Essays on Labor Allocation by Small Scale Farmers in the Brazilian Amazon

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ACADEMIC ABSTRACT

Human health is frequently omitted from household-level studies on agricultural productivity, land-use choices, and forest degradation and deforestation. Intuition, however, suggests that it could be an extremely important factor. This dissertation is built on three essays that use household survey data from the Brazilian Amazon to examine the conditions under which human health and other critical market conditions are important factors in determining household agriculture production choices and efficiency.

Essay I (Chapter 2) examines how health affects the labor allocation and production choices of migrant smallholders in the Brazilian Amazon. We show that the impacts of illness on household decisions depend critically on labor market function in the rural areas of the tropics. Furthermore, results from a formal statistical test of the labor markets shows that they do not work well, in other words are incomplete or thin, in the study area. These results are important both in specification of future smallholder household economic models and in targeting policies to better alleviate poverty and encourage more sustainable use of forest and land resources in similar tropical regions.

Essay II (Chapter 3) investigates the role of health as a productive input and non-input factor of farm production. The impact of health is decomposed into direct effect on the production function and indirect effects on technical efficiency. The finding of the essay suggests that poor health has significant negative impacts on rural household production. The

most important policy implication is that careful designing of agriculture development and rural settlements programs is important, and the provision of health care should be tied to these development projects.

Essay III (Chapter 4) examines the demand for labor applied to land clearing, staple food production, livestock, working off-farm, and time taking care of sick people in the household. Specifically, the empirical application examines the impact of disease on labor allocation, accounting for time lost by households taking care of sick members as a non-productive activity. Disease plays an important role in household decisions because farm activities are performed inefficiently by sick households and changes in household labor efficiency brings about a change in the relative price of competing uses for a household's time.

Chapter 5 provides a summary and general conclusion of the work, and then provides comments on policy design and recommendations for further studies. In summary, the combined results of these studies show that both health condition and the quality of labor markets have significant interacting impacts on the labor allocation decisions by smallholders with accompanying welfare and deforestation implications.

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GENERAL AUDICENCE ABSTRACT

Most of the rural population of the Brazilian Amazon is made up of small-scale farmers – the so-called 'smallholders' – who are characterized by a lack of access to formal credit, a disconnection from social services, poor access to markets, and a dependency on their own labor as the main input in agricultural production, and thus survival. Since labor is the main input used in smallholder activities, albeit to different extents, anything that changes total household labor or labor efficiency adjusts the relative returns of competing uses, and thus labor allocation decisions. This PhD dissertation is an effort to understand whether markets, family health, and seasonality affect labor allocation decisions, and furthermore, whether those allocation decisions vary depending on productive activity. Based on cross-sectional farm data from the Brazilian Amazon, I find that the impacts of illness on household decisions depend critically on how well labor market function in rural areas. The results from a statistical test of the labor markets shows that they do not work well in the study area. These results are important both in specification of future smallholder household economic models and in targeting policies to better alleviate poverty and encourage more sustainable use of forests and land resources in similar settings. Also, I find that poor health has a significant negative impact on technical efficiency of rural household farm production. The most important policy implication is that careful designing of agriculture development and rural settlements programs is important, and the provision of health care care should be tied to these type of development projects. Finally, in the context of the region of study, where labor markets are thin, disease

plays an important role on in household decisions because farm activities are performed inneficiently by sick households and change in labor efficiency brings about a change in relative prices of competing uses of household's time. My empirical work supports the hypothesis that health influence labor allocation decisions. In conclusion, the combined results of these studies show that both health conditions and the quality of labor markets have significant interacting impacts on the labor allocation decisions by smallhodlers with accompanying welfare and deforestation implications.

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CHAPTER 1

Introduction

1.1 Introduction

Aspiring households have migrated to the Amazon Basin in waves since the 1960s, either induced by government policies or voluntarily seeking opportunities that land settlement is perceived to afford (Crist, 1963; Eidt, 1962; Hiraoka and Yamamoto, 1980; Moran, 1988; Rudel, 1983). Between 1970 and 2000 the population in the Brazilian Amazon grew from 5.3 million to 20 million people, with nearly six million people living in rural areas (Browder, 1997). This growth in rural population was largely the result of an agrarian reform program that settled more than 1 million people in the region, distributing nearly 355,000 square kilometers. It is estimated that the formally settled households have been joined by another half again of informal settlers (Lima et al., 2006) .

Land reform in Latin America, however, has largely focused on giving access to land while ignoring the bottlenecks farmers face to become competitive producers. An immediate implication of this incomplete land reform approach is that rural setlements are established without proper access to complementary inputs, such as capital, technology, and health services (de Janvry, et al, 2002). Newly settled families receive land and employ family labor to produce outputs. But, many other inputs such as seeds, fertilizer, tools, and equipement, are not easy to aquire due to the remote nature of the settlements, poor infrastructure, limited credit, and lack of extension services (Sparovek, 2002). Furthermore, households living on the forest frontier, in Brazil and elsewhere, have poor access to health services and suffer an elevated index of poor health (Colfer et al., 2006; Confalonieri, 2005). A case in point, the Brazilian Amazon contains 98% of the country's Malaria cases, 35% of leprosy cases, high incidence of tuberculosis, and many other diseases that are relatively easy to treat (Colfer et al., 2006; Confalonieri, 2005).

Most of those people living in rural areas of the Brazilian Amazon are smallholder farmers. Typically, they employ cleared forest and their own labor to plant and produce crops, tend pasture for cattle ranching, and collect non-timber forest products. Their work frequently depends on strength and endurance, and therefore good health is critical. However, the impact of health on farm production, labor decisions, and welfare of these smallholders has not been rigorously studied in the Amazon. Because sickness directly reduces labor time available and indirectly impacts labor quality if sick family members must work, farm activities may not be performed efficiently by households whose members are sick. This relationship has been found in many studies set in Africa and Asia (Grossman, 1972; O'Donnel, 1995; Strauss and Thomas, 1998; Kochar, 2004; Takasaki et al., 2004; Amacher et al., 2004a; Amacher et al., 2004b; Kenjiro, 2005), but has yet to be considered in Latin America, to our knowledge.

How illness changes household decisions also depends critically on labor markets in the rural areas (Bardhan and Udry, 1999). With complete markets, households can simply hire labor freely at the market wage to compensate for the loss of household labor time due to disease, although their income might be lower. When markets are incomplete, however, labor cannot be freely hired (a market wage may not even exist), and sick households are fully subject to both direct and indirect impacts of disease (de Janvry et al., 1991; Rosenweig, 1984). It is difficult to generalize labor market characteristics across countries and regions (Benjamin, 1992; Jacoby, 1993; Grimard, 2000).

Past research with Amazon smallholders has recognized elements of market completeness for labor in the region (Caldas et al., 2007; Perz and Walker, 2002; Perz et. al., 2006, Walker et al., 2002). Yet researchers have often made simplifying assumptions about labor markets, failing to rigorously test for completeness in the market. As far as we know, no empirical analysis of the region has been done to test the quality of labor markets. This is an important point because choosing the wrong assumption about labor markets can lead researchers, as well as policy makers, to a misunderstanding of the role that health may play on labor, input decisions, production, and overall welfare of sick farming households.

The dynamic relationship between labor markets, access to health, and labor productivy warrants research attention. As mentioned above, the work of subsistence farmers often relies on good health. A large body literature has assessed the impact of health status on production decisions (see surveys by Deolalikar, 1988; and Strauss and Thomas, 1998 and applied studies by Takasaki, et al., 2004; Schultz, and Tansel, 1997). In these studies, the impact of health status on production has largely focused on "direct productivity effects" through the estimation of production functions. In this framework, health is treated as an input in the production process and it is assumed that farmers are fully technically efficient. That is, farmers are assumed to produce the maximum output that can be obtained from any given vector of inputs. This methodology assesses health status as an investment good similar to physical capital that simply receives returns. This approach allows the measurement of the marginal effect of health status directly on output. In this approach, it is impossible to measure the indirect impact of health status on technical efficiency as from the very start this approach assumes that farmers are fully technical efficient. As far as we know, an approach to simultaneously estimate the direct and indirect impact of health status on smallholder production, similar to previous studies on the direct and indirect impact of extension services on smallholders production, has not been conducted to understand the impact of health status on smallholders production (Battese and Broca, 1997; Dinar et al 2007; Bravo-Ureta, 1993).

The core of this dissertation is a set of essays (listed as Chapters 2, 3 and 4) that use data from a household survey conducted in Brazilian Amazon to examine whether household health is an important factor in determining household agriculture productivity. **Essay I** examines how labor and production of migrant smallholders in the Brazilian Amazon is impacted by disease. The impacts of illness on household decisions depend critically on labor market function in the rural areas of the tropics. Results from a formal statistical labor market tests shows that labor markets are thin in the study area. These results are important both in specification of future smallholder household economic problems and in targeting policies that better alleviate poverty and encourage more sustainable use of forest and land resources in similar tropical regions.

Essay II investigates the role of health as a productive input and non-input factor of production. By using a non-neutral stochastic production approach, the impact of health is decomposed into direct effects on the production function and indirect effects on the technical inefficiency. The findings of the essay suggest that household health status have significant impacts on rural household agriculture production. The most important policy implication is that careful designing of agricultural development and rural settlements programs is important, and the provision of health care should be tied to these development projects.

Essay III examines the factors related to demand for labor by jointly estimating a system of labor share equations applied to land clearing, staple food production, livestock, working off-farm, and time taking care of sick people in the household. In the region of study, where labor markets are thin, disease can play an important role in household decisions because labor of sick family members has to used, when possible, due to lack of hired labor, and labor of healthy family member may need to be diverted to take care of sick household members. In addition, farm activities must be performed inefficiently by sick members and changes in household labor efficiency may bring about a change in the relative price of competing uses of a household's time. The results show that the number of sick days not working by family members has a statistically significant negative impact on the share of labor allocated to agriculture, livestock, and working off-farm and it has a positive impact on labor allocated caring for sick family members and, perhaps surprisingly, labor allocated to land clearing.

Many policy implications that follow from the results of these three essays and we imagine that these policies would apply to other cases where agriculture development and rural settlement projects are designed in ignorance of the role of public health and markets for factors of production. To address problems like those studied herein, policies designed at the intersection of agriculture, labor markets, and health delivery are needed. For instance, policy makers should design agriculture settlement policies that take into consideration the functioning of labor markets and access to health services. Isolated action limited to the boundaries of each sector, like the ones found in the Brazilian Amazon, will not succeed.

1.2 Field research Methods and Study Area

The objective of this section is to describe the data collection methods and the study area. Data come from a housheold survey conducted in ten villages near the TransAmazon Highway in Marabá, a Municipality of the State of Pará, in the Brazilian Amazon (Figure 1). From May to November 2006, a total of 355 household were interviewed using formal questionnaires. A sample of 355 households was selected from the study villages. In each village, the process of household selection involved: (i) meeting with the village leader, (ii) introduction meeting with community association; (iii) village census; and (iv) random selection of households with the participation of the community members. A census of the village was carried out to obtain a sample frame from which to draw our sample.

I worked with two research assistants during the survey year. From May to November 2006 the research assistants and I interviewed residents of the sample households using a structured questionnaire. The questionaires cover the following topics: demographics, asset ownership, agriculture, livestock, and forest production, access to credit, deforestation, land holding, income, expenditure, and health variables. Interviwes were conducted at the house of the household with the head of the household. Much care was taken in the collection of data on health status, health expenditures, income, labor allocation, farm production, and land use. It is important to notice that we used a recall perior of the last year agriculture production. In collecting the data, we used comprehensive checklists of labor allocation, sickness, income and expenditure source to aid respondent momory.

The experience from our fieldwork showed to us that it is easier to collect accurate data on household demographics, land holdings, farm biophysical characteristics, distance to markets, wage rate at local markets, hired labor, consumption, land-use, price of inputs and outputs, access to credit, and agriculture production compared with income, labor allocation, and health status and health related expenditures. We collected data on labor allocation in terms of proportion of time spent on different categories of activities during the period of recall: clearing land, agriculture production, livestock production, time working off farm, time sick not working, and time sick while working. Women in the household were more precise about the amount of time each household member spent sick, while men were answering more clearly questions related to production.

The questions on disease and health were a sequence of questions that started asking whether some of the housheold members got sick in the previous agriculture production year (yes or no question for each household member). Then, we followed up with specific questions about the type of disease (we had a long list of disease we develop with a local doctor), duration of the disease (number of days the household members spent sick), expenditures on the diseases (money spent with doctors fee, medicine, and travel to health facilities), and finally we asked questions about time spent sick while working (measured in days) and time sick not working by the household members that got sick (measured in days). Through this sequence of questions, we could pinpoint the exact months that a sick household member stayed at home or went to work while sick (pre-planting, planting, harvesting seasons).

To supplement the data obtained from the household surveys, focus group discussions were conducted with the Municpal Secretary of Health in the Municipality of Marabá. The purpose of the cofal group was to obtain local and specialized perceptions about the local environment, types of disease most prevalent in the region, the causes of the disease, and the potential effectiveness of different policies to reduce the burden of disease on households. The main conclusions of the focus groups discussions were: (i) the villages located furthest from the main city were more exposed to diasease that were already eradicated in other places (malaria, yeallow fever, leishmanioses, etc); (ii) most of the disease were of simple treatment, however, due to distance they were not treated; (iii) the disease were not livestock driven; and (iv) the lack of coordination between the National Institute of Agrarian Reform and the Municipality could be improved to reduce the burden of disease on households.

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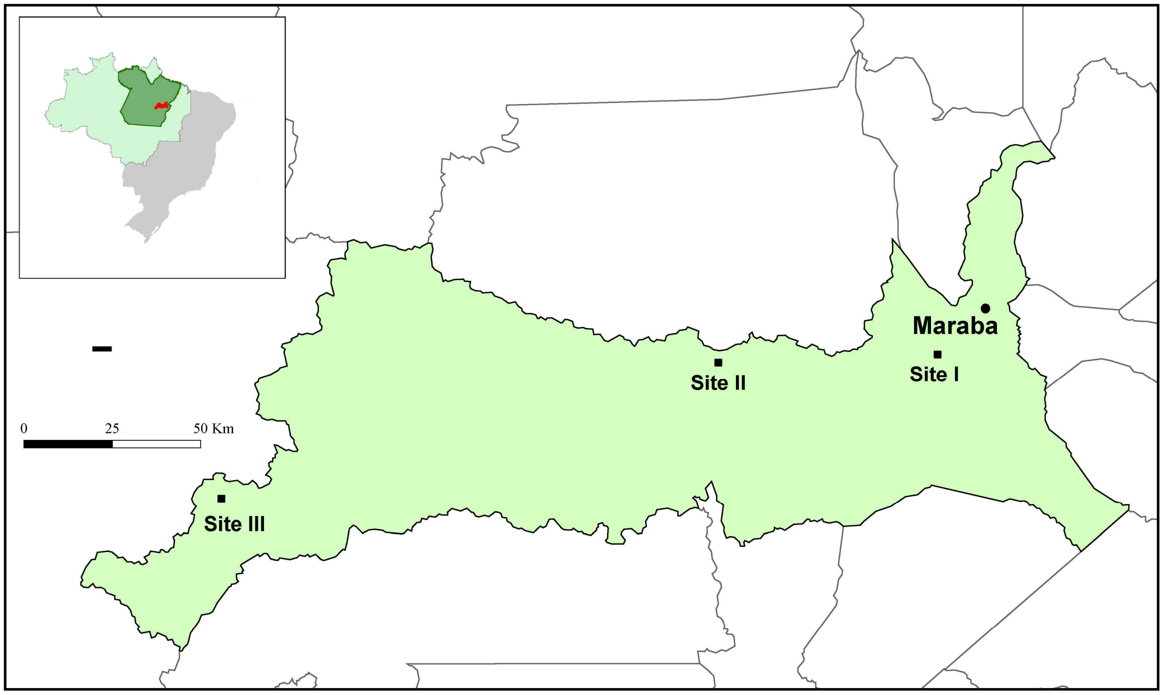
Figure 1. Location of the study area in the municipality of Marabá, Pará State, Brazil



CHAPTER 2

Understanding the Labor Allocation Decisions of Smallholders in the Brazilian Amazon

Abstract

Most of the rural population of the Brazilian Amazon is made up of small-scale farmers – the so-called ‘smallholders’ – who are characterized by a lack of access to formal credit, a disconnection from social services, poor access to markets, and a dependency on their own labor as the main input in agricultural production, and thus survival. Since labor is the main input used in smallholder activities, albeit to different extents, anything that changes total household labor or labor efficiency adjusts the relative returns of competing uses, and thus labor allocation decisions. Using a sample of households from the Transamazon forest frontier in Brazil, we seek to understand whether markets, family health, and seasonality affect labor allocation decisions, and furthermore, whether those allocation decisions vary depending on productive activity. We find that staple food and livestock labor demands are affected importantly by factors other than price and biophysical characteristics of the land itself. These results collectively raise questions about the ability of households to smooth the impact of disease by allocating labor to economic activities, such as cattle grazing, that are not labor intensive. These results also suggest the importance of both modeling households across seasons and incorporating health effects into household models for the Brazilian Amazon. We also note that labor markets vary by season and production choice, which implies that the assumption of complete labor markets is incorrect in the Amazon and the complexity of household decsions needs be taken into consideration in policy design

Key words: Farming, Labor, Seperability, Shadow wages, Seasonality, Health, Amazon.

