years ago).

Total farm labor effects are expected to be positive for both equations—$(\alpha_1 + \alpha_2)>0$ and $(\beta_1 + \beta_2)>0$—as more labor would lead to higher production. A similar conclusion can be made about the variable for the other inputs. This coefficient would be expected to be positive for cacao production in particular, although it might not be for the biodiversity equation. We expect cacao Nacional production systems to be more diverse than CCN-51 cropping systems; thus, the coefficient of family labor in the Nacional production system ($\alpha_2>0$) is expected to be positive in the biodiversity regression. Since Cacao CCN-51 has been promoted as having higher yields than cacao Nacional, the family labor and hired labor effects would be expected to be larger than the effect of family labor for cacao Nacional alone ($\alpha_2<0$) in the cacao production regression.

The variables flat and hilly are interpreted with respect to steep slope in the regressions. The steep slopes would be expected to be the most biodiverse parcels. Farmers tend to plant the flat areas with the cash crop first, as they are easier to maintain and harvest. To prevent erosion, the farmers in this area often grow trees and bushes on the steepest slopes or leave them forested, as the steep areas are often on stream and river banks. Thus, the steeper areas would be more likely to be more biodiverse than other areas. The coefficient for flat would be expected to be a large negative number, while the coefficient for hilly would be expected to be a smaller negative number.

The variable for insecure land rights definitely would be expected to have an impact on the biodiversity regression. Households that fear that their property rights may be removed would only invest in crops with short harvests, such as annual crops, instead of trees, which do not provide revenue for several years. Thus, the insecure land rights variable would be expected to have a negative coefficient in the biodiversity equation. The variable for the initial land size is a measure of the area planted by the household. This could determine its ability to invest in its farm in order to increase production. A positive coefficient would be expected for this variable in the production equation.

Ethnicity is another important variable in the equations. This variable is included as a dummy variable distinguishing between those households that do and do not have a member of the indigenous Tsa'chila nation as its head. There is a significant population of Tsa'chila who farm large areas of the region. The culture of the Tsa'chila is distinct from the rest of the population. They believe that all plants and animals have spirits and need to be protected. This belief would suggest that they would be more likely to protect the various varieties of plants and animals on their land. In addition, they use many medicinal plants that they grow in their fields, which would add to the diversity of plants in their fields. So the ethnicity coefficient in the biodiversity regression would be expected to be a positive, but may be negative in the production regression as Tsa'chila farmers do not have as much training in modern agricultural practices.

The length of time that someone owned property would also influence the biodiversity equation. The longer a household has owned land, the more it would be expected to invest in trees and other crops with long-term returns. So they would be expected to have larger biodiversity coefficients. Since cacao becomes more productive over time, the coefficient for the age of the trees would be expected to be positive for the production regression. For cacao production, the age and the density of the cacao trees are also expected to have positive coefficients since mature trees give more fruit and closer planting may result in higher yields.

6. Results

6.1. Estimated Results of the Production Equations

The estimated coefficients for the variables determining production of cacao and related biodiversity are presented in Table 2. The most important input used for cacao production and planned biodiversity on these farms appears to be family labor, whose elasticity coefficient is 0.31 in the cacao production equation for both types of cacao, 0.22 for cacao CCN in the biodiversity equation, and 0.29 for cacao Nacional in the biodiversity equation. Thus, family labor has a positive impact on planned biodiversity, which is larger in parcels with a majority of cacao Nacional (as hypothesized). Although family labor does not have a differential impact in percentage terms on cash crop production,[ix] the marginal productivity of labor derived from this elasticity will be lower for more labor intense farms or production systems.

Hired labor and other inputs have smaller coefficients, which are not significant for either type of yield. The large differences in the coefficients between hired labor and family labor reflect the fact that hired labor and family labor are not good substitutes in either type of production. Other variables that significantly explain the cash crop production regression are tree density and tree age, both of which have a positive effect on cacao production, as expected.