2.1 Introduction

From the mountain slopes of Peru, Bolivia, Colombia, and Ecuador to Northeast and Southern Brazil, aspiring households have migrated to the Amazon Basin in waves since the 1960s, either induced by government policies or voluntarily seeking opportunities that land settlement is perceived to afford (Crist, 1963; Eidt, 1962; Hiraoka and Yamamoto, 1980; Moran, 1988; Rudel, 1983). Starting in the 1960s agrarian reform programs in Brazil[1] have settled more than five million people in the Amazon and Cerrado biomes, granting ownership over nearly 1 million square kilometers and helping the population increase to more than 20 million in the Amazon alone, with nearly six million people living in rural areas (Browder, 1997). Furthermore, Lima et al. (2006) suggest that the informal, uncounted settlements may add another half as many to the rural population.

Most of the rural population of the Brazilian Amazon is made up of small-scale farmers – so-called 'smallholders' – who are characterized by a lack of access to formal credit, a disconnection from social services, poor access to markets, and a dependency on their own labor as the main input in agricultural production, and thus survival. Each allocated approximately 100 ha, usually fully forested, in the settlement program, these smallholders clear land in order to produce crops or establish pasture for cattle ranching (Homma et al., 1992). Although it is reasonable to assume that smallholders are seeking to improve their economic and personal well-being, by clearing land they are often seen as agents of deforestation, and are estimated to be responsible for approximately 20% of all forest clearing in the Brazilian Amazon (Brandao Jr and Souza Jr, 2006; Chomitz, et al., 2007). This dichotomy between economic development and individual well-being on one side and

[1] The 'Assentamento' programs have been led by the Instituto de Colonizacao e Reforma Agraria (INCRA).

environmental degradation on the other is not unique to the Amazon, and presents a key nexus between development goals and the conservation of natural resources.

Smallholders in the Amazon typically engage in a combination of three economic activities: collection of non-timber forest products (NTFPs), ranching, and agriculture. The collection of NTFPs, however, is understood to be an activity that has the lowest returns and is usually seen as complementary to the main activities of ranching and agriculture (Nepstad and Schwartzman, 1992; Nepstad et al., 1999). Since labor is the main input used in smallholder activities, albeit to different extents, anything that changes total household labor or labor efficiency affects the relative returns of competing uses, and thus labor allocation decisions. Since labor is a scarce resource, recent literature on smallholders has almost singularly focused on its allocation in order to understand the economic and environmental consequences of these decisions (Bluffstone, 1995, Fisher, et al., 2005, Kohlin and Parks 2001, Cooke 1992, Shively and Fisher, 2004, Shively, 2001). In this cited work, households are usually assumed to evaluate the relative returns of their time employed in each possible economic activity, choosing both the activities to participate in and the extent of participation for family members. But, without understanding why, when and how smallholders allocate their key resource in production, and which conditions drive changes in both overall allocation as well as the possible impacts of reductions in productivity – e.g., the market, seasonal, or health factors that affect variability in labor – it will be more difficult to design policies that attain the dual goals of economic development and resource conservation.

Here we examine the complex nature of labor allocation on smallholder farms in the Brazilian Amazon to understand how and why labor is allocated during the year. In past work with Amazon smallholders, social scientists have recognized the different degrees of market completeness for labor in the region (Caldas, et al., 2007, Perz and Walker, 2002, Perz, et al., 2006, Walker, et al., 2002), but often choose to ignore it. We move away from a simple view of labor – it is allocated to maximize profits, or even minimize risk – that is often presented in discussion of households on the frontier to a more nuanced perspective that accepts the fluidity of decision-making by smallholders to maximize welfare under ever changing market, personal, and environmental conditions.

In particular, we seek to understand whether markets, family health, and seasonality affect labor allocation decisions, and furthermore, whether those allocation decisions vary depending on productive activity: e.g., between food production and ranching. Our goal, and thus our addition to the literature, is to quantify the complexity of decision making in these systems, and to illuminate the need for policies or investment that accommodate the multitude of relationships between labor and conservation outcomes, for example: if sick people tend towards activities that require less total labor, in this case ranching, it could be said that a program to improve smallholder health may be considered a conservation investment.

Indeed, one aspect that has not been examined with Amazon smallholders in any rigorous sense is the extent to which disease plays a role in labor allocation decisions. The myriad farm activities may not be performed efficiently by sick households, since sickness directly reduces labor time available and indirectly impacts efficiency of production if sick family members must work; this has been found in many studies set mainly in Africa and Asia (Amacher, et al., 2004b, Amacher, et al., 2004a, Grossman, 1972, Kenjiro, 2005, Kochar, 2004, O'Donnell, 1995, Strauss and Thomas, 1998, Takasaki, et al., 2004). The Brazilian Amazon, however, contains 98% of the country's Malaria cases, 35% of leprosy cases, and a high incidence of tuberculosis (Colfer, et al., 2006). The Amazon basin also has a high incidence of many other diseases such as yellow fever, leishmaniasis, chagas disease, rabies, dengue, respiratory problems due to haze and smoke from land clearing fires, and cholera (Colfer, et al., 2006, Confalonieri, 2005). Many diseases are relatively simple to treat, but due to the lack of access to basic health services they tend to go untreated. Consequently, these diseases become a great burden to rural households and are likely a factor in labor decisions (Alves and Timmins, 2001).

The remainder of the chapter builds a series of models and estimations that serve to generate a more complete picture of the labor allocation process. First, we present a brief overview of the concept of seperable or non-separable market conditions for households. We then build a household model for a typical smallholder that embeds the issue of market seperability into decision-making. We then incorporate the issues of seasonality, household demographics, health, and productive activity into the household model and estimate production functions and labor demand equations that quantify the impact of these issues on the household.

2.2 A Health-AugmentedHousehold Model

We use a conventional household model but augment it to include a health production function and the possibility of labor market inseparability. In the presence of sickness, it is useful to write a household time constraint as: $T-S(\Gamma)=L+l$, where T is the household's total time endowment, l is leisure time, L is a vector addition of labor time in all activities to which labor is employed, and S is time spent sick and not working by household members conditioned on health production Γ, described in more detail below. Labor time working is divided among time spent on the farm L^f, off farm L^{off}, and taking care of sick family members at home L^{ts}. Total time that the household spends working is: $L=L^f+L^{ts}+L^{off}$.

Time sick does not enter directly into the utility function of the household as an independent argument[2]. Utility is a function of consumption and leisure, $U(C,l;\theta)$, where θ is a vector of given household characteristics important to utility. Goods consumed may be purchased, C^m, or produced by the household, C^a, and total consumption is defined as $C=C^a+C^m$.

Household farm production links household labor time, hired labor working on the farm, and land employed to the amount of agricultural goods produced, $Q=f\left\{\phi(\Gamma)L^f, L^h; A\right\}$, where $f\{\cdot\}$ is a concave production function. We introduce ϕ as a 'labor-augmenting' health efficiency parameter to reflect farm labor efficiency that varies across households according to their health production status. L^h is hired labor, and A is a land input used in agricultural

[2] We are focusing on the labor effect of sickness. The disutility of being sick is not central in our study. Also, time sick reduces income and therefore consumption in the utility function. The sickness impact captures the important disutility effects of sickness.

production. To simplify, A is assumed to be fixed and exogenous; it is assumed that most land is cleared upon settlement, thus representing a sunk cost for Amazon smallholders (see also Merry and Amacher, 2009).

Define the health production function as $\Gamma = h\{L^{ts}, E, \upsilon\}$. This function is increasing in non-labor inputs such as medicines and health facility visits, E, and household labor inputs, L^{ts}, both of which are under control of the household. Health production also depends on a vector of exogenous environmental factors that affect disease υ, such as climate and access to health care facilities among others.

The household health production function has a direct impact on sick days not working $S(\Gamma)$, and an indirect impact on the efficiency of labor when household members work while sick, $\phi(\Gamma)$. How disease affects households is more complex, however, because at low levels of disease sick household members may work, affecting both impacts, but at high levels of disease work may not be possible, and then only the direct impact matters. This discontinuity in the effects of health is given by noting that $S(\Gamma) = h(L^{ts}, E, v) > 0 \ if \ \kappa < \hat{\kappa}$ and $\phi(\Gamma) = h(L^{ts}, E, v) > 0 \ if \ \hat{\kappa} < \kappa < 1$, where $\hat{\kappa}$ is a threshold value for the severity of disease. If disease is severe, a household cannot work because he or she is so debilitated by disease that it is best to stay home and recover from sickness, in this case $\hat{\kappa} > \kappa$, and disease affects time working. If disease is less serious, then $\hat{\kappa} < \kappa < 1$ and the person works (albeit less efficiently) and disease affects production. Note that in any household of our sample, a given laborer will fit into one case when sick or healthy.[3]

[3] What this means for our estimation is that the impact of disease enters the household problem in the time endowment constraint as well as in the full income constraint by changing labor efficiency, and regressions described later will be specified accordingly.

The Amazon smallholder household participates in markets. Denote the market price of agricultural goods as p^a, the price of non-labor health inputs as p^e, the wage rate of hired and family labor as w. The household has exogenous non-production income equal to y. These help to define the household's decision problem as one of maximizing utility subject to its economic environment, with household time allocated to leisure, time working off farm, and time working on the farm.

Formally, the household's utility-maximization problem is written as follows:

$$\max_{C,l} U[C,l;\theta] \tag{1}$$

subject to the following constraints on full income (*M*), the household total time endowment, and health production respectively:

$$M = p^a\{f[\emptyset(\Gamma)L^f, L^h; A] - wL^h - p^e E + wL^{off} + y \tag{2}$$

$$T(\theta) - S(\Gamma) = l + L^{off} + L^{ts} + L^f$$

$$\Gamma = h(L^{ts}, E, v)$$

Where we have now written the total time endowment as a function household characteristics, which may determine time available for work such as family size, as in Benjamin (1992). Substituting gives a more intuitive budget constraint:

$$C + p^e E + wl + wL^{ts} = y + p^a f[\phi(L)L^f, L^h; A] + w[T(\theta) - S(\Gamma)] = M \tag{3}$$

Full income has three parts: exogenous income (first RHS term), non-maximized farm profit represented by $p^a f\left[\phi(\Gamma)L^f, L^h; A\right] - w\left[L^h - L^f\right]$, and the value of the household's time endowment (third RHS term). Following a standard procedure in the literature cited earlier, we first treat full income as fixed and solve the problem above to obtain an indirect utility function. Then, we maximize full income M in this indirect utility function given maximized profits (Benjamin 1992). The solution gives the ordinary demand function for leisure, $l^m \stackrel{\text{def}}{=} l^m(w, y + \pi + wT(\theta); \theta, \Gamma)$, where π is farm profit. Now the household's optimal labor supply function for family labor in all activities follows from this leisure demand solution and the household time constraint. This supply function is, after defining total labor supply over all j activities:

$$L^{sp} = \left(\sum_{i=1}^{j} L^j \right) \quad \text{or,} \quad L^{sp}(w, M; \theta, \Gamma) = T(\theta) - S(\Gamma) - l^m \tag{4}$$

The labor functions are conditioned on household characteristics and health production. Finally, we can define total farm labor demand, which comes from hired and family labor as $L^*(w; A, \Gamma)$. If the household model is separable, total farm labor demand is simply chosen by setting the market wage equal to the marginal product, or $L^*(w; A)\ s.t. f_L[.] = w$.

2.3 *Interaction between Markets and Household Decisions*

A key underlying concept of this study is issue of separability in markets and its effect on household model design and estimation. Separability can be roughly captured in the idea that if a smallholder wants to participate in a market and unable to purchase or sell a desired good, then the market is incomplete, or ‘thin’. The result is that the decisions made in those markets are different from those in markets where everything is available and all information known, or other words where the market is complete. Indeed, a large review of household level studies on tropical deforestation (Angelson, 2007; and Angelson and Kaimowitz, 1999) found that the significance, sign and magnitude of variables explaining deforestation worldwide depends on the underlying assumption about completeness of labor markets.

In the case of perfect or complete markets, households simply choose the level of labor and capital inputs to maximize profits from farm production, and these decisions thus separate from consumption decisions. Labor decisions in these cases depend only on input prices and biophysical characteristics of the farm, all of which are exogenous to the household. In this case, the household endowments, such as land, durable goods, labor, and savings, and preferences such as sex, age, gender, and education do not play any role in production decisions. Furthermore, with complete markets, households can simply hire labor freely at the market wage to compensate for the loss of household labor time due to disease, although their income might be lower. When markets are incomplete, however, labor cannot be freely hired (a market wage may not even exist), and sick households are fully subject to both direct and indirect impacts of disease. And finally, household production decisions are not affected by consumption preferences. A household model in such a market is said to be 'separable'. When markets are imperfect, however, separability fails and production decisions become dependent on household characteristics, in addition to other factors (Bardhan and Udry, 1999, de Janvry and Kanbur, 2006). The pioneering work in this area was done by Jacoby (1993), Benjamin (1992), and Thornton, (1994) who demonstrated the use of shadow wages to estimate labor supply functions for the different economic activities.

When seperability fails, however, labor functions are no longer determined by the market wage, but rather a shadow wage rate (denoted w^* in what follows) that is a function of household characteristics and other factors, including for example, health. For smallholder households in the Amazon, non-separability can come through two possible labor market constraints, first $\bar{L}$, which defines the maximum amount of labor a farmer can hire for his farm outside the household at a competitive wage rate, and second, $\underline{L}$, which represents the greatest amount of labor the household can supply off farm at a market wage rate. If these constraints bind the household's decisions, the market wage no longer determines labor choices and as a consequence these choices are conditioned on the shadow wage and household characteristics.

To see this, consider two possible constraints where separability fails. The first occurs if on-farm labor demand is greater than household labor supply available in addition to any hired labor net of household time spent sick. The second occurs if household labor supply less time spent sick by household members is greater than on farm labor demand in addition to off-farm labor opportunities. These two cases respectively are summarized using our labor supply functions and time sick discussed above as:

$$L^{sp}(w, M; \theta, \Gamma) - S(\Gamma) < L^*(w; A) + \bar{L} \quad (5)$$

$$L^{sp}(w, M; \theta, \Gamma) - S(\Gamma) > L^*(w; A) + \underline{L} \quad (6)$$

When either (5) or (6) hold, separability fails and the amount of labor used depends on preferences, farm production technology and disease. Clearly, disease, demographic characteristics, and constraints on labor markets can lead to non-separability as well, as can seasonality of labor demand. For example, (5) represents a 'peak' season where marginal productivity of labor on the farm is greater than market wages and the household wants to hire additional workers but cannot. Disease makes this labor market constraint more binding, because illness can drive a significant wedge between household own labor supply, which is likely to be applied on farm, and farm labor demand. In turn, households will try to hire people from outside their household. However, due to the constraint on hiring labor from outside the household during the peak season, separability breaks down.

Equation (6) characterizes a 'slack' season. Here, on farm labor productivity is smaller than the prevailing market wage. In this case, labor supply by households is greater than on-farm labor demand. Now, sick time by household members reduces labor supply. Thus, depending on how much time is lost due to illness we can see that sickness can cancel or reduce the impact of the labor market constraint on the amount of days a household can work off farm. The interaction of the ration and disease implies that sicker households may be less likely to be constrained according to equation (6), meaning a more separable state. Detecting non-separability even after including the impact of disease makes a strong case for severely dysfunctional labor markets. But it also decreases the power of a test for separability because labor markets may not be working properly and disease decreases household labor supply. So, the constraint might be satisfied due to the impact of sickness on labor supply and not because of clearing labor markets.

In all cases where separability fails, a shadow wage must be used instead of a market wage when estimating labor choice equations as Benjamin (1992) and Jacoby (1993) have shown. Shadow wages have a certain context in our disease-based household model. If due to labor market constraints it becomes optimal for a household member to work to a point where (6) or (7) holds, then a shadow wage known to the household but unobserved to the researcher exists that makes these equations hold as equalities and brings the household into equilibrium where labor demand equals labor supply for each family. In this case, family labor demand for the farm is chosen so that the marginal value product of this labor time is equal to the shadow wage, $w*$ and not the market wage rate.

From the household utility maximization problem, these constraints mean that the specification of observed labor demand, which we will estimate in the following sections, now comes from the derivative of the profit function evaluated at the shadow wage,

$$L^D = L^*(w^*; A) = -\frac{d\pi(w^*;A)}{dw^*}. \qquad (7)$$

The shadow wage that defines labor demand for the household is endogenous to household decisions and must be suitably estimated and instrumented along with estimation of the household's labor equations, a point we take up in the next section. How labor decisions change as household characteristics and disease change is also more complex. This is because changes to labor decisions come from changes that disease makes to the shadow wage embodied required to bring equality to the constraints (5) and (6). Implicitly differentiating (7), the effect of household disease, for example, on labor is given by, $\frac{dL^D}{d\Gamma} = \frac{\left[-\frac{d\pi(w^*;A)}{dw^{*2}}\right]dw^*}{d\Gamma}$. The first term on the RHS of this effect is positive due to concavity of the production function, while the second term is the effect of disease on the shadow wage and is not generally known a priori.

This work builds on social science studies in the region by estimating household shadow wages based on the first-order conditions for utility maximization in the context of a non-separable household model. A test of model separability is undertaken that examines the relationship between staple food and cattle production, household demographic composition, and health. We then go beyond the basic separability tests, however, to determine the extent to which separability may be season-specific. This is an important line of inquiry given that some seasons, such as pre-planting, are less labor intensive than harvesting or planting, and a season specific approach overcomes the problems with period aggregation common in the literature. To accomplish these goals, an updated household model that explains the economic decision-making process within the household accounting for non-seperability, health, and seasonality, across production activities is developed, and then we proceed to discuss econometric specification, model estimation, and final results.

2.4 Data and Summary Statistics

Our data come from a household survey conducted in ten villages located near the TransAmazon Highway in Marabá, a Municipality in the State of Pará, in the Brazilian Amazon. The data was collected between May and November 2006 (**Figure 1**). Randomly selected villages, stratified by municipal population densities were selected to provide as much variation as possible in access to markets, disease, environment, and public health. Villages were located anywhere between 12 and 300 km away from the city of Marabá. In each village, households were randomly selected from lists obtained from the president of the village's local community association, with sample sizes stratified based on village population. As in much of the economics literature on households, interviews were undertaken with the head of household, using a recall instrument based on the past year. A total of 335 households were interviewed, and no households refused to answer survey questions.

Summary statistics and descriptions of the variables used in the estimation are reported in **Table 1,** for both households that had at least one sick household member and households with no sick people during the period sampled. In our sample, there were 174 reported non-sick households and 165 households with sick family members during the previous seasons. On average, households in the survey area have 4.7 members, and sick and non-sick household sizes are not statistically different in this respect. The mean age of the head of household is 49 years. Adult mean education measured as years in school is about 4.67. However, household heads in sick families are significantly less educated, with only 4.02 years of school reported.

Main economic activities are crop farming and livestock ranching. Staple food like rice, beans, corn, and manioc are the main crops produced and the main livestock is cattle for beef production. Household endowments are significantly different depending on disease.

Sick households have more livestock and less land, highlighting the fact that less labor intensive activities are chosen when sick perhaps to avoid the constraints noted earlier. Also, sick households are those living farthest from the main city where health care may be available. The mean per capita income for non-sick households is also significantly lower by about $R200 (1R$=1.77US$). As the model shows, health households hire more outside labor when available and lease their land in greater proportion than non-sick households. Sick households tend to clear more land, either for ranching or because sometimes the wood can be sold for supplemental income. All of this suggests that we should find non-separability in labor decisions due to disease as our model predicts.

Table 1. Household Structure and Characteristics by Health Status

	Non-Sick		Sick		
	Mean	**Std. Err.**	**Mean**	**Std. Err**	**P-value**
Number of households	174		165		
Household Structure					
Household size	4.49	0.20	4.91	0.18	0.12
Number of children	1.50	0.15	1.79	0.12	0.13
Number of adults	2.87	0.12	3.07	0.11	0. 21
Number of males	1.66	.08	1.68	0.07	0.84
Number of females	1.21	.08	1.39	.06	0.06
Household characteristics					
Age household head	48.29	12.67	50.25	11.51	0.14
Head education	4.55	2.59	4.02	1.97	0.03
Adults education	4.76	2.84	4.61	2.39	0.61
Children education	2.88	2.52	2.63	1.79	0.38
Asset Ownership					
Livestock (R$)	9,150.06	990.50	12,436.87	1,273.12	0.05
Land (R$)	49,760.11	5,399.65	39,637.42	2,034.42	0.06
Agriculture capital (R$)	772.51	1,345.15	770.17	964.90	0.98
Durable goods(R$)	1,192.21	3,550.65	1,578.89	4,725.29	0.41
Farm Production					
Value of staple food (R$)	1,745.93	252.37	2,481.02	303.41	0.07
Value of animal (R$)	1,598.99	292.34	2,180.90	311.70	0.18
Hired labor (yes or no)	0.26	0.04	0.17	0.03	0.04
Inputs (R$)	242.50	50.43	309.74	44.14	0.32
Lease land (yes or no)	0.03	0.02	0.12	0.02	0.00
Farm distance to city(km)	99.14	6.82	130.70	11.92	0.03
Labor Allocation Across All Seasons					
Land clearing (days)	7.30	1.19	13.39	1.34	0.00
Agriculture (days)	52.29	5.45	48.65	4.04	0.58
Livestock (days)	34.42	4.20	29.58	3.43	0.37
Off farm (days)	40.75	7.60	47.12	7.15	0.54

2.5 *Econometric Specification for Production Functions*

The first step is to estimate the production functions described earlier for crop production and cattle grazing, $Q = f\left\{\phi(\Gamma) L^f, L^h; A\right\}$. The following Cobb-Douglas specification widely estimated in the literature is used:

$$q_i^j = \alpha^j + \beta^j z_i^j + \gamma^j \theta_i^j + \varphi^j V_i^j + \delta^j H_i + \psi^j \Omega_i + \varepsilon_i^j \tag{8}$$

where i indexes the household, $j \in (1,2)$ indexes staple food $(j=1)$ and livestock production $(j=2)$ activities, $q_i^j = \log(Q_i^j)$ is aggregate output, z_i^j is a vector of log quasi-fixed factors, θ_i^j is a vector of human capital variables, V_i^j is log of variable inputs used in production, H_i are health variables that may have an impact on production, Ω_i is a vector of non-production factors, α^j, $\beta^j, \gamma^j, \varphi^j, \delta^j$, and ψ^j are activity specific vectors of parameters to estimate. The error term ε_i^j is assumed to be mean zero and represents unobserved household and land characteristics that influence production as well as uncontrolled disturbances to production due to weather. The production function is measured in terms of the total value of crops produced, which is the convention in the economic household literature to account for different units.

The quasi-fixed factors of production include total area of the farm and number of days worked by the household on the farm. The vector of human capital variables is adult mean education and household experience. The input variables are agriculture land area, leased land, improved seeds, and hired labor. The vectors of disease-related variables included in the production function $(i.e.\ \phi(\Gamma)\ \text{in}\ Q)$ are number of sick people in the household, the number of household sick days, and dummy variables indicating whether household members were sick in the pre-planting, planting and harvesting seasons. The non-production factors are variables such as distance to markets.

Ordinary least squares estimation of (8), however, suffers from several specification problems. We include it here for the sake of comparison to the 2SLS model. In our case, while the quasi-fixed factors of production z_i^j are exogenous, the specific allocation of those inputs between livestock and staple food production are not, and the input quantities for each activity is chosen by the household. Thus, if a household has knowledge of unobserved variables present in ε_i^j when making these input choices, the resulting choices could be correlated with ε_i^j. A traditional solution to this problem is to apply instrumental variable methods.

Before discussing this approach, we rewrite (8) to be specific about the endogeneity problem. This is done by decomposing the unobservable term ε_i^j into two parts, ω_i^j and ξ_i^j,

$$q_i^j = \alpha^j + \beta^j z_i^j + \gamma^j \theta_i^j + \varphi^j V_i^j + \delta^j H_i + \psi^j \Omega_i + \omega_i^j + \xi_i^j \qquad (9)$$

the term ξ_i^j represents unobservable variables to the household when deciding the level of inputs to be used in production. This may result from deviations in expected rainfall, abnormal crop failure, accidental fires, or any other unexpected event. On the other hand, ω_i^j is observed by the household, but not by the researcher, when households choose input levels. This term can be composed of farm work experience, knowledge of weather patterns in a region, or expected labor losses due to disease in a season. The important point is that ξ_i^j is uncorrelated with input decisions, while ω_i^j is correlated with input decisions.

The instrumental variables approach used herein is a 2SLS method that relies on finding appropriate instruments. These instruments are variables that are correlated with the endogenous variables but do not enter the production function and are uncorrelated with the error term ω_i^j. The input demand function suggests that input prices have direct impacts on choices of inputs, yet in this case, these prices are taken by each smallholder and do not enter the production function, therefore they are uncorrelated with ω_i^j.

Following the above discussion, we estimate the production function using both OLS and 2SLS, using Instrumental Variables, for comparison. The Instrumental Variable estimation is as given:

$$q_i^j = \alpha^j + \beta^j z_i^j + \gamma^j \theta_i^j + \varphi^j V_i^j + \delta^j H_i + \psi^j \Omega_i + \varepsilon_i^j \tag{10}$$

$$\begin{aligned} z_i^j &= \rho^j + \tau^j K_i^j + \eta_i^j \\ V_i^j &= \vartheta^j + \pi^j W_i^j + \mu_i^j \end{aligned} \tag{11}$$

where K_i^j and W_i^j are vectors of additional exogenous variables, $\left(\eta_i^j, \varepsilon_i^j\right)$ and $\left(\mu_i^j, \varepsilon_i^j\right)$ are correlated, i.e., $E\left(\beta_i^j, \varepsilon_i^j\right) = 0$ and $E\left(\mu_i^j, \varepsilon_i^j\right) = 0$. The instruments in K_i^j and W_j^i should be able to predict the allocation of V_i^j and z_i^j yet be uncorrelated with the unobserved variables in ε_i^j that affect input choices. Based on the data available, we selected variables for K_i^j and W_j^i that meet the criteria of good instruments described above. The first set of instruments is related to household factor endowments. We use aggregate land/labor ratio and capital/labor ratio by gender as instruments, because the intensity of these inputs determines the returns from agricultural production, interpreting the number of workers in each category as resources endowments of the household allow us to use them as as instruments (Jaboby, 1993). Land is considered a fixed endowment because land settlements in the Brazilian Amazon is determined by policy makers, not by the farmers and the trade of land is not allowed in the land settlements established by the federal government. The second set of instruments is exogenous variable input prices. We also estimate the correct heteroskedasticity using the variance-covariance of φ^j and β^j using White's procedure (White, 1980).

Finally, we test whether labor markets are complete by estimating the shadow wage using the estimated marginal value product of labor $w^* = \frac{\partial \hat{f}(\cdot)}{\partial L}$, where $\hat{f}$ is the estimated production function. Household labor choice functions can then be estimated using this wage rate for the estimation equations.

2.5.1 Results for household production functions for staple food and livestock

The results of fitting both ordinary least squares (OLS) and instrumental variables (2SLS) for staple food and livestock production, are shown below in **Table 2** and **Table 3**, respectively. In the estimated staple food production adult male labor, agricultural land, leased land, and improved seed input use are statistically significant. Note that OLS and 2SLS coefficients differ for most parameters. For instance, the hired labor coefficient is large and significant in the OLS regression, but small and insignificant in the 2SLS regression, indicating that unobserved endogenous factors are indeed important and render only the 2SLS estimates asymptotically consistent. Interestingly, none the health related-variables are important to staple food production, which may explain the importance of this activity to household welfare.

In the estimated production function for livestock, we can also see that output is statistically significant and increasing for most of the inputs: capital, pasture area, leased land, use of improved seeds, and livestock immunization. Again, we observe differences between the parameters estimated by OLS and 2SLS, meaning that 2SLS is the appropriate and consistent form of estimation due to endogeneity. The adult male labor coefficient is large and highly significant in OLS and insignificant in 2SLS. Hired labor follows the opposite pattern where it is negative for both OLS and 2SLS. However, it is significant only in the 2SLS results. These results are reasonable because the traditional livestock production system in the region uses extensive technology with low labor input and little management time, thus, the family labor coefficient is insignificant. When they have to hire labor, it has a negative effect on production.

Comparing the responsiveness of output to labor between staple and livestock production systems, we observe that the coefficient on labor devoted to staple food positive and significant while it is not statistically significant for livestock production function. This indicates staple food production is the activity that best measures the opportunity cost of time faced by smallholders in the study area. Also, it makes sense to observe the coefficient on land devoted to livestock is two times larger than the coefficient on land devoted to staple food production. Livestock production requires large amounts of land converted to pasture and cattle has a higher aggregated value when compared to staple food. Frequently, early in the morning adult male labor take the herd to the selected pasture and let it graze until the afternoon when the herd is taken back to the corral. In between, most of the staple food production activities may be undertaken on other land units.

Table 2. Staple Food Production Function in the Brazilian Amazon (value of output)

	Instrumental Variable	**Ordinary Least Squares**
Ln Adult Male Labor (days)	0.31530**	0.32824***
	(0.156)	(0.0718)
Ln Adult Female Labor (days)	0.07211	0.07994
	(0.134)	(0.0698)
Ln Agriculture Plot Size (ha)	0.16862**	0.23987***
	(0.185)	(0.176)
Ln Hired Labor (R$)	0.10220	0.17340***
	(0.0647)	(0.0472)
Ln Capital (R$)	0.18361***	0.16784**
	(0.0997)	(0.101)
Ln Distance to Nearest Market (km)	-0.00117	-0.00944
	(0.127)	(0.130)
Ln Value Leased Land (R$)	0.08230*	0.07938*
	(0.0507)	(0.0570)
Ln Value Improved Seeds (R$)	0.11932**	0.11062*
	(0.0473)	(0.0493)
Adult Mean Education (years)	-0.03196	-0.02763
	(0.582)	(0.613)
Age Household Head (years)	1.42819	1.49344
	(0.256)	(0.278)
Age Household Squared (years)	-1.77750	-1.81565
	(0.00229)	(0.00251)
Experience (years)	-1.08691	-1.16299
	(0.210)	(0.225)
Experience Squared (years)	1.43784	1.49083
	(0.00218)	(0.00235)
Ln Days Sick	0.03751	0.02625
	(0.0874)	(0.0674)
Sick in the Pre-Planting Season (yes & no)	0.02732	0.02874
	(0.349)	(0.356)
Sick in the Planting Season (yes & no)	0.01453	0.01550
	(0.322)	(0.331)
Sick in the Harvesting Season (yes & no)	-0.03950	-0.03903
	(0.411)	(0.423)
Observations	335	335
F		8.658
R^2	0.341	0.351
RMSE	2.196	2.239

Standardized beta coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3. Livestock Production Function in the Brazilian Amazon (value of output)

	Instrumental Variables	**Ordinary Least Squares**
Ln Adult Male Labor (days)	0.1009	0.2773***
	(0.311)	(0.0444)
Ln Female Adult Labor (days)	0.0341	0.0268
	(0.101)	(0.0363)
Ln Hired Labor (R$)	-0.1274**	-0.0305
	(0.0563)	(0.0368)
Ln Sick People in the Household	0.1139	-0.0739
	(0.974)	(0.279)
Ln Capital (R$)	0.1560*	0.1418**
	(0.110)	(0.0756)
Ln Distance to Nearest Market (km)	-0.0112	-0.0099
	(0.129)	(0.128)
Ln Area Pasture in the Lot (ha)	0.2992***	0.2839***
	(0.135)	(0.113)
Ln Leased Land (R$)	0.0390	0.0687**
	(0.0435)	(0.0303)
Ln Fencing (R$)	0.0492	0.0250
	(0.0218)	(0.0199)
Ln Improved Seeds (R$)	0.0746*	0.0926**
	(0.0283)	(0.0261)
Ln Lot Size	-0.0422	-0.0589
	(0.219)	(0.225)
Ln Value Animal Immunizations (R$)	0.4613***	0.3906***
	(0.0897)	(0.0365)
Ln Adult Mean Education (years)	0.0819	0.0437
	(0.679)	(0.545)
Age Household Head (years)	-0.8747	-0.8174
	(0.159)	(0.164)
Age Household Squared (years)	0.5925	0.5325
	(0.00137)	(0.00146)
Experience (years)	0.6160	0.5398
	(0.147)	(0.144)
Experience Squared (years)	-0.3713	-0.2905
	(0.00143)	(0.00152)
Ln Days Sick	-0.1399	0.0468
	(0.274)	(0.0801)
Sick in the Pre-Planting Season (yes & no)	-0.0793	-0.0761
	(0.267)	(0.260)
Sick in the Planting Season (yes & no)	0.0858	0.0594
	(0.343)	(0.236)
Sick in the Harvesting Season (yes & no)	-0.0306	-0.0434
	(0.309)	(0.284)
Observations	335	335
F		15.01
R^2	0.613	0.652
RMSE	1.398	1.372

Standardized beta coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

2.5.2 Estimating shadow wages from the production functions

Results for estimated shadow wages *w** are reported below in **Table 4**. The mean value of the shadow wage for households in or sample is R$10 (USD1 = 1.77R$). In addition, **Table 4** reports the impact of disease on the estimated shadow wage. The male shadow wage for sick households is R$10. This value is nearly two times greater than the average male shadow wage for non-sick households, which is around R$6. These results together with the fact that sick households supply slightly more labor to land clearing and off farm work suggest that the impact of disease on the shadow wage is positive.

From our model, this would indicate that the behavior of the households sampled is similar to cases 2 and 4 of the Appendix. In both cases, we saw that the disease effect on the shadow wage is positive whenever the impact of disease on labor-augmenting health efficiency parameter and days sick not working can be compensated by non-sick household members. Thus, in case 2 the impact of disease on household labor supply times labor-augmenting health efficiency parameter is greater than the negative impact of disease on labor-augmenting health efficiency parameter on labor supply. In case 4, there is an additional impact of the increase in sick days not working that needs to be taken into account. These effects have not been identified in the literature on disease and smallholder behavior, yet we find them important for our representative sample.

Table 4. Estimated Shadow wage from Staple Food and Livestock Production

Shadow wage	**Observations**	**OLS**		**2SLS**	
		Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
All households					
Adult Male Shadow Wage	335	12.60	21.38	9.90	14.54
Sick Household					
Adult male shadow wage	165			10.50	15.22
Non-Sick Households					
Adult male shadow wage	174			6.13	7.13

2.6 Specifying household labor demand by season and production activity

The main concern here is to test model separability in labor and production decisions, which implies that the demand for own labor by the household should depend only on farm biophysical characteristics and input prices. Thus, we first estimate the demand for labor as a function consistent with the Cobb-Douglas production function specification (and associated profit maximization), but we augment this function to include household characteristics and health:

$$L_i^j = \beta_1^j + \beta_2 \log w_i^* + \beta_3^j \log A_i^j + \beta_4^j R_i^j \tag{12}$$

where L_i^j is labor demand in for each activity staple food and livestock production, w_i^* is the household specific shadow wage, A_i^j is agricultural land, and R_i^j is other inputs used in agricultural production. We already know from the theory that by definition the shadow wage must be a function of household characteristics and health status when the model is non-separable, so we can write $w_i^*(D, H)$. Following Benjamin (1992) we write this as $w_i^* = m(D, H)w = 1 + \sum_{i=1}^{G} D_i + \sum_{i=1}^{K} H_i$, as a function of the market wage and demographic and health status vectors of size G and K in our sample for each *i* household. Taking the log of this in the labor supply functions of (12) then provides a test for separation through first estimating labor functions as follows:

$$L_i^j = \beta_1^j + \beta_2^j \log w + \theta^j \sum_{i=1}^{G} D_i + \vartheta^j \sum_{i=1}^{K} H_i + \beta_3^j \log A_i^j + \beta_4^j R_i^j + \varepsilon_i^j \tag{13}$$

where the coefficients θ^j and ϑ^j are the elasticity of labor demand with respect to household characteristics *D* and to several measures of household health status included in *H*. With this specification, rejecting the null hypothesis that $\left(\theta^{j}=\vartheta^{j}=0\right)$ implies that separability fails, and further the set of variables (*H* or *D* or both) that lead to rejection amount to the reason that separability fails.