Land and several aspects related to land ownership are found to be very important determinants of biodiversity, yet not so of cacao production. For example, the surface of the land, whether flat, hilly, or steep, has a significant impact on biodiversity and cacao production. Flatter parcels tend to have a lower number of plant species, relative to steeper land. This result confirms the observations that farmers plant the steeper areas with trees and bushes to prevent erosion. This conclusion complements previous research which found that land steeper landscapes are more likely to be forested (Kellman et al., 1998). Kinnaird et al.(2003) found that in Sumatra deforestation occurred six times faster on flat areas as compared to hilly surfaces.

A similar effect is observed through the initial amount of cultivated land. This coefficient suggests that less wealthy farmers have more diverse fields, since they may need to plant additional crops in the plots to meet their subsistence needs. In addition, experimental evidence has shown that poorer households are more risk averse than wealthier households (Yesuf and Bluffstone 2009). As crop diversity reduces production and market risks, these households

[ix] The marginal productivity of labor may still be lower for more labor intensive farms or systems.

would have diversified fields in order to mitigate risk (Di Falco and Chavas, 2006).

We also found that the number of years that households have owned their land is also positively correlated with biodiversity. This result complements earlier discoveries on land tenure and investment. Farmers who own their land longer have had more time to invest in their land including planning more perennial crops thus enhancing crop diversity (Li, Rozelle, and Brandt, 1998). Furthermore, our conclusions support the conservation literature, which suggests that insecure property rights have a strong negative effect on forest conservation and biodiversity (Amacher et al., 2008). However, insecure property results did not significantly affect cacao production. The result may be due to the fact that the sample is composed mostly of low income farmers with small noncommercial farms. Differences in access to credit because of land insecurity (Eswaran and Kotwal, 1995), which affect productivity, are minimal in our sample. Those households with land titles have very little extensions of land to serve as collateral.

Finally, the variable indicating whether the household head belongs to the indigenous Tsa'chila group or not indicates that households with this type of ethnic trait have more biodiversity but less cacao production, relative to other households in the sample. This result supports the hypothesis that the Tsa’chila would choose to leave their lands forested for cultural and spiritual reasons and that they would produce less crops because they have less knowledge about modern agricultural practices. This result complements findings that indigenous communities throughout Latin America, Africa, and Asia are more likely to have diversified production systems and are slower to adopt modern technologies (Brookfield and Padoch, 1994). Beliefs, customs, and cultural practices discouraged the Tsimane indigenous community in Bolivia from participating fully in the market economy (Godoy et al., 2005).

6.2. Shadow Wage Results

From the family labor coefficients in the previous section, the shadow wage is calculated for one day of family labor. Our results are presented below. The two different components of our shadow wage are from cacao production (w_Q*= $p(\partial Q/\partial L)$) and the benefits from biodiversity (w_V*= $\gamma\ \partial V/\partial L$). These two terms represent the value of both an extra quintal of cacao and the amount of an extra-variety that can be produced with an extra day of labor.

The value of biodiversity or of adding an extra variety consists of multiple market and nonmarket components. Some of these, such as self-consumption or production of substitutes for medicinal plants, may be easier to estimate, but others, such as ornamental or ritual use, are at best difficult to estimate. In this sense, the value of biodiversity is "hypothetical". However, a lower bound can only be created for this value based on the market price of goods for self-consumption, which will apply for specific cases. For example, if cacao Nacional is intercropped with cassava, producing 50 quintals per intercropped hectare, at 7 US dollars per quintal, the marketable $\partial V/\partial L$ for this variety would be 0.49. Thus, assuming that the subjective value γ is close to the market value, additional shadow wage due to intercropping would be about 3 US dollars per hectare. If cacao Nacional is intercropped with oranges, the shadow wage would be at least 1.10 US dollars higher (for 4000 Units/ha at 0.04 US dollars per unit). Added to this shadow wage would be benefits, such as shade, soil enhancement, ornamental and cultural value, medicinal and ritual uses, etc.

In order to capture some of the market benefits of the planned biodiversity from cacao production, we created a price index that accounts for the market value of all the plants that farmers grow on their farms. We use production values for fruits and crops, and plant values for trees and plants that do not yield a product. For perennial trees, we use annualized values.

Multiplying our price index by $\partial V/\partial L$ yields our estimates for w_V* presented in Table 3, column 2. Column 1 contains the estimates for the shadow wage component of cacao production, w_Q*, for different production systems and for different markets. Column 3 adds these values to form the lower bound, $\underline{w}$*, by market and cacao system.

These results show that the estimated $\underline{w}$* in all markets and production systems is larger than the maximum wage attainable in the market (the range of all daily wages in the market is between 7 and 12 US dollars). In fact, people could earn as much as 5 US dollars extra for a day of working on their own farms.[x] This shadow wage can be higher than the market wage because hired labor and family labor are not substitutes, and family size limits the available family labor.

The magnitude and type of extra benefits will depend on the production system used by farmers use and the market where they sell. If farmers did not diversify and plant other species with their cash crop, the relevant shadow wage for them would be w_Q*, the portion of earnings obtained from cacao production only. This value is still in the range of high market wages across markets and systems. This range of wages is generally paid when no meals are provided for workers, meaning that w_Q* alone provides sufficient incentives for farmers to work on their own farms, relative to working off-farm in the agricultural sector. That is, the market unambiguously underestimates the opportunity cost of family labor in our sample.

The highest cash rewards would be attained when planting the majority of the land with CCN-51 and selling in the standard market, while the lowest cash benefits would be attained with Nacional in the standard market. However, adding biodiversity benefits, families may be better off by growing cacao Nacional regardless of which market they sell in. This result is

[x] An important qualification of this result has been pointed out by an anonymous reviewer. Because selling several different products from intercropped plants in the system is not as easy as selling a single one (just cacao), the present way of calculating a market price for the shadow wage may be problematic. As we point out in the conclusions, new empirical methods for measuring shadow values need to be explored.

consistent with the fact that, in spite of all the advertisement for the higher productivity of CCN-51, 76% of our farmer sample still grow Nacional in the majority of their plots, and of those growing mainly CCN, 62% still keep some parcels with Nacional as well. Moreover, when asked what type of cacao they would like to plant in the future, 60–70% of the farmers across production systems said they would like to plant Nacional.

The difference in the shadow wage portion from cacao production (w_Q*) for cacao Nacional growers who sell in specialty markets versus those who sell in standard markets is not very large. While w_Q* is higher for farmers selling in specialty markets, a closer examination shows that in spite of the price premium received in specialty markets, the small difference in labor rewards is due to the high amount of labor required by specialty market producers. Moreover, specialty market producers have seen the value of their biodiversity reduced as the estimate for wv* shows, compared to their counterparts who sell in the standard markets. This is likely due to the intensification of cacao plants per hectare to fulfill the volume requirements to participate in the specialty markets, which results in less intercropping. Overall, a family selling their cacao in the specialty market may obtain about 1.30 US dollars more than a family selling CCN-51 in the standard market, yet the reduction in plant diversity will be associated with lower shadow benefits of ($1.57 US dollars) relative to Nacional growers who are not under the pressure of volume requirements. Altogether, this analysis produced a result that would seem to contradict conventional economic theory. Households could prefer to raise cacao Nacional instead of cacao CCN-51 even though cacao CCN-51 is more profitable. Our results also revealed that the cacao Nacional production system provides benefits that are not captured in a standard production analysis. Shadow prices include additional values that households obtain from cacao production.