Our test relies on the effect of health and household structure on labor demand. Thus, it is once again important to take into account endogeneity of the right-hand side variables of (13). Estimation of equation 13 is likely to result in biased estimates for ϑ^{j} since health status is an endogenous function of household decisions and probably measured with error.

Another possible problem is that the variable household size might be endogenous. However, since other household demographic variables are exogenous to the labor demand equation, following Benjamin (1992) and Grimard (2000), we correct for this endogeneity by again employing enough instruments to ensure identification along with a two stage least squares estimators with exogenous variables used as instruments. This specification is as follows:

$$\begin{aligned} L_i^j &= \beta_0^j + \beta_1^j \log w + \theta^j \sum_{i=1}^{G} D_i + \vartheta^j \sum_{i=1}^{K} H_i + \beta_3^j \log A_i^j + \beta_4^j R_i^j + \varepsilon_i^j \\ H &= \alpha + \gamma N + u \end{aligned} \tag{14}$$

In particular, N are variables used as instruments for health status suspected endogenous health variables such as financial resources a household spent on health treatment and doctors visits. For statistical inference, we estimate the variance-covariance of ϑ using the standard White procedure as well (White, 1980).

2.6.1 Results for seasonal labor demand in staple food production

In the case of labor demand for staple food production, we reject separability in the pre-planting and planting seasons, but are unable to do so for the harvest period. As we mentioned in the theoretical section, pre-planting represents peak season, where returns to labor on the farm are high. The planting season is between the peak and slack seasons. In the peak season, disease drives a significant wedge between household labor supply and farm labor demand. In turn, households try to hire non-household laborers to compensate for labor lost due to disease or low labor efficiency. However, at this point, due to labor shortages in the peak season, separability breaks down.

Our empirical results show that the number of sick people in the household had a negative and significant impact on labor supply in the pre-planting season (-0.23), and the number of sick people as well as the number of days sick while working had a significant and negative impact on labor demand in the planting season (-0.13 and -0.32). The total number of days sick had a positive impact on labor demand in the planting season (0.44). Both the F and likelihood ratio tests results for inclusion of the health variables show that those health-related variables cannot be excluded from the regression in the pre-planting and planting season (F=16.24, LR=15.51 and F=6.91 and LR=19.72, respectively). Other variables that are important to labor demand in the planting season are the size of the agriculture area under cultivation, the cost of fencing the property, and the price of manioc. There is a well-determined negative shadow wage estimated coefficient for pre-planting season of -0.41.

In addition, the demand for labor in the planting season is affected by household demographic variables. This situation could arise because a household is still willing to supply labor to local markets even after taking into account the days lost due to disease. However, household members are prevented from doing so because desired labor supply exceeds available off farm employment opportunities, i.e. $L^{sp}\left(M, w; \Gamma\right) - S\left(\Gamma\right) > L^{*} + \overline{L}$. Thus, the only option for family members is to satisfy the need for employment working on its own farm. The F test and likelihood ratio tests indicate that the demographic variables should not be excluded from the regression (F=4.90 and LR=19.85, respectively). Thus, separability no longer holds. Here, household composition variables have a significant and positive impact on labor demand. Other variables important to labor demand in the planting season are: land area under cultivation, and the price of manioc. The elasticity of shadow wage in the planting season is -0.51.

In the harvesting season there are few opportunities to work on and off the farm in the production of staple crops. First, it is important to know that in the smallholder production system harvesting crops takes only few days. Also, household mobility to seek employment elsewhere is limited because most roads are closed due to heavy rain. In this case, however, our test does not have much power to test the impact of disease and household demographics. Basically, L^{*} and $\underline{L}$ are small and unlike the first case where a household member could meet the need for extra employment by working more on the farm, now households cannot employ extra labor supply anywhere. Our results are consistent with these observations, and the only variables that are statistically significant in the model are the elasticity of the shadow wage and land area under agriculture.

Table 5. Labor Demand for Staple Food Production in the Pre-Planting Season

	PP1_S	PP2_S	PP3_S
Age Household Head	-0.180199	-0.208138	-0.161820
	(0.0387)	(0.0390)	(0.0394)
Household Head Experience	0.158736	0.185298	0.175053
	(0.0379)	(0.0381)	(0.0383)
Ln Distance to Village (km)	0.035809	0.032266	0.061539
	(0.206)	(0.207)	(0.199)
Ln Lot Size (ha)	-0.013895	0.398722	0.346900
	(0.231)	(0.499)	(0.502)
Ln Area Under Cultivation (ha)	0.267377***	0.270000***	0.257519***
	(0.138)	(0.138)	(0.137)
Ln Price Leased Land (R$)	0.038011	0.029270	0.033715
	(0.372)	(0.375)	(0.370)
Ln Price of Fencing (R$)	0.187392**	0.188426**	0.166898**
	(0.213)	(0.211)	(0.213)
Ln Price of Improved Seeds (R$/Sack)	-0.032044	-0.053584	-0.081127
	(0.613)	(0.612)	(0.599)
Ln Price of Manioc (R$)	0.170743*	0.148786	0.152692*
	(0.322)	(0.329)	(0.314)
Ln Price of Beans (R$)	0.018262	0.005811	0.013583
	(0.404)	(0.411)	(0.391)
Ln Price of Rice (R$)	0.049336	0.056553	0.035026
	(1.420)	(1.499)	(1.424)
Ln Wage Rate (R$)	0.063056	0.040779	0.052927
	(0.530)	(0.495)	(0.487)
Ln Exogenous Income (R$)	-0.111143	-0.085655	-0.073211
	(0.0277)	(0.0284)	(0.0274)
Ln Shadow wage (R$)	-0.414562***	-0.422615***	-0.407804***
	(0.126)	(0.127)	(0.129)
Household Size		-0.413809*	-0.384137
		(0.346)	(0.351)
Share Adult People in the Household		-0.036765	-0.074967
		(2.295)	(2.061)
Share Children in the Household		-0.032853	-0.026796
		(2.280)	(2.043)
Sick People in the Household			-0.233865***
			(0.0496)
Number of Days Sick While Working			-0.107350
			(0.00277)
Number of Days Sick			0.102730
			(0.00244)
Observations	222	222	222
F	4.620	4.235	5.440
R2	0.199	0.220	0.269
Rmse	1.478	1.469	1.433

Standardized beta coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6. Labor Demand for Staple Food in the Planting Season

	PL1_S	PL2_S	PL3_S
Age Household Head	-0.131685	-0.168109	-0.121961
	(0.0263)	(0.0255)	(0.0249)
Household Head Experience	0.177954	0.218175	0.173690
	(0.0259)	(0.0250)	(0.0244)
Ln Distance to Village (km)	-0.073954	-0.094958	-0.102554
	(0.129)	(0.128)	(0.129)
Ln Lot Size (ha)	0.018596	0.250724	0.191323
	(0.166)	(0.271)	(0.272)
Ln Area Under Cultivation (ha)	0.273744***	0.294005***	0.298736***
	(0.0929)	(0.0898)	(0.0859)
Ln Price Leased Land (R$)	-0.044449	-0.057917	-0.070524
	(0.221)	(0.217)	(0.209)
Ln Price of Fencing (R$)	0.124642	0.125870	0.086134
	(0.150)	(0.146)	(0.146)
Ln Price of Improved Seeds (R$/Sack)	0.023012	0.036312	0.034353
	(0.368)	(0.366)	(0.344)
Ln Price of Manioc (R$)	0.243148***	0.214382**	0.205606**
	(0.184)	(0.187)	(0.183)
Ln Price of Beans (R$)	0.056660	0.085646	0.057912
	(0.252)	(0.235)	(0.232)
Ln Price of Rice (R$)	0.052618	0.059213	0.054290
	(0.540)	(0.505)	(0.510)
Ln Wage Rate (R$)	0.057482	0.021656	0.049187
	(0.313)	(0.306)	(0.306)
Ln Exogenous Income (R$)	-0.027383	-0.025731	-0.018800
	(0.0168)	(0.0165)	(0.0162)
Ln Shadow wage (R$)	-0.463990***	-0.484750***	-0.508302***
	(0.0817)	(0.0805)	(0.0773)
Household Size		-0.259008	-0.186999
		(0.176)	(0.186)
Share Adult People in the Household		0.624361*	0.555785*
		(1.071)	(0.992)
Share Children in the Household		0.511171*	0.466626*
		(1.086)	(1.004)
Number of Sick People in the Household			-0.126523*
			(0.0381)
Number of Days Sick While Working			-0.324098**
			(0.00153)
Number of Days Sick			0.437199***
			(0.00112)
Observations	222	222	222
F	3.885	4.037	4.519
R2	0.209	0.268	0.330
Rmse	0.909	0.881	0.849

Standardized beta coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7. Labor Demand for Staple Food in the Harvesting Season

	HV1-S	**HV2_S**	**HV3_S**
Age Household Head	-0.365289	-0.351461	-0.369793
	(0.0293)	(0.0298)	(0.0302)
Household Head Experience	0.479864	0.466308	0.480865
	(0.0293)	(0.0297)	(0.0302)
Ln Distance to Village (km)	-0.056373	-0.039085	-0.044203
	(0.119)	(0.122)	(0.124)
Ln Lot Size (ha)	0.066734	0.029470	0.009910
	(0.187)	(0.357)	(0.369)
Ln Area Under Cultivation (ha)	0.175151^{*}	0.165317	0.167760
	(0.129)	(0.132)	(0.133)
Ln Price Leased Land (R$)	-0.044998	-0.045578	-0.046041
	(0.272)	(0.276)	(0.280)
Ln Price of Fencing (R$)	-0.033715	-0.033788	-0.045266
	(0.166)	(0.168)	(0.171)
Ln Price of Improved Seeds (R$/Sack)	0.021818	0.016873	0.019345
	(0.485)	(0.487)	(0.498)
Ln Price of Manioc (R$)	0.078375	0.073363	0.073388
	(0.236)	(0.240)	(0.238)
Ln Price of Beans (R$)	0.018263	0.009884	0.001386
	(0.210)	(0.214)	(0.219)
Ln Price of Rice (R$)	0.027520	0.030590	0.032234
	(0.563)	(0.571)	(0.563)
Ln Wage Rate (R$)	-0.042264	-0.038554	-0.033023
	(0.291)	(0.300)	(0.311)
Ln Exogenous Income (R$)	-0.044011	-0.043322	-0.036200
	(0.0215)	(0.0217)	(0.0222)
Ln Shadow wage (R$)	-0.429539^{***}	-0.426135^{***}	-0.435578^{***}
	(0.0910)	(0.0934)	(0.0956)
Household Size		0.032711	0.061514
		(0.272)	(0.279)
Share Adult People in the Household		-0.162848	-0.187039
		(0.714)	(0.706)
Share Children in the Household		-0.191715	-0.214605
		(0.712)	(0.704)
Number of Sick People in the Household			-0.039051
			(0.0612)
Number of Days Sick While Working			-0.010679
			(0.00149)
Number of Days Sick			0.091434
			(0.00124)
Observations	222	222	222
F	2.860	2.490	2.119
R2	0.160	0.164	0.171
Rmse	1.055	1.060	1.064

Standardized beta coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

2.6.2 Results for seasonal labor demand in livestock production

Table 8 shows the results for the livestock labor demand in the pre-planting season. Earlier we mentioned that livestock production in the Amazon requires little management effort and few inputs. Therefore, despite the fact that pre-planting season is the peak season, disease is unlikely to affect labor demand because livestock production does not require much physical effort[5]. That is, the efficiency of labor is not an important input. Labor is important to the extent that household member can walk back and forth from the corral to the pasture where the livestock is going to spend the day grazing. In the pre-planting season, we find weak evidence that disease is important. The F test 2.43 is not significant at the level of significance 0.05, while the likelihood ratio test statistics 9.26 is significant. The only health related variable that is significant is the number of sick people in the household. Also, it is important to note that the shadow wage of labor is not significant. However, herd size and price of livestock are highly significant.

Livestock production seems to be an important activity in the sense that households want to supply more labor to off farm markets, but they are constrained by the lack of off farm opportunities. Thus, the only way for them to employ household members is to work on the farm with livestock production. In this situation, household demographic variables are likely to be important in the labor demand for livestock production. Our results show that, indeed, household demographic variables should not be excluded from labor demand. The F-test statistics is 8.17 and likelihood ratio test statistics is 26.02, both showing that demographic variables are significant. The elasticity of labor demand with respect to household size, share

[5] Its possible though that disease could reduce family resources, therefore meaning a smaller herd although that is an exogenous variable in this model.

of adult in the household, and share of children in the household are all positive and highly significant in the model.

In the planting season, health related variables are no longer important. Separability breaks down, however, because household demographic variables are significant (F=10.91, and likelihood ratio= 38.08). The elasticity of labor demand with respect to household size is positive and significant with an estimated coefficient of 0.34. Also, the shadow wage of labor becomes significant and negative in the planting season with an estimated coefficient of -0.22. Other variables that are important in the model are price of livestock and herd size. Results for the harvesting season is similar to the planting season. The livestock demand for labor is more or less constant across all seasons, unlike the labor demand for staple food production, which drops considerably in the harvesting season. In this case, our test has considerable power because off farm employment is almost nonexistent and family members want to supply more labor. However, the only option available to employ household members is livestock production. The F-test statistics is 11.95 and likelihood ratio test statistics is 44.54. These tests statistics result show that we can reject the null hypothesis that the coefficients on demographic variables are equal to zero.

Table 8. Labor Demand for Livestock Production in the Pre-Planting Season

	PP1_L	**PP2_L**	**PP3_L**
Ln Adult Mean Education (Years)	0.299743	0.169369	0.166950
	(0.470)	(0.472)	(0.462)
Experience (Years)	1.253062	0.856375	0.837222
	(0.104)	(0.103)	(0.101)
Age Household Head (Years)	-1.272061	-0.886170	-0.860448
	(0.105)	(0.103)	(0.102)
Ln Distance to Nearest Market (Km)	0.011457	-0.037659	-0.031470
	(0.171)	(0.162)	(0.163)
Ln Lot Size (ha)	-0.038426	-0.029674	-0.043997
	(0.248)	(0.230)	(0.237)
Ln Area of Pasture (ha)	0.123804	0.082304	0.091643
	(0.133)	(0.124)	(0.122)
Ln Price of Leased Land (R$)	-0.018423	-0.017123	-0.025712
	(0.328)	(0.316)	(0.330)
Ln Herd Size	0.270193^{***}	0.264317^{***}	0.265018^{***}
	(0.110)	(0.106)	(0.108)
Price of Agriculture Transportation (R$/Km)	-0.084362	-0.059154	-0.059952
	(0.795)	(0.771)	(0.769)
Ln Price of Improved Seeds (R$)	0.004507	0.010113	0.014465
	(0.575)	(0.546)	(0.555)
Ln Price of Fencing (R$)	0.010340	0.008880	0.021108
	(0.209)	(0.210)	(0.216)
Ln Price of Livestock Immunization (R$)	0.084721	0.073571	0.078815
	(0.132)	(0.139)	(0.133)
Ln Price of Hired Labor (R$/Day)	0.056003	0.045654	0.054445
	(0.768)	(0.718)	(0.721)
Ln Price of Livestock (R$)	0.292517^{***}	0.313344^{***}	0.318376^{***}
	(0.101)	(0.0983)	(0.0963)
Ln Exogenous Income (R$)	0.092936	0.071050	0.060017
	(0.0243)	(0.0243)	(0.0244)
Ln Shadow wage (R$/Day)	-0.182521^{*}	-0.117389	-0.125207
	(0.0905)	(0.0906)	(0.0922)
Household Size		0.288596^{***}	0.276185^{***}
		(0.0522)	(0.0544)
Share of Adults in the Household		0.412810^{***}	0.436410^{***}
		(0.734)	(0.804)
Share Children in the Household		0.271175^{**}	0.294830^{**}
		(0.711)	(0.784)
Sick People in the Household			0.119284^{*}
			(0.0695)
Number of Days Sick While Working			0.042361
			(0.00228)
Number of Days Sick			-0.159457
			(0.00188)
Observations	307	307	307
F	5.455	5.847	5.792
R2	0.175	0.242	0.265
Rmse	1.577	1.519	1.504

Standardized beta coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 9. Labor Demand for Livestock in the Planting Season

	PL1_L	PL2_L	PL3_L
Ln Adult Mean Education (Years)	0.219277	0.096223	0.081780
	(0.499)	(0.488)	(0.498)
Experience (Years)	0.270725	0.013349	-0.096428
	(0.109)	(0.108)	(0.111)
Age Household Head (Years)	-0.231435	0.011882	0.121181
	(0.110)	(0.109)	(0.111)
Ln Distance to Nearest Market (Km)	0.226230*	0.162044	0.162569
	(0.151)	(0.143)	(0.142)
Ln Lot Size (ha)	-0.062014	-0.028089	-0.029912
	(0.199)	(0.191)	(0.192)
Ln Area of Pasture (ha)	0.088688	0.053181	0.044966
	(0.117)	(0.109)	(0.109)
Ln Price of Leased Land (R$)	-0.031377	-0.024700	-0.037804
	(0.289)	(0.289)	(0.294)
Ln Herd Size	0.370502***	0.364606***	0.369926***
	(0.107)	(0.0973)	(0.0981)
Price of Agriculture Transportation (R$/Km)	-0.137661*	-0.111497	-0.114914
	(0.763)	(0.748)	(0.748)
Ln Price of Improved Seeds (R$)	0.005898	0.001629	-0.003859
	(0.541)	(0.506)	(0.512)
Ln Price of Fencing (R$)	0.023862	0.025374	0.024560
	(0.206)	(0.193)	(0.200)
Ln Price of Livestock Immunization (R$)	0.032778	0.019893	0.016869
	(0.119)	(0.130)	(0.131)
Ln Price of Hired Labor (R$/Day)	0.052567	0.045566	0.046668
	(0.712)	(0.639)	(0.645)
Ln Price of Livestock (R$)	0.359070***	0.389838***	0.386654***
	(0.0905)	(0.0867)	(0.0870)
Ln Exogenous Income (R$)	0.009305	0.000144	-0.005440
	(0.0217)	(0.0209)	(0.0211)
Ln Shadow wage (R$/Day)	-0.283889***	-0.223299**	-0.215488**
	(0.0801)	(0.0848)	(0.0851)
Household Size		0.344083***	0.321822***
		(0.0442)	(0.0452)
Share of Adult in the Household		0.035204	0.035554
		(1.096)	(1.137)
Share Children in the Household		-0.062648	-0.046272
		(1.054)	(1.101)
Number of Sick People in the Household			0.075692
			(0.0596)
Number of Days Sick While Working			-0.126369
			(0.00171)
Number of Days Sick			0.049564
			(0.00148)
Observations	307	307	307
F	10.91	14.32	11.86
R2	0.284	0.368	0.380
Rmse	1.422	1.344	1.337

Standardized beta coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 10. Labor Demand for Livestock on the Harvesting Season

	HV1_L	**HV2_L**	**HV3_L**
Adult Mean Education (Years)	0.195983	0.066785	0.060807
	(0.532)	(0.527)	(0.539)
Experience (Years)	0.118658	-0.136722	-0.174234
	(0.113)	(0.114)	(0.117)
Age Household Head (Years)	-0.047913	0.195389	0.239310
	(0.114)	(0.115)	(0.117)
Ln Distance to Nearest Market (Km)	0.132848	0.065906	0.072437
	(0.161)	(0.149)	(0.150)
Ln Lot Size (ha)	-0.074259	-0.040058	-0.049473
	(0.209)	(0.198)	(0.203)
Ln Area of Pasture (ha)	0.065908	0.021604	0.020165
	(0.122)	(0.114)	(0.113)
Ln Price of Leased Land (R$)	-0.013655	-0.008228	-0.016504
	(0.331)	(0.309)	(0.315)
Ln Herd Size	0.375999***	0.364434***	0.371726***
	(0.116)	(0.103)	(0.104)
Price of Agriculture Transportation (R$/Km)	-0.025496	0.001466	0.000220
	(0.805)	(0.790)	(0.799)
Ln Price of Improved Seeds (R$)	0.004995	0.001870	-0.002490
	(0.549)	(0.511)	(0.525)
Ln Price of Fencing (R$)	0.043649	0.045164	0.047236
	(0.212)	(0.197)	(0.202)
Ln Price of Livestock Immunization (R$)	0.030886	0.016099	0.017795
	(0.112)	(0.113)	(0.114)
Ln Price of Hired Labor (R$/Day)	-0.004379	-0.013399	-0.011231
	(0.779)	(0.694)	(0.696)
Ln Price of Livestock (R$)	0.388758***	0.419605***	0.422339***
	(0.0937)	(0.0883)	(0.0885)
Ln Exogenous Income (R$)	-0.006297	-0.019043	-0.024499
	(0.0235)	(0.0222)	(0.0225)
Ln Shadow wage (R$/Day)	-0.295819***	-0.221835**	-0.221703**
	(0.0997)	(0.103)	(0.104)
Household Size		0.383505***	0.377285***
		(0.0474)	(0.0509)
Share of Adult in the Household		0.042977	0.055114
		(1.206)	(1.257)
Share Children in the Household		-0.102020	-0.082174
		(1.193)	(1.243)
Number of Sick People in the Household			0.044670
			(0.0667)
Number of Days Sick While Working			-0.051982
			(0.00220)
Number of Days Sick			-0.032915
			(0.00197)
Observations	307	307	307
F	8.960	12.16	10.19
r2	0.268	0.367	0.374
Rmse	1.515	1.417	1.416

Standardized beta coefficients; Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

2.6.3 Final Testing for Complete Markets (Seperability) across Seasons

The regression results for labor demand in staple food and cattle production across pre-planting, planting, and harvesting seasons are shown above in **Tables 5-10**. Based on the statistics collected from these models, we test exclusion restrictions in order to understand labor demand for staple food and livestock production across all agriculture seasons in the Brazilian Amazon. **Table 11** presents a summary of the test results. In each table, we have three labor demand models. The first model is the neoclassical (and assumed separable) labor demand model where only prices of inputs and farm characteristics are used in the regression. The second labor demand model additionally includes household demographic variables, and the third model includes in addition to prices of inputs, farm characteristics, and household demographic the health status related-variables. If health status variables cannot be excluded from the model, then column 1 and column 2 are mis-specified models. We keep the mis-specified models in the table indicate the problem that may rise when health related variables are omitted.

Table 11. Testing for Complete Labor Markets across Seasons in the Brazilian Amazon

Season	Model	Test Statistic[a] F	Test Statistic[a] Likelihood Ratio	Null Hypothesis	Results at (0.05)
Staple Food Labor Demand					
Pre-Planting	Model (PP1_S)	4.62 (0.0000)	49.30 (0.0000)	$H_0 : \beta_{\text{Prices \& Farm Characteristics}} = 0$	Reject
	Model (PP2_S)	1.50 (0.2153)	5.80 (0.1216)	$H_0 : \beta_{\text{Household Composition}} = 0$	Do not Reject
	Model (PP3_S)	7.57 (0.0001)	14.54 (0.0023)	$H_0 : \beta_{\text{Health Status}} = 0$	Reject
Planting	Model (PL1_S)	3.89 (0.0000)	52.06 (0.0000)	$H_0 : \beta_{\text{Prices \& Farm Characteristics}} = 0$	Reject
	Model (PL2_S)	4.16 (0.0070)	17.12 (0.0007)	$H_0 : \beta_{\text{Household Composition}} = 0$	Reject
	Model (PL3_S)	6.91 (0.0002)	19.72 (0.0002)	$H_0 : \beta_{\text{Health Status}} = 0$	Reject
Harvesting	Model (HV1_S)	2.86 (0.0006)	38.68 (0.0006)	$H_0 : \beta_{\text{Prices \& Farm Characteristics}} = 0$	Reject
	Model (HV2_S)	0.58 (0.6321)	1.21 (0.7502)	$H_0 : \beta_{\text{Household Composition}} = 0$	Do not Reject
	Model (HV3_S)	0.60 (0.6135)	1.84 (0.6065)	$H_0 : \beta_{\text{Health Status}} = 0$	Do not Reject
Livestock Labor Demand					
Pre-Planting	Model (PP1_L)	5.46 (0.0000)	59.07 (0.0000)	$H_0 : \beta_{\text{Prices \& Farm Characteristics}} = 0$	Reject
	Model (PP2_L)	8.17 (0.0000)	26.02 (0.0000)	$H_0 : \beta_{\text{Household Composition}} = 0$	Reject
	Model (PP3_L)	2.43 (0.0655)	9.26 (0.0261)	$H_0 : \beta_{\text{Health Status}} = 0$	Do not Reject
Planting	Model (PL1_L)	10.91 (0.0000)	102.62 (0.0000)	$H_0 : \beta_{\text{Prices \& Farm Characteristics}} = 0$	Reject
	Model (PL2_L)	10.91 (0.0000)	38.08 (0.0000)	$H_0 : \beta_{\text{Household Composition}} = 0$	Reject
	Model (PL3_L)	1.85 (0.1383)	6.23 (0.1356)	$H_0 : \beta_{\text{Health Status}} = 0$	Do not Reject
Harvesting	Model (HV1_L)	8.96 (0.0000)	11.95 (0.0000)	$H_0 : \beta_{\text{Prices \& Farm Characteristics}} = 0$	Reject
	Model (HV2_L)	11.95 (0.0000)	44.54 (0.0000)	$H_0 : \beta_{\text{Household Composition}} = 0$	Reject
	Model (HV3_L)	1.04 (0.3742)	3.44 (0.3283)	$H_0 : \beta_{\text{Health Status}} = 0$	Do not Reject

[a] Test statistics are given with associated *p*-values in parenthesis.

2.7 Conclusions

This study found that there is a complex relationship between markets, labor allocation, and environmental degradation raises an important question for empirical research. The functioning of labor markets have implications for the efficiency of allocating resources within the household and for the design of economic and environmental policy by governments. The effectiveness of public policies to create sustainable development outcomes for smallholders on the Amazon frontier and elsewhere depends crucially on understanding markets for factors of production and the behavior of smallholders with respect to labor allocation. A further (and shown here, critical) complication in labor use among smallholders is disease, as poor health requires additional resources, less time available to work, and potentially lower efficiency of labor when sick members must work because of constraints they face in labor markets. The "completeness" of labor market is also of fundamental importance when understanding labor allocation, and thus production decisions and resultant degradation by smallholders. We are not aware of other studies that have rigorously examined all of these links.

Indeed, in rural settings where farm households engage in different economic activities and supply their own farm labor demand, seek off farm labor opportunities, and have varying health status across seasons, labor markets may be complete in some seasons but incomplete and non-separable in others, depending upon constraints on labor households face and the timing of poor health.

In this paper, we have studied this problem for the case of migrant smallholders in the Brazilian Amazon by estimating a labor demand model for each important economic activity and season, and then testing separability of labor decisions taking into account fluctuation in farm labor demand, disease, and off farm labor opportunities. Based on cross-sectional household data set collected in the Brazilian Amazon, our empirical results indicate that separability breaks down in almost all seasons. However, the reasons for this breakdown vary across season and economic activity.

In particular, we find that staple food and livestock labor demands are affected importantly by factors other than market prices and biophysical characteristics of the land. These results collectively raise questions about the ability of households to smooth the impact of disease by allocating labor to economic activities, such as cattle grazing, that are not labor intensive. These results also suggest the importance of both modeling households across seasons and incorporating health effects into household models for the Brazilian Amazon.

In the staple food production activity, separability of labor decisions breaks down due to correlations between labor demand and health status variables in the pre-planting season. However, lack of separability in the livestock activity is explained by correlation between labor demand and household demographic variables in the pre-planting season. Different factors are at work in these because staple food and livestock production technologies require different levels of labor efficiency to be executed well. Livestock production in the Brazilian Amazon can be done well with low labor efficiency, as it requires little management effort time. Thus, it is evident that lack of separability cannot generally be caused by a correlation between disease and labor demand in the case of livestock. Indeed, our results show that violation of the separation hypothesis is always due to correlation between demographic variables and labor demand as far as livestock activity is concerned.

In the planting season, however, we found that separability breaks down because of correlations between demographic and health status variables for staple food. The planting period is between the peak and slack seasons as we have previously defined labor constraints.

This means that marginal productivity of labor on the farm is approaching equivalence or is just smaller than the market wage rate. Our results show that separability breaks down here because of both correlations between labor demand and household demographic variables, and labor demand and health status variables. This situation indicates that household labor supply is greater than on farm labor demand, but this happens at the same time that there are limited opportunities to work off farm. Extra employment can be found only on the family's farm. Thus, we see a positive and significant correlation between labor demand and demographic variables like family size. We also observe a negative correlation between poor health and labor demand, which can be explained by the fact that disease is making family members labor less efficient. In the harvesting season, we found a separable and perfectly competitive labor market as far as labor choices for staple food production. But, separability fails again in the livestock case during this time period, and there is again a positive correlation between labor demand and household demographic variables.

In the Brazilian Amazon, there are economically large and statistically significant divergences between actual input allocation decisions at household specific shadow wages and those that would be predicted in a separable model of profit maximization. The pattern of rejection we found in the separability tests here suggests further studies on deforestation are needed. Since labor allocation from the household is the major reason that deforestation occurs with smallholders, understanding the mechanisms by which labor is chosen and forest is cleared is needed to ultimately predict the level of future deforestation in this sensitive region.

The fact that labor demand for livestock production is correlated with household demographic variables, but not with health status indicates that further studies should also investigate the role of livestock as a mechanism to smooth the impact of disease on labor choices for staple food production. The results we find are the first bit of evidence that the observed rapid adoption of cattle ranching in the frontier Amazon by smallholders living in disease prone environments with low access to public health is not mere coincidence. The results indicate that ranching is a more attractive economic activity because labor demand for livestock production is not correlated with disease.

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APPENDIX

Appendix A

A discussion on the impact of health on labor supply and demand (comparative statics for labor supply equations)

Table 12, below, summarizes the results in this Appendix. The second derivative of the profit function with respect to the wage rate is negative. The only sign that we do not know in $\frac{dL^D}{d\Gamma} = \frac{\left[-\frac{d\pi(w^*;A)}{dw^{*2}}\right]dw^*}{d\Gamma}$ is the derivative of the shadow wage with respect to household health. At the optimum in a nonseparable model the marginal productivity of labor is characterized by $f_{L^{sp}}[\cdot] \neq w$ and fact, $f_{L^{sp}}[\cdot] = w^*$. Thus, the first order condition to profit maximization defines the shadow wage under each labor constraint (5) and (6):

$$f_{L^{sp}}\left[\phi(\Gamma)L^{sp}\left(w^*, M^*;\Gamma\right) - S(\Gamma) - \overline{L}, L^h; A\right] - w^* = 0 \tag{A1}$$

$$f_{L^{sp}}\left[\phi(\Gamma)L^{sp}\left(w^*, M^*;\Gamma\right) - S(\Gamma) - \underline{L}, L^h; A\right] - w^* = 0 \tag{A2}$$

Using implicit differentiation of these conditions we can find the impact of household health on the shadow wage. After some simplifications, this effect can be written,

$$\frac{dw^*}{d\Gamma} = -\frac{\frac{dL^{sp}(\cdot)}{d\Gamma}\phi(\Gamma) + \frac{d\phi(\cdot)}{d\Gamma}L^{sp} + \frac{dS(\cdot)}{d\Gamma}}{\frac{dL^{sp}(\cdot)}{dw}\phi(\Gamma) - \frac{dL^*}{dw}} \tag{A3}$$

The denominator is unambiguously positive because the sign of $\frac{dL^{sp}(\cdot)}{dw}$ is positive, the health-augmenting parameter lies between (0,1), and the sign of $\frac{dL^*}{dw}$ is negative. Therefore, the sign of the shadow wage with respect to health parameter depends only on the sign of the numerator. In order to find this sign, we need to consider the following cases: (i) $\frac{dS(\cdot)}{d\Gamma} = 0$ and $\frac{dL^{sp}(\cdot)}{d\Gamma} = 0$

, (ii) $\frac{dS(\cdot)}{d\Gamma} = 0$ and $\frac{dL^{sp}(\cdot)}{d\Gamma} > 0$, (iii) $\frac{dS(\cdot)}{d\Gamma} = 0$ and $\frac{dL^{sp}(\cdot)}{d} < 0$, (iv) $\frac{dS(\cdot)}{d\Gamma} > 0$ and $\frac{dL^{sp}}{d\Gamma} = 0$, (v) $\frac{dS(\cdot)}{d\Gamma} > 0$ and $\frac{dL^{sp}(\cdot)}{d\Gamma} > 0$, and (vi) $\frac{dS(\cdot)}{d\Gamma} > 0$ and $\frac{dL^{sp}(\cdot)}{d\Gamma} < 0$.

Case 1: Disease has an impact only on labor efficiency

In this case, the elasticity of labor supply with respect to disease and the impact of disease on sick days not working are both equal to zero. Thus, the only term left in equation A3 is the middle term of the numerator, $\frac{d\phi(\Gamma)}{d\Gamma} L^{sp}$. Assuming that the impact of disease on labor efficiency is negative, then, the impact of disease on shadow wage is positive. This is likely the case for minor diseases, as these change labor efficiency, but the overall impact is not big enough to make households change labor supply behavior. In addition, minor diseases have no impact on sick days.

Case 2: Disease has an impact on labor efficiency, and a positive impact on labor supply

Here, the impact of disease on shadow wage can be positive or negative. As before, disease has no impact on sick days not working. Thus, the last term in the numerator of equation A3 is not taken into account. The sign of the shadow wage is positive if the elasticity of labor supply with respect to disease times the health efficiency parameter is greater than the impact of disease on labor-augmenting health efficiency parameter times labor supply. In this case, diseases change household labor supply behavior. For instance, non-sick households might be willing to work more to compensate for the lost labor efficiency of sick family members. Thus, the shadow wage of labor might become positive if the amount of labor supplied by non-sick household is greater than the loss associated with the impact of disease on labor supply. On the other hand, if the impact of disease on labor efficiency dominates than the sign of the shadow becomes negative.

Case 3: Disease has impact on labor efficiency, and a negative impact on labor supply

If the impact of disease on elasticity of labor supply is negative and there is no impact of disease on days sick not working then the sign of the shadow wage is positive. From the numerator of A3, we can see that the first two terms become negative. Thus, the impact of disease on the sign of the shadow is positive. We believe this case might happen when a widespread disease hits the whole family. Thus, people in the household cannot compensate the loss of labor efficiency of sick family member, as everyone is equally sick. The total household time endowment is not affected, but labor efficiency is reduced. This situation, in turn, is likely to raise the opportunity cost of time for household members.

Case 4: Disease has an impact on labor efficiency and sick days not working

As in the first case, the elasticity of labor supply with respect to disease and the impact of disease on sick days not working are equal to zero. As there is no change in labor supply, we are concerned only with the impact of disease on labor efficiency and time sick not working. Thus, the terms in equation A3 that are important in this case are the middle and last term of the nominator, $\frac{d\phi(\cdot)}{d\Gamma}L^{sp}$ and $\frac{dS(\Gamma)}{d\Gamma}$. As before, we assume that the impact of disease on labor efficiency is negative. In this case, the impact of disease on labor supply is positive. Then, the impact of disease on shadow wage can be both positive and negative. The impact is positive if the impact of disease on the labor-augmenting efficiency parameter times labor supply is greater than the impact of disease on sick days not working. Otherwise, the impact the disease on shadow wage is negative.

Case 5: Disease impacts labor efficiency, sick days not working, and a positive impact on labor supply

This is very similar to case 2, however, we have to take into account the impact of disease on time sick. Thus, the sign of the shadow wage is positive only if the impact of disease on labor supply times labor-augmenting health efficiency parameter together with the impact of disease on time wick not working is greater than the impact of disease on labor-augmenting health efficiency parameter times labor supply. Otherwise, the sign of the shadow wage is negative. Again, we see that anything that pushes the number of days worked down and cannot be compensated by household labor supply behavior drives shadow wage up. In this case, households try to compensate labor lost due to disease by working more, however, this strategy may not be enough to compensate the impact of disease on the labor-augmenting health efficiency parameter.

Case 6: Disease has an impact on labor efficiency, sick days not working, and a negative impact on labor supply

Now, the sign of the impact of disease on shadow wage depends crucially on the magnitude of the elasticity of sick days not working with respect to disease. The sign of the shadow wage is positive if the elasticity of labor supply with respect to disease times labor-augmenting health efficiency parameter together with the impact of disease on labor efficiency time labor supply is greater than the impact of disease on time sick not working. Otherwise, the expected sign of the shadow wage is negative.

Table 12. Analyzing the impact of Disease on Shadow Wage

		Impact of disease on sick days not working	
		$\frac{dS(\cdot)}{d\Gamma}=0$	$\frac{dS(\cdot)}{d\Gamma}>0$
Impact of disease on labor supply	$\frac{dL^{sp}}{d\Gamma}=0$	$\frac{dw^*}{d\Gamma}>0$	$\frac{dw^*}{d\Gamma}>0 \Rightarrow \frac{d\phi(\cdot)}{d\Gamma}L^{sp}(\cdot)>\frac{dS(\cdot)}{d\Gamma}$ $\frac{dw^*}{d\Gamma}<0 \Rightarrow \frac{d\phi(\cdot)}{d\Gamma}L^{sp}(\cdot)<\frac{dS(\cdot)}{d\Gamma}$
	$\frac{dL^{sp}}{d\Gamma}>0$	$\frac{dw^*}{d\Gamma}>0 \Rightarrow \frac{dL^{sp}(\cdot)}{d\Gamma}\phi(\cdot)>\frac{d\phi(\cdot)}{d\Gamma}L^{sp}(\cdot)$ $\frac{dw^*}{d\Gamma}<0 \Rightarrow \frac{dL^{sp}(\cdot)}{d\Gamma}\phi(\cdot)<\frac{d\phi(\cdot)}{d\Gamma}L^{sp}(\cdot)$	$\frac{dw^*}{d\Gamma}>0 \Rightarrow \frac{dL^{sp}(\cdot)}{d\Gamma}\phi(\cdot)+\frac{dS(\cdot)}{d\Gamma}>\frac{d\phi(\cdot)}{d\Gamma}L^{sp}(\cdot)$ $\frac{dw^*}{d\Gamma}<0 \Rightarrow \frac{d\phi(\cdot)}{d\Gamma}L^{sp}(\cdot)>\frac{dL^{sp}(\cdot)}{d\Gamma}\phi(\cdot)+\frac{dS(\cdot)}{d\Gamma}$
	$\frac{dL^{sp}}{d\Gamma}<0$	$\frac{dw^*}{d\Gamma}>0$	$\frac{dw^*}{d\Gamma}>0 \Rightarrow \frac{dL^{sp}(\cdot)}{d\Gamma}\phi(\cdot)+\frac{d\phi(\cdot)}{d\Gamma}L^{sp}(\cdot)>\frac{dS(\cdot)}{d\Gamma}$ $\frac{dw^*}{d\Gamma}>0 \Rightarrow \frac{dS(\cdot)}{d\Gamma}>\frac{dL^{sp}(\cdot)}{d\Gamma}\phi(\cdot)+\frac{d\phi(\cdot)}{d\Gamma}L^{sp}(\cdot)$

CHAPTER 3

The Direct and Indirect Effects of Health on Smallholder Technical Efficiency in the Brazilian Amazon

Abstract

Households living on the forest frontier of the Brazilian Amazon, as elsewhere in the world, have limited access to credit – reducing their available capital – and rely primarily on family labor for farm production. And, where access to health services is poor, and the incidence of disease is high, the resulting effect on the quantity and quality of family labor may have a negative impact on production efficiency. In this paper, we clarify the impact of health as a direct production input and an indirect non-input variable on production technical efficiency using a non-neutral stochastic production approach. Based on cross-sectional farm data from the Brazilian Amazon, our empirical results indicate that health status, measured by time sick, has significant impacts on rural household production. The estimated results show that a 1% percent decrease in health status may result in a direct reduction in output of 0.2%, and an indirect reduction in output of 2.39%. At the mean, this loss in efficiency corresponds to a decline of nearly R$100 in output value per year by housheold. We also find that the majority of smallholder farmers operate below the efficient production frontier. The average technical efficiency rating for smallholders at the mean is only 36%. This result indicates that farmers could potentially increase output by 64% with the current state of technology and level of input, but with different production allocation decisions. Furthermore, the technical efficiency for sick households was 31%, while for non-sick households 39%. These results support earlier findings that health status is an important factor in smallholder production. We add to these findings by showing that health has both direct and indirect impacts on production.
Key words: Agricultural production efficiency, health, Amazon,

3.1 Introduction

In the absence of access to formal credit, and thus capital, smallholder farmers[5] on the Amazon frontier employ labor as their key asset in agricultural and livestock production. A dependence on one key asset for production is, however, fraught with risk. In this case, risk materializes through family health, which affects the quality and quality of available labor. The Amazon frontier is an unhealthy place to live. There, one finds 98% of Brazil's malaria cases, 35% of leprosy cases, and a high incidence of tuberculosis, among other possible calamities (Colfer et al., 2006; Confalonieri, 2005). Many of the diseases in these isolated rural settlements are relatively simple to treat. However, due to the lack of access to basic health services they tend to go untreated until serious, and can become a great burden to smallholder families (Alves and Timmins, 2001). Furthermore, the physical conditions in the region are dangerous and injuries, such as broken bones, and even snakebites, are common.

While agricultural and livestock production on the frontier may appear to be simple processes, they are, in reality, a series of complex, interactive decisions allocating available resources to maximize their returns, and perhaps more importantly minimize the risk of catastrophic failure. These decisions are based, among many other factors, on knowledge of marginal costs and likely returns, the existence of labor markets,[6] and, since labor is a key asset, family health (Hufman, 1980; Fafchamps and Quisumbling, 1999; Taylor and Yunez-Naude, 2000; Yang, and An, 2001). Indeed, health plays a key role in production decisions by

[5] In this document, the terms, subsistence farmers, households, and smallholders are used interchangeably to represent the families living on small farms (usually 100 ha) on the Amazon frontier.
[6] Furthermore, the impact of poor health on household production decisions depends critically on the quality of the rural labor market. With complete markets, households can simply hire labor freely at the market wage to compensate for the loss of household labor time due to disease, although their net income might be lower. When markets are incomplete, however, labor cannot be freely hired (a market wage may not even exist), and then sick households are fully subject to both direct and indirect impacts of poor health (Strauss and Thomas, 1998).

reducing the labor endowment and constraining labor efficiency (Grossman 1972; O'Donnell, 1995; Strauss, 1998; Amacher, 2004a; Amacher, 2004b; Takasaki, 2004; Kochar, 2004; and Kenjiro, 2005). So, although smallholders may know how to produce optimally given the input and technology available, they may not do so because of poor health (Yamano and Jayne, 2003).

That health status affects farming efficiency is well known (Grossman, 1972). In particular, health status contributes to production through a "labor productivity effect" as well as an "input allocation effect" (Welch, 1970). The former refers to the effect health status has on technical efficiency, while the latter refers to changes in labor efficiency resulting in allocation of inputs to alternative uses.[7] A large body of literature has assessed the impact of health status on production decisions (see Deolalikar, 1988; Strauss and Thomas, 1998; Takasaki, et al., 2004; Schultz, and Tansel, 1997). However, studies of the impact of health status on production have largely focused on labor productivity effects through the estimation of production functions. In this framework it is assumed that farmers are fully technically efficient and health is treated as an input in the production process. This methodology assesses health status receives returns as an investment good similar to land, which then allows them to measure of the marginal effect of health status directly on output (Yang, 2004).

An interesting departure from this framework relaxes the assumption of technical efficiency and allows the input-output combination of each smallholder to be located anywhere on or below the production frontier. This approach has been used extensively in the literature

[7] Since labor is a main input used in smallholder activities, albeit to different extents, anything that changes household labor efficiency brings about a change in the relative return of competing uses of the household's time. Consequently, they reallocate their labor and physical resources across activities in the farm. In a similar fashion, this idea has been used to understand the effect of education on the choice of income activities (Taylor and Yunex-Naude, 2002; and Yang and An, 2002).

to examine inefficiency among farmers with respect to extension services (Battese and Broca, 1997; Sherlund, 2002; Dinar, 2007; Bravo-Ureta, 1993). To our knowledge however, this approach has not been used to explore the impact of health status on smallholder efficiency.

Our work builds on the aforementioned literature to estimate a stochastic production frontier that accounts for the direct and indirect impacts of health on production. Following Huang and Liu (1994) and Battese and Coelli (1995), we specify a stochastic production frontier model that allows health status to be an input in the production function as well as a non-input variable that interacts with input variables, causing an indirect impact on technical efficiency. We then use the estimated model to simultaneously test the direct and indirect impact of health status on household farm production.

The remainder of this paper is organized as follows. First, we develop a stochastic production model that incorporates the impact of health status on both technical efficiency and household production. Second, we describe the data consisting of a sample of 335 households collected in the Brazilian Amazon. In the third section, we estimate stochastic production functions and use formal statistical tests to check whether health status should be part of the production function and the technical inefficiency function, or whether it should be included in both. We use the results of the statistical testing to specify the correct stochastic production frontier model and estimate the direct and indirect effects of health status on smallholder production. Finally, we offer concluding remarks and policy recommendations.

3.2 A Stochastic Frontier Model to address the impact of Health

In this section we provide a description of the stochastic frontier model relevant for our study. Suppose a household production function is given by $f(z;\beta)$, where $f(\cdot)$ is a neoclassical technology, z is a vector of inputs, and β are constant parameters. A perfectly efficient household working in a deterministic environment would produce $q = f(z;\beta)$. A households's efficiency, however, may be affected by farm-specific demographic, socioeconomic, and environmental characteristics, as well as knowledge and experience with respect to inputs productivity (Bravo-Ureta and Pinheiro, 1993). Therefore, a stochastic frontier analysis relaxes the implicit assumption of efficiency and certainty of production (Aigner et al. 1977; Meeusen and van den Broeck, 1977).

Even in a stochastic frontier analysis, output is always assumed to be strictly positive, so that the degree of technical efficiency is always greater than zero. Suppose the degree of technical efficiency is represented by $\phi \in (0,1]$. In addition, suppose random (unobserved) shocks have impacts on household production. Then, the simple production function can be re-written as: $q \equiv f(z;\beta)\phi\exp(e)$, where e is an error term. Taking the natural log of the transformed production function, we have: $\ln(q) = \ln f(z;\beta) + \ln(\phi) + e$. Defining $v = -\ln(\phi)$ we have: $\ln(q) = \ln f(z;\beta) + e - v$. The symmetric component, distributed as $e \sim iid\ N(0,\sigma_e^2)$, represents any stochastic factors affecting production beyond the household's control. The asymmetric component, $v \geq 0$, is interpreted as pure technical inefficiency. Different specifications of the e and the v terms give rise to distinct models.[8]

The last equation presented in the paragraph above is the starting point of our analysis. Previous studies of the impact of health status on production have mostly focused on the restricted version of the model above, that is, $ln(q) = lnf(z;\beta) + e$, where health is treated

[8] The distributional assumptions are: Half-normal, Truncated normal, Exponential, and Gamma (see Khumbakar, 2004).

as an input in the production process and households are efficient so that $\nu = 0$. In this specification, farmers produce the maximum amount of output for any vector of inputs.

On the other hand, the unrestricted model relaxes the assumption of technical efficiency and allows the input-output combination of each household to be located anywhere on or below the production frontier. This approach has been extensively used in the literature to explain technical inefficiency among smallholder producers with respect to access to extension services, education, and environmental production conditions (Battese, 1995; Sherlund, 2002; Dinar, 2007; Bravo-Ureta, 1993), but not yet, as far as we know, to explain the role of health.

In this paper, our central focus is on the link between health status and household farm productivity. Therefore, we need a model that allows us to measure the impact of health status as an input in the production function and a non-input variable that interacts with inputs variables causing an impact on technical efficiency. We apply the non-neutral specification developed by Huan and Liu (1994), and Battese and Coelli (1995), and further adapted by Dinar, Karagiannis, and Tzouvelekas (2007). The non-neutral specification assumes that technical efficiency is non-neutral with respect to input use. Such a specification fits our purpose well, since we are interested in understanding the direct impact of health status on output and on the indirect impact of health status on technical efficiency.

3.3 Empirical Specification and Model

Consider the following general form of the stochastic production frontier:

$$q = f(z, h; \beta) \exp(e) \qquad (1)$$

where the health status h is included as a separate input. In our study, we use Cobb-Douglas and Translog specifications for *f*(.). The Translog specification is flexible, and allows us to keep the details of the technology assumptions as general as possible. Also, in (1) we can write the error term as: $e \equiv \varpi - \varphi$, where the component ϖ is a symmetric, independent, and identically distributed error representing those factors that cannot be controlled by farmers. The component φ is a nonnegative error term representing the shortfall of output from the production frontier due to poor technical efficiency. Technical inefficiency is defined in an output-oriented format and is the maximum amount by which output can increase for a given production technology and observed input use.

For the purposes of the present study, φ can be replaced by the following linear specification:

$$\varphi = g(z, h; \vartheta) + \xi \geq 0 \tag{2}$$

where z is a vector of farm inputs, h are health related variables, φ is a vector of parameters to be estimated, and ξ is assumed to be independent, but not identically distributed, random variables. Given that $\varphi \geq 0$, then ξ must be greater or equal to $-g(z, h; \vartheta)$. In this way, the distribution of ξ is truncated at $-g(z, h; \vartheta)$. The statistical error of the production frontier is assumed to be mean zero, normally distributed, and having constant variance$\left(\sigma_{\varphi}^{2}\right)$.

After substituting equation (2) into equation (1) and taking logs, we have:

$$\ln(q) = lnf(z, h; \beta) + g(z, h; \vartheta) + \xi \tag{3}$$

Considering the stochastic nature of production, we can now determine the direct and indirect impact of health status on output by differentiating (3) with respect to h:

$$\frac{\partial lnE(q)}{\partial \ln(h)} = \frac{\partial lnf(z, h; \beta)}{\partial \ln(h)} - \delta \frac{\partial g(z, h; \vartheta)}{\partial \ln(h)} \tag{4}$$

where E is the expectation operator (the error in (3) is mean zero), and

$\delta = 1 - \sigma^{-1}\{\phi(\rho - \sigma)[\Phi(\rho - \sigma)]^{-1} - \phi(\rho)[\Phi(\rho)]^{-1}\}$.[9] The term σ^2 is the variance of the normal distribution that is truncated at zero to obtain the distribution of μ. Also, $\rho = \frac{\mu}{\sigma}$, $\phi(.)$, and $\Phi(.)$ are the density, and cumulative distribution functions of the standard normal variable, respectively.

The first term on the right hand side of the equation (4) is the direct effect of health status on farm output, for both its contribution to output and its impact on input productivity. The second term on the right hand side is the indirect impact of health status, i.e, the impact of health on the efficient utilization of available technology. If farmers are technically efficient the indirect effect is zero and the impact of health status on household performance is determined solely by the direct effect. Also, the indirect effect could be zero in presence of technical inefficiency as long as the latter is independent of the household health status.

The empirical model we can use to estimate the impact of health status on output is given given by the following flexible Translog equation:

$$\ln(q_i) = \beta_0 + \sum_{d=1}^{D} \beta_d D_i + \sum_{j=1}^{J} \beta_j \ln(z_{ji}) + {}^1\!/_2 \left[\sum_{j=1}^{J} \sum_{k=1}^{K} \beta_{j,k} \ln(z_{ji}) \ln(z_{ki})\right] + \nu_i + u_i \qquad 5(a)$$

$$u_i = \varpi_0 + \sum_{h=1}^{H} \varpi_h \ln(H_{hi}) + \sum_{m=1}^{M} \sum_{h=1}^{H} \varpi_{mh} ln(z_{mi}) ln(H_{hi}) + \xi_i \qquad 5(b)$$

where i is used to index households, j is used to index the inputs of male labor, hired labor, agriculture plot size, seeds, capital, and days sick while working. D signifies demographic variables, z are farm production inputs, and H is health status variables, finally, β and ϖ are a vector of parameters to be estimated.

We employ a Translog specification to be able to derive the output elasticity with respect to health status. Output elasticity is evaluated at a point on the production frontier.

[9] See Battese and Broca (1997)

Therefore, the second term of equation (4) must be zero. And the elasticity of output with respect to health status is given by:

$$\frac{\partial \ln q(.)}{\partial \ln(H_i)} = \beta_j + {}^1\!/_2 \sum_{j=1}^{J} \beta_{jk} \ln(H_i) \ln(z_{ji}) \tag{6}$$

The first term on the right hand side of (6) is the direct impact of health status on farm output and the second term is the impact of health status on productivity of conventional inputs.

The indirect impact of health status is given by:

$$\frac{\partial \ln E(-u_i|e_i)}{\partial ln(H_i)} = -\delta \frac{\partial g(z,H;\vartheta)}{\partial ln(H_i)} = -\delta \left(\varpi_h ln(H_i) + \sum_{j=1}^{J} \varpi_{jh} ln(z_{ji})\, ln(H_i)\right) \tag{7}$$

After substituting equation (5b) into equation (5a) the model is estimated using a single equation estimation maximum-likelihood procedure. The variance parameters of the likelihood function are estimated in terms of $\sigma_S^2 = \sigma_v^2 + \sigma^2$ and $\gamma = \sigma^2/\sigma_S^2$, where γ is a value between zero and one. The closer γ is to one, the higher the probability that technical efficiency is significant in explaining output variability. As usual the farm-specific estimates of output-oriented measures of technical efficiency are obtained from the conditional expectation of $exp(-u_i)$.

The empirical model specified in (5a) and (5b) allows us to test several hypotheses by placing restrictions on parameters of interest. First, we test if parameter restrictions of the Cobb-Douglas specification is supported by the data: i.e., $\beta_{jk} = 0(\text{for all j and k})$. In addition, we test the hypothesis of constant return to scale: $\sum \beta_j = 1$ and $\sum \beta_{j,k} = 0$. Also, we test if health is an important input in the model: $\beta_{j=h} = \delta_{j,h} = 0(\text{for all h, j})$. Then, we test whether the systematic technical inefficiency impacts are zero:

$\gamma = \varpi_h = \varpi_{m,h} = 0\left(\text{for all } d, m, \text{and } h\right)$. Finally, we will test a less restrictive approach by testing if $\varpi_{m,h} = 0\left(\text{for all } h \text{ and } m\right)$. Here the model allows technical inefficiency, but assumes it arises independently from the interactions between health status and inputs. All results from these tests are presented in the empirical results section.

It is important to note here that our data set does not contain detailed measurements on farm and/or plot specific variables related to the environmental conditions facing producers, soils, rainfall pattern, and topography. As Sherlund et al (2002) pointed out, however, the problem of not including environmental production variables that intuitively affect both output and inputs subject to farmer control leads to biased estimates of the parameters describing the production frontier, and thus an overstatement of technical inefficiency, and a biased estimate of the correlates of technical efficiency (Wooldridge, 2006; and Cameron and Travedi, 2005). In spite of the lack of variables measuring environmental conditions in the data, however, our review of the soils, precipitation, and topography of the region shows that more than 90% of the municipality of Marabá has soils called *latossolo vermelho-amarelo*[10], the average temperature is 26°C, and annual rainfall range is small and averages 1,800 to 2,200mm/year across our sample region. Marabá is characterized by a well defined rainy and dry seasons. The rainy season is concentrated from November to March, and the dry season from May to September. With few exceptions (*Serra dos Carajas, Serra do Cinzeiro, Serra do Paredão, and Serra do Encontro*) most of the municipality topography ranges between 85-134 meters above sea level. Indeed, most of the high altitude areas are either protected areas or

[10] This soil claissification is based on the Brazilian System of Soil Classification done by the Brazilian Agricultural Research Corporation (Embrapa).

inaccessible. Thus, the environmental variables that might influence both output and inputs are fairly homogenous across the study site.

Finally, health status variables for non-sick households represent zeroes in the survey data. Unfortunately, the presence of many zero-valued observations is troublesome for the estimation of a Translog stochastic production frontier. In order to deal with zero values and at the same time obtain unbiased estimates of the frontier functions parameters, the literature has proposed two options. The simpler option, and the one we use, is to set $ln(0) = (\zeta/10)$, where ζ is the smallest strictly positive observation in the sample (Sherlund et al, 2002)[11].

[11] The second option is to transform the health status variables using the Box-Cox transformation function, i.e. H_i^((λ))=((H_i^((λ))-1))⁄λ. Provided that λ is strictly positive, the Box-Cox transformation is well defined for zero input levels, -1⁄λ. As λ tends to zero, the Box-Cox transformation is ln (H_i) (Caves, et al, 1980).

3.4 Data Description

Data come from a household survey completed in 10 villages in Marabá, a municipality in the State of Pará in the Brazilian Amazon, between May and November 2006. Sample villages were selected randomly in the region. In each village, households were randomly selected from lists obtained from the President of the village's local community association, to which all households belonged. Interviews were undertaken with the head of household using a recall instrument based on smallholder decisions of pre-planting, planting, and harvesting seasons during the past year. In total, 335 households were sampled and no households refused to answer survey questions. The main agriculture outputs smallholders produce in the study area include annual crops such as rice, beans, corn and manioc as well as perennial crops such as coffee, cocoa and pepper.

In **Table 13** we present descriptive statistics from the survey. The results show that 35% of the households had at least one household member sick. These "sick" households produced, on average a value of R$2,182 compared to R$4,688 for "non-sick" households. Households with sick people used twice as much labor (family and hired labor) to produce nearly half of the output of households with no sick family members using the same capital, land, and production technology. Overall, sick households conducted nearly 98 days of labor on the farm. However, nearly half of the time employed in agriculture by households with sick family members was reported to be working while sick (43 days), while only 55 days were days working while well – i.e., fully productive. Non-sick households, on the other hand, spent on average 50 days working on the farm. Sick household hired more than twice as much outside labor to help with production compared to non-sick households, 143 and 71 days respectively. The remaining agricultural capital, plot size, and expenditures in improved seeds as well as demographic variables are about the same between sick and non-sick households in the sample.

Table 13. Descriptive Statistics for variables in the stochastic frontier model for smallholders in Marabá, Brazil.

Variable	Sample Mean	Sample Standard Deviation	Minimum	Maximum
Overall				
Output (R$)	3,813.00	6,757.00	60.00	64,111.00
Male Labor (Days)	52.00	59.00	1.38	337.00
Hired Labor (Days)	96.58	296.00	2.00	2,500.00
Agriculture Capital (R$)	762.00	1,140.00	1.80	12,128.00
Value of Seeds (R$)	130.00	309.00	2.00	3,000.00
Agriculture Plot Size (ha)	3.42	3.83	1.00	43.00
Number of Adults in the Household	2.90	1.50	1.00	10.00
Number of Children in the Household	1.70	1.50	0.00	11.00
Age of Household Head (Years)	49.00	12.23	20.00	89.00
Number of Sick people in the household	0.70	1.37	0.00	12.00
Sick Days Working	29.26	78.18	0.00	580.00
Sick Households				
Output (R$)	2,182.00	3,555.00	5.00	32,526.00
Male Labor (Days)	55.00	56.43	5.00	337.00
Hired Labor (Days)	143.00	378.00	2.00	2,500.00
Agriculture Capital (R$)	733.00	856.00	1.80	3,754.00
Value of Seeds (R$)	158.00	295.00	2.00	1,680.00
Agriculture Plot Size (ha)	3.60	4.46	1.00	43.00
Number of Adults in the Household	3.24	1.70	1.00	10.00
Number of Children in the Household	1.64	1.48	0.00	7.00
Age of Household Head (Years)	49.00	11.00	19.00	75.00
Number of Sick people in the household	1.05	1.31	0.00	8.00
Sick Days Working	43.64	98.69	0.00	580.00
Non-Sick Households				
Output (R$)	4,688.00	7,831.00	59.94	64,111.00
Male Labor (Days)	50.42	60.00	1.38	310.00
Hired Labor (Days)	71.23	237.92	2.00	2,000.00
Agriculture Capital (R$)	777.18	1,268	1.80	12,128.00
Value of Seeds (R$)	114.94	316.50	2.00	3,000.00
Agriculture Plot Size (ha)	3.30	3.46	1.00	21.78
Number of Adults in the Household	2.84	1.31	1.00	8.00
Number of Children in the Household	1.68	1.85	0.00	11.00
Age of Household Head (Years)	49.00	12.49	20.00	89.00

3.5 Results

3.5.1 Results of the non-neutral stochastic production frontiers

The parameter estimates of the production frontier, equation (5a) with (5b) substituted into it, and the efficiency model, equation (6), along with their corresponding standard deviation, t-statistics, and p-values are presented in **Table 14** and **Table 15**, respectively. In both tables we have estimated a non-neutral Cobb-Douglas and Translog stochastic production frontier. The first part of **Table 14** shows the parameter estimates of the production functions, including the variance parameters, σ^2 and γ. In the final section of **Table 14** there is a summary of key statistics for the estimated models.

For the Translog specification, output is statistically significant in all productive inputs, based on appropriate joint tests of the first and second order terms for each variable in the Translog specification. The Translog function is well behaved (positive and diminishing returns), with the exception of hired labor and agriculture capital variables. Output is also strongly correlated with number of adults and children in the household as well as days sick while working and many of the interactions between inputs variables. The estimated variances σ^2, σ_v^2 and σ_u^2 are 0.53, 0.44, and 1.91, respectively. The ratio parameter, γ =0.81, is positive and statistically significant at a 5% level of significance, indicating that technical inefficiency is likely to have an important role in explaining output variability among farmers in the sample.

For the Cobb-Douglas specification, output also is statistically significant in all productive inputs. The specification also is well behaved (positive and diminishing returns), and output is also strongly correlated with all input variables, with the exception of agricultural capital. The estimated variances σ^2, σ_v^2 and σ_u^2 are 2.26, 0.40, and 1.85, respectively. The ratio parameter, γ =0.82, is positive and statistically significant at a 5% level of significance, also indicating that technical efficiency is likely to have an important role in explaining output variability among farmers in the sample.

In the first part of **Table 14**, the Translog specification shows that health status affects the production frontier. The variable 'number of days sick while working' contributed positively to output. In addition, the statistically significant second-order effects picked up in the model indicate that the usage of improved seeds is a substitute for low efficiency of labor while people are sick – the same logic applies to hired labor. Sick households hire more labor to compensate for the low efficiency of sick workers. And, the additional male labor spent on agriculture is a substitute for the low efficiency of sick workers. In a household where there are both sick and non-sick adult males, non-sick adult males tend to work more to compensate for the time lost and low efficiency of sick workers. In the Cobb-Douglas specification, the variable sick days working was not statistically significant.

Table 14. Parameter estimates of the non-neutral Cobb-Douglas and Translog stochastic production frontiers (value of output).

Coefficients	**Cobb-Douglas Specification**				**Translog Specification**			
	B	**se**	**t**	**P**	**B**	**se**	**t**	**P**
Number of Adults in the Household	0.1252346	0.045041	2.780439	0.005429	0.136158	0.044755	3.042294	0.0023478
Number of Children in the Household	-0.080967	0.040605	-1.99404	0.046148	-0.0893474	0.03972	-2.24942	0.0244861
Age Household Head	-0.00159	0.005402	-0.29435	0.768493	-0.0055577	0.005215	-1.06580	0.2865121
Adult Male Labor (Days)	0.1290689	0.065698	1.96457	0.049464	0.4316143	0.445623	0.968563	0.3327633
Hired Labor (Days)	0.1490794	0.044517	3.348811	0.000812	-0.3085225	0.284838	-1.08315	0.2787409
Household Agriculture Plot Size (ha)	0.4443898	0.13856	3.207196	0.00134	0.5941627	0.701336	0.847187	0.3968907
Agriculture Capital (R$)	0.1001911	0.063034	1.589479	0.111952	-0.2561056	0.442174	-0.57920	0.5624565
Value of Seeds (R$)	0.1330887	0.042668	3.11919	0.001814	0.2884591	0.206026	1.400111	0.1614801
Number of Days Sick while Working (Days)	0.1234206	0.103691	1.190273	0.233939	0.6792672	0.311522	2.180479	0.029222
$1/2\,(Male\ Labor)^2$					-0.0295252	0.05441	-0.54265	0.5873733
$1/2\,(Hired\ Labor)^2$					0.0501419	0.03247	1.544254	0.1225268
$1/2\,(Ag. Plot\ Size)^2$					0.0340773	0.132454	0.257277	0.796965
$1/2\,(Ag. Capital)^2$					0.0162708	0.034631	0.469838	0.6384705
$1/2\,(Sick\ Days\ Working)^2$					-0.0121109	0.027056	-0.44762	0.6544274
$1/2\,(Value\ of\ Seeds)^2$					-0.0423811	0.02475	-1.71237	0.0868293
(Male Labor) × (Ag. Plot Size)					-0.0721184	0.192914	-0.37384	0.7085251
(Male Labor) × ($Hired\ Labor$)					0.0104037	0.062045	0.16768	0.8668353
(Male Labor) × (Ag. Capital)					0.0204501	0.077979	0.26225	0.793129
(Male Labor) × (S. Days Working)					-0.1993745	0.096127	-2.07408	0.0380715
(Male Labor) × (V. Seeds)					-0.1346488	0.046055	-2.92365	0.0034595
(Hired Labor) × (Ag. Plot Size)					-0.1381036	0.099797	-1.38384	0.1664063
(Hired Labor) × (Ag. Capital)					0.0475201	0.059653	0.796613	0.4256758
(Hired Labor) × (V. Seeds)					0.0387458	0.028326	1.367878	0.1713504
(Hired Labor) × ($Sick\ Days\ Working$)					-0.1144765	0.042608	-2.68672	0.0072157
($Ag. Plot\ Size$) × (Ag. Capital)					-0.0316603	0.190425	-0.16626	0.8679514
($Ag. Plot\ Size$) × (V. Seed)					0.1180647	0.09784	1.206708	0.2275446

$(Ag.Capital) \times (\mathrm{V.Seed})$					0.0768109	0.046072	1.667212	0.0954723
$(Sick\ Days\ Working) \times (\mathrm{Ag.Plot\ Size})$					-0.2657349	0.179412	-1.48115	0.1385676
$(Sick\ Days\ Working) \times (\mathrm{Ag.Capital})$					0.0415468	0.084408	0.492214	0.6225681
$(Sick\ Days\ Working) \times (\mathrm{V.Seeds})$					-0.1071449	0.039781	-2.69337	0.0070734
Constant	6.698203	0.615348	10.88523	0.000	7.526817	1.752871	4.293993	0.0000175
$Ln(\sigma)^2$	0.8149324	0.203116	4.01	0.0000	0.8575939	0.225168	3.81	0.000
$Inverse\ Logit\ \gamma$	1.520609	0.623327	2.44	0.0149	1.459553	0.670237	2.18	0.029
σ^2	2.25902	0.45884			0.530829	0.530829		
γ	0.82063	0.09175			0.811464	0.102540		
σ_u^2	1.85382	0.47439			1.913012	0.554653		
σ_v^2	0.40520	0.20230			0.444470	0.231650		
N	335				335			
Log. Likelihood	537.58732				-518.13255			
Wald chi2	61.95000				106.25			
Prob > Chi2	0.00000				0.00000			

3.5.2 Results of non-neutral stochastic inefficiency effect models

The parameter estimates of non-neutral Cobb-Douglas and Translog stochastic efficiency effect models, Equation (5b), are presented in **Table 15**. The estimated parameters show us the significance, magnitude, and direction of the interaction between health status, as a non-input variable, and input variables that cause an impact on technical efficiency.

The health status variables, number of sick people in the household, and sick days while working are all statistically significant and negatively related to technical efficiency (or, as shown, positively related to technical inefficiency). This result supports the argument mentioned earlier that disease indeed has an impact on labor efficiency**.** In addition, it is clear that male labor, plot size, agriculture capital, hired labor, and use of improved seeds are positively related to technical efficiency (again, negatively related to technical inefficiency) when interacting with the number of sick people or sick days working. These results support the idea that these inputs are used to different degrees to offset the impact of disease on technical efficiency.

The negative parameters estimated for the interaction explanatory variables between health status and inputs might be explained by adaptations sick households make to reduce the impact of health status on technical efficiency. For instance, farmers may hire labor to compensate for the loss of efficiency of family labor due to poor health. They may also employ more non-sick labor of their own family labor allocation to compensate for the loss of efficiency by sick family members. They may also switch crop combinations and rely on more extensive farming techniques, where labor efficiency is not as important as intensive, or more productive uses of land, if available. In the worst case scenario, smallholders may lease their land and forgo their own production activities. These strategies are only possible in complete labor markets, and highlight the importance of efficient rural markets for factors of production and the provision of health services.

Table 15. Parameter estimates of non-neutral Cobb-Douglas and Translog stochastic inefficiency effect models.

Coefficients	**Cobb-Douglas Specification**				**Translog Specification**			
	B	**se**	**t**	**p**	**b**	**se**	**t**	**p**
Conditional Mean								
Number of Sick People in the Household	2.395819	1.292957	1.852977	0.063886	3.007386	1.443323	2.083654	0.0371917
Sick Days Working	0.1140675	0.279718	0.407794	0.683425	1.406747	0.55779	2.522002	0.0116689
(Sick People) × $(Male\ labor)$	-0.530806	0.241629	-2.19678	0.028036	-0.6455657	0.275202	-2.34579	0.0189869
(Sick People) × $(Hired\ labor)$	0.0751622	0.103032	0.729501	0.465696	0.1392587	0.128365	1.084862	0.2779829
(Sick People) × $(Ag. Plot\ Size)$	0.1150273	0.419174	0.274414	0.783766	0.3047224	0.654877	0.465313	0.6417076
(Sick People) × $(Ag. Capital)$	-0.207965	0.160684	-1.29425	0.195579	-0.3053326	0.191056	-1.59813	0.1100135
(Sick People) × $(V. Seed)$	0.1015279	0.097868	1.037401	0.299549	0.1144867	0.113194	1.011424	0.3118136
(Sick Days Workinge) × $(Male\ labor)$	0.1364758	0.056255	2.426004	0.015266	-0.0261305	0.096605	-0.27049	0.7867852
(Sick Days Working) × $(Hired\ labor)$	0.0190045	0.023727	0.80098	0.423143	-0.1030107	0.056975	-1.80798	0.070609
(Sick Days Working) × $(Ag. Plot\ Size)$	0.0862907	0.110392	0.781677	0.434405	-0.3458566	0.354871	-0.9746	0.3297601
(Sick Days Working) × $(Ag. Capital)$	-0.086063	0.041133	-2.0923	0.036412	-0.0865273	0.077907	-1.11065	0.2667194
(Sick Days Working) × $(V. Seed)$	0.004559	0.026316	0.173241	0.862462	-0.131771	0.070119	-1.87925	0.0602098
$Constant$	1.000219	0.656082	1.524533	0.127376	0.6858973	0.845489	0.811243	0.417226

3.5.4 Technical efficiency by health status

The frequency distributions of technical efficiency scores for the Translog and Cobb-Douglas specification are reported below in **Table 16**. At the bottom of the same table, we also report the corresponding estimates of the 95% confidence intervals computed using predicted technical efficiency levels for both models. On average, results show that smallholders have not been successful in implementing the best-practice production technology, and do not achieve maximum possible output. Mean output-oriented technical efficiency was only 36% for the Translog and 30% for the Cobb-Douglas specification. Considering that the Translog is the correct specification, farmers could increase output by 64% with the current state of technology and unchanged input use. Furthermore, the results show that households with sick family members are statistically less efficient than non-sick households. In the Translog specification, non-sick household presented mean output-oriented efficiency around 39% while sick households only achieved mean output-oriented efficiency of 31%. In the Cobb-Douglas specification, the gap in mean output-oriented efficiency was even larger with non-sick household having a mean around 34% and sick households only 20%. For both specifications, however, a conventional t-test confirms the statistically significant differences in technical efficiency among households with sick and non-sick family members at a 5% level of significance.

Table 16. Frequency distribution of technical efficiency by health status

Efficiency	Translog			Cobb-Douglas		
	Farm Households		All households	Farm Households		All households
(percent)	Sick	Non-Sick		Sick	Non-Sick	
<=20	45	52	97	69	71	140
20-30	13	32	45	13	26	39
30-40	15	22	37	21	25	46
40-50	17	37	54	8	36	44
50-60	11	35	46	3	28	31
60-70	11	18	29	3	23	26
70-80	4	19	23	0	8	8
80-100	1	3	4	0	1	1
All households	117	218	335	117	218	335
Mean (%)	31	39	36	20	34	
Std. Deviation (%)	22	21	22	17	21	
Absolute Difference (%):						
Mean(Sick)-Mean(Non-Sick)			8			15
H_0: Difference=0						
Ha: Difference $\neq 0$						
T-Value			3.1471		6.6955	
Pr(T>t)			0.0018		0.0000	

3.5.4 Specifying the Stochastic Production Frontier

Table 17 presents several hypotheses concerning the correct specification of the production frontier model in (5a) and (5b). First, the parameter restrictions of the Cobb-Douglas model are rejected by the likelihood ratio test at the 10% level. Thus, the Translog model (even though there are some insignificant parameters) is supported by the data. The hypothesis of constant returns to scale, however, is rejected at the 5% level of significance. But, health clearly affects output – the parametric restriction imposed by the Translog model with no interaction between health and inputs is rejected at the 5% level of significance.

The final tests in **Table 17** assess the specification of technical inefficiency**.** Results show that the production function formulation, with and without (5b) is rejected at 5% level of significance. Therefore the null hypothesis that the systematic technical inefficiency parameters are zero is rejected and there is, indeed, stochastic technical inefficiency in the model. Further, we tested whether the model was non-neutral. That is, we tested the null hypothesis that there is no interaction between health status and inputs. This hypothesis was rejected at 5% level of significance. Together, these results imply that the majority of farmers (or at least a statistically significant proportion) in the sample operate below the production frontier.

Table 17. Model specification tests[a].

Null Hypothesis	**Test Statistic**	**Decision at 0.05**
Functional Form (Cobb-Douglas vs Translog)		
$H_0 : \beta_{j,k} = 0 (\text{for all j and k})$	38.91 (0.010)	Reject
Returns to Scale		
$H_0 : \sum \beta_j = 1 \text{ and } \sum \beta_{j,k} = 0$	12.46 (0.002)	Reject
Direct Impact of Health on Output		
$H_0 : \beta_{j=h} = \beta_{j=h,k} = 0 (\text{for all h, j})$	18.32 (0.011)	Reject
Technical Inefficiency		
$H_0 : \gamma = \varpi_h = \varpi_{m,h} = 0 (\text{for all } d, m, \text{and } h)$	27.87 (0.006)	Reject
$H_0 : \varpi_{m,h} = 0 (\text{for all } h \text{ and } m)$	25.56 (0.004)	Reject

[a] Test statistic are given with associated p-values in parenthesis.

3.5.5 Direct, indirect and total impact of health status on farm output

Knowing the correct specification of the model, as indicated by the tests in Table 17, we are able to estimate the direct, indirect, and total impact of health on farm output. The estimate of the total direct effect, from equation (6), indicates that a 1% increase in time sick, holding all else constant, would result in a 0.20% decrease of output. The indirect effect, measured by equation (7), indicates that a 1% increase in time sick while working results in a 2.39% decrease in output. The average direct and indirect impact value of health status on output is estimated to be R$17 and R$52, respectively. So, on average each household in the sample lost R$69 due to the impact of health status on production.

These results highlight the fact that the indirect impact of health on output is more than three times greater than the direct impact. Another way of interpreting these results is that the impact of health status is stronger in widening the technology gap than in widening the management gap. As mentioned before, the production function approach assumes that farmers are fully efficient. That is, farmers produce the maximum output that can be obtained from any given vector of inputs. But, this result implies that farm output would have been severely underestimated if the simple production function approach under an assumption of 100% efficiency had been used.

3.6 Conclusions

In rural settings where access to health services is difficult and incidence of disease is high, poor health may be deleterious to production efficiency of farm households. In this paper, we clarify the role of health as a productive input, and non-input, variable that interacts with input variables in determining technical inefficiency. By using a non-neutral stochastic production approach, we decompose the returns to health status into a direct effect on the production function and indirect effects on technical efficiency. Based on cross-sectional farm household data collected in a survey 356 households in the Brazilian Amazon, our empirical results indicate that health status has significant impacts on production. We find that a 1% percent decrease in health, measured by time sick while working and number of sick people in the household, may result in a direct impact of 0.2% reduction in output and an indirect effect of 2.39%. Using the sample average, this efficiency loss corresponds to nearly R$100 per year. Also, our results show that the majority of smallholder farmers operated below the efficient production frontier. The estimated mean output-oriented technical efficiency for all farmers was just 36%. This result indicates that farmers could increase output by 64%, even with the current state of technology and unchanged input uses. Furthermore, the mean output-oriented technical efficiency for sick households was 31%, while for non-sick households it was 39%. These results support results from other research, conducted in different regions of the world, that health status is important for household production. Our work builds on these earlier studies to show that health status is an important input in the production function as well as a non-input variable that interacts with input variables.

There are many policy implications that emerge from our results. The most important is that the careful design of rural settlement health programs is an important policy instrument, and perhaps more important than previously thought, for rural household economic development. Therefore, the provision of health care should be an integral part of rural settlement planning and implementation. This recommendation may sound simple, but Brazil has increasingly decentralized the provision of universal and free health care. Today, the responsibility for the provision of health care services falls on Municipal governments, many of which are not prepared for the additional burden placed on them by Federally planned settlements, which remains centralized at the National Institute of Colonization and Agrarian Reform (INCRA). Although INCRA has regional offices, most of the decisions regarding the creation of new rural settlements are not jointly planned with the Municipalities in which they are undertaken. Indeed, there are several settlements that have been created where there is no provision of any health care services. Our results suggest there will be serious negative efficiency and income generation consequences for smallholders operating under these circumstances. Secondly, since the decision to set up new settlements is not done jointly with local populations and health authorities, INCRA tends to ignore the fact that settlements are often located 300-400 km away from a main city, where doctors and health facilities are located, in these cases, the provision and access to health care becomes prohibitively expensive.

Our results present evidence that most of the farmers in the sample are below the production frontier. This finding indicates that there is a lot of scope to increase agricultural output. Given the levels of inneficiency it is not necessary the introduction of new technologies. Efficiency gains would raise competitiveness of farmers by raising output as well as farm profits. There is a strong case for supporting small scale farmers through technical assistance so that they can achieve higher efficiency from the production technology available to them. The mechanisms to improve efficiency are well known by policy makers and include effective education and extension services, credit availability, input supplies (particularly high-quality seeds), output marketing, and market information, among other factors. The conclusions presented regarding technical efficiency are similar to the results of many other studies of technical efficiency, where farmers are producing inneficiently (Bravo-Ureta, et al. 1993).

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CHAPTER 4

Markets, Health and Labor Allocation in the Brazilian Amazon

Abstract

The literature has largely ignored the impact of disease on smallholder's decisions regarding labor allocation, even though labor allocation decisions might be linked to household health status. In this chapter, we study the factors related to demand for labor by jointly estimating a system of labor share equations applied to land clearing, staple food production, livestock, working off-farm, and time taking care of sick people in the household. In the context of the region of study, where labor markets are thin, disease can play an important role in household decisions because farm activities are performed inefficiently by sick households and change in household labor efficiency brings about a change in the relative price of competing uses of a household's time. Our empirical results support the hypothesis that health influences the labor allocation decisions. The number of sick days not working by family members has a statistically significant negative impact on the share of labor allocated to agriculture, livestock, and working off-farm, and it has a positive impact on labor allocated to taking care of sick family members and, surprisingly, labor allocated to land clearing. These results are important for conservation and development policies. It is appealing to consider labor allocated to off-farm work and land clearing as substitutes, so that policies designed to improve off-farm labor reduces land clearing by smallholders. However, the results presented here suggest that there are important complementarities among disease, labor allocated to land clearing and off-farm-work.

Key words: Households, labor allocation, health, Amazon

4.1 Introduction

Historically, smallholders have been responsible for more than 20% of deforestation in the Brazilian Amazon (Chomitz, 2007, INPE, 2017). Previous research on tropical deforestation by smallholders has largely focused on how the decision to clear land is related to markets, smallholder's preferences, timber sales, prices of inputs and outputs, off-farm employment opportunities, roads and property rights, among others (Pinchon, 1997; Pendleton and Howe, 2002 Alston, Libcap, and Muller, 2000; Angelson and Kaimowitz, 1999l Shiveley, 2006; Takasaki, 2007). These studies usually model the derived demand for land cleared and assume that households maximize utility with perfect markets for factors of production, especially labor.

Indeed, the early models of household behavior and deforestation were largely based on the strong assumption of perfect markets for the factors of production (Angelson, 2007; Takasaki, 2007). The assumption of perfect (complete) markets, however, has significant implications for the allocation efficiency of resources within the household. Under the assumption of complete markets, a household simply chooses the level of inputs to maximize profits. These input decisions depend only on biophysical characteristics of the farm (soil quality, topography, plot size, access to water, etc) and prices. Here the household decisions regarding production are affected by consumption behavior, and the model is said to be 'separable'. When markets are imperfect, however, separability breaks down and production decisions become dependent on household characteristics, rather than consumption patterns (Bardham and Udry, 1999; de Janvry and Kanbur, 2006; and Singh and Strauss, 1986).

It was only when the assumption of complete markets for factors of production was relaxed that a range of interesting questions about deforestation and household behavior appeared in the literature (Alix-Garcia, 2007; Barrett, 1999; Blufstone, 1995, 1998; Fisher et al, 2005; Kholin and Parks, 2001; Shiveley and Fisher, 2004; Zwane, 2007). With incomplete labor markets households no longer have the option to hire labor outside to compensate for productivity loss from a sick family member, for example. Also, households have limited ability to find jobs outside their own farm. Thus, households have to balance their labor allocation accordingly. For this reason, a complete labor market framework does not provide insights into why households might work beyond the point where marginal product of labor equals wage, or why household activity choice is no longer chosen based solely on relative returns to economic activity.

Although significant advances continue to be made in the modelling of deforestation, a large part of the literature has relied on single equations to estimate the demand for land cleared (Barbier and Burguess, 2001). The focus on single equation models can result in an incomplete explanation of smallholder behavior because the decision to allocate labor to forest clearing is made in the context of households' overall labor allocation decisions among productive and non-productive activities (Shaik ad Larson, 2003; Shiveley and Fisher, 2004; Fisher, Shiveley, and Bucola, 2005). And, single equation models have a limited ability to incorporate substitution effects among the competing productive and non-productive activities on household labor endowment (Shaikh and Larson, 2003).

The literature on deforestation also largely ignores the impact of disease on smallholders' decisions related to land-use, even though land clearing might be linked to household health status (Amacher et al., 2004a, Kochar, 2004; O'Donnel, 1995; Strauss and Thomas, 1998). With little or no access to credit, and thus technology, the production process in which forests are converted into cleared land for agriculture or ranching is labor-intensive.

Household labor is the key input to slash-and-burn forests, plant crops and grasses, control weeds, and harvest crops. Households living in remote areas of tropical countries, however, have poor access to health care and greater incidence of disease (Colfer, Sheil, and Kishi, 2006; Confaloniere, 2005). Remote areas with high incidence of disease often overlap with area with high deforestation (Pattanayak et al., 2006), yet few rigorous empirical studies have been done on the interaction between the demand for land clearing by smallholders and disease.

Illness often factors into labor allocation decisions through at least two channels. First, illness reduces the quantity of labor available to the household. Second, it also affects quality of available labor. Inevitably, disease results in a loss of income and possibly higher health care expenditures. But illness may also result in a change in the labor allocation decisions by households, and may require the purchase of wage labor support. Therefore the local labor markets may provide an additional framework to link economic activities, health, and land use.

In this paper, we build on the literature to model deforestation demand based on the Almost Ideal Demand System (AIDS) developed by Deaton and Muellbauer (Shively and Fisher, 2004; Fisher et al, 2005). Specifically, we study the demand for labor applied to land clearing, staple food production, livestock, working off-farm, and time taking care of sick people in the household. Our empirical application examines the impact of disease on labor allocation, and we account for time lost by households taking care of sick members as a non-productive activity. In the context of this paper, disease can play an important role in household decisions because farm activities are performed inefficiently by sick households, and changes in household labor efficiency brings about a change in the relative price of competing uses for a household's time. Therefore, a single-equation demand for labor as applied by previous studies on land-use would miss important interactions among economic activities that require different level of labor efficiency. The system of equations we use in this paper better captures the trade-offs a household faces when dealing with disease.

The remainder of this paper is organized as follows. First, we introduce a simple agriculture household model that is commonly found in the literature. Second, we present the econometric model used to estimate the results, which has three subsections: a discussion of using first order condition to derive the reduced form labor demand equations; a review of the problem of non-participation; and a presentation of the system of labor equations. In a third section, we present the estimation results. And finally, we present the conclusions of the paper.

4.2 Household Model

In order to investigate the impact of disease on labor allocation, we must specify how health variables enter into household problem. We use a conventional household model but add a health production function to show the relationships between the market, environment, health, and consumption. The model draws upon the economic theory of farm households (Singh, and Strauss, 1986; Bardhan and Udry, 1999) and empirical studies of household labor allocation (Jacoby, 1993; Thornton, 1994; Amacher et al, 1990).

4.2.1 An Illustrative Model

The main components of our model are a utility function, a production function, and markets. In the presence of poor health, the deterministic household time constraint is: $T - S(\Gamma) = L + l$, where the household's total time endowment is T. $S(\Gamma)$ is time spent sick and not working by household members, which is itself a function of health production represented by Γ, which is described below. The total time available to work is $T - S(\Gamma)$ and this time endowment is divided among time working on the household's own farm plots L^j, and off farm wage earning work L^{off}, time taking care of sick people L^{ts}, and leisure time l. Total time that household spends working is $L = \sum L^j + L^{ts} + L^{off}$. Also, labor spent on the farm, L^j, can be allocated to staple food production or livestock, represented by L^r and L^g, respectively. Thus, $\sum L^j = L^r + L^g$. It is important to note that j is an index for staple food $(j = r)$ and livestock $(j = g)$. Therefore, L^r is labor allocated to staple food production while L^g is labor allocated to livestock production.

Time sick