7. Conclusions

The need exists to better conceptualize the production decisions of small landholder households. Many studies of farmers' production decisions have begun to include factors besides economic profits, such as subsistence needs and overall household welfare. The impact of production methods on biodiversity is an important factor to smallholder households as it affects farm sustainability and family consumption security and safety. Production values are especially important in specialty markets with strict environmental standards and in developing countries where the agricultural commodities for these markets are being produced.

To analyze the importance of biodiversity in the production of cacao, we created a model that disentangles the effects of family labor for biodiversity and for the production of cacao, and allows us to estimate how these rewards may influence shadow wages in different proportions. Our analysis of shadow wages extends the theoretical work of Jacoby (1993) and Skoufias (1994) by including biodiversity rewards. The shadow wage that includes biodiversity as a value in the price provides a method for determining the true impact of a production method on overall smallholder household decisions.

The Ecuadorian cacao case provides a good example of the need for the inclusion of additional values in the household decision model. When comparing the shadow wages, the traditional production methods for cacao Nacional proved to be the best production decision when the value for biodiversity was included in analyzing the smallholder production decision. Our analysis also reveals that family and hired labor are not perfect substitutes; on-farm family labor has a higher opportunity cost, which induces family members to work on the farm instead of participating in agricultural labor markets.

Our model shows how trade-offs exist between cash and biodiversity incentives in different production/market systems. For example, accessing specialty markets in the region studied requires changes in the production system, which in turn reduces the biodiversity benefits in favor of the cash rewards due to price premiums. However, the premiums that farmers are receiving barely exceed the marginal productivity loss due to labor intensification. Thus, farmers whose priority is to obtain cash quickly and whose valuation of biodiversity is very low would actually prefer to grow cacao in the CCN-51 monoculture system, rather than trying to access the price premiums in specialty markets. It is mostly farmers in the middle ranges of liquidity constraints and valuation of biodiversity who will be willing to participate in specialty markets.

Our study leaves several areas to be examined to better understand smallholder households' production decisions. First, stated-preference and other empirical methods that give a value to the non-market benefits for biodiversity should be explored to create shadow values that include the heterogeneity of farmers' preferences for biodiversity in a more accurate way. Second, our conceptual framework could be expanded to explore the risk benefits of agroforestry across diversified and monoculture production systems (Reitsma et al., 2001).

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Table 1. Description of variables in the theoretical model

Variable	Description
C	Market goods
V	Non-market benefits from planned biodiversity
D	Household characteristics such as family size or ethnicity
h	Labor supply of the household
T	Total stock of time for the household
M	Market labor
$\bar{M}$	Upper limit of off-farm work in the market
l	Home time
L_1	Labor dedicated to the agroforestry system
L_2	Labor dedicated to monoculture system
H	Hired labor
Q_1	Cacao yield in the agroforesty system
Q_2	Cacao yield in monoculture system
$\hat{Q}$	Predicted cacao yield
p_c	Market price for cacao in the conventional market
p_s	Market prices for cacao in the specialty market
a	Premium given cacao Nacional in the specialty market
K	Liquidity available to the farmer at beginning of planting period
A	Quasi fixed assets such as land
z	Non labor production inputs
p_z	Price for non labor production inputs
p_z*	Shadow input price
ω	Market wage
$w*$	Shadow wage
λ	Shadow value for income
μ_o	Shadow value for participation in the labor market
μ_M	Shadow value for access to the labor market
μ_K	Marginal utility of capital
Υ	Household environmental preferences

Table 2. Description of variables used in the estimation

Variable Name	Description	Mean	Std Dev
Biodiversity	Number of per hectare plant species in the parcel[11]	1.37	1.44
Production	Per hectare quintals of cacao produced in the parcel	8.80	7.85
Family labor	Per hectare days of family labor for cacao production	26.17	20.83
Nal	Term interacting Family labor and the predicted choice of cacao Nacional (as opposed to CCN)	0.77	0.28
Hired labor	Per hectare days of hired labor for cacao production	12.17	11.11
Other inputs	Per hectare cost of other inputs besides labor for cacao production (US dollars)	39.38	63.10
Flat parcel	Dummy variable indicating if the parcel where cacao is planted is a flat terrain	0.36	0.48
Hilly parcel	Dummy variable indicating if the parcel where cacao is planted is neither a flat nor steep terrain	0.19	0.39
Steep parcel	Dummy variable indicating if the parcel where cacao is planted is steep terrain	0.45	0.50
Initial land	Size of land when the household began farming (hectares)	17.91	24.14
Insecure land	Dummy variable to represent if the household has insecure property rights (communal land, squatted land, or inherited land, as opposed to purchased or received from the government through land reform)	0.56	0.50
Years parcel owned	Number of years that the household has had the parcel of land	22.14	16.54
Ethnicity (head of household)	Dummy variable =1 if the head of the household is indigenous Tsa'chila, as opposed to being Mestizo or Afro-Ecuadorian.	0.32	0.47
Tree Age	In years	8.78	7.87
Tree density	Number of cacao trees per hectare	554.42	228.74
Explanatory variables for predicted inputs:	Education of head, age of head, number of males over 12 years old, number of females over 12 years old, number of kids between 0 and 5 years, wages ($/day), price of fertilizer, price of insecticide, price of weeding, ethnicity, perception of biodiversity in Nacional relative to CCN system 3 years ago, ethnicity, has car.		
Explanatory variables for predicted production system:	Price of cacao sold, land size when started farming, health 3 years ago, perception of quality of water, soil and biodiversity with Nacional versus CCN 3 years ago, ethnicity, age of head, education of head, household size, kids 0 to 5 years old, wage ($/day), price of fertilizer ($/unit), price of insecticide, price of weeding, distance to markets.		

[11] These include native forest trees and wood trees (e.g. teak, bolsa, laurel), medicinal plants and trees, plants used for rituals, annual crops (the main in the sample are corn, cassava, legumes and malanga), perennials (the most representative being plantains, citrics, guaba, avocado).

Table 3. Cacao production and biodiversity simultaneous estimation

	Cacao			Biodiversity		
Variable Name	Coef.		Std. Err.	Coef.		Std. Err.
Log of family labor	0.31	*	0.18	0.22	**	0.09
Nacional* log of family labor	-0.01		0.13	0.07	**	0.04
Log of hired labor	-0.14		0.13	-0.08		0.06
Log of other inputs	-0.03		0.13	0.11		0.09
Flat parcel	-0.09		0.47	-0.75	**	0.13
Hilly parcel	-0.41		0.42	-0.47	**	0.15
Insecure land rights	0.19		0.24	-0.52	**	0.12
Initial land size (ha)	0.00		0.00	-0.005	**	0.00
Ethnicity (head of household)	-0.41	*	0.22	0.77	**	0.14
Years land owned	--		--	0.014	**	0.00
Tree age	0.02	*	0.01	--		--
Tree density	0.002	**	0.0004	--		--
Constant	0.81		0.59	0.05		0.33
sigma1_1	0.098	**	0.021			
sigma1_2	-0.006		0.016			
sigma2_2	0.257	**	0.082			
Log pseudolkelihood			-50.813			
Wald chi2(21)			1218.38			
Prob > chi2			0			

* Significance at the 10% level

** Significance at the 5% level

Table 4. Shadow wage by cacao variety and market type

Price in US dollars Per Day of Labor	Portion from Cacao (w_Q*)		Share from Other Plants (w_V*)		Shadow Wage Lower Bound ($\underline{w}$*)
Shadow wage for cacao Nacional sold in standard markets	12.34	+	4.82	=	17.17
Shadow wage for cacao Nacional sold in specialty markets	12.71	+	2.88	=	15.60
Shadow value for a day of labor for cacao CCN-51 sold in standard markets	14.03	+	0.30	=	14.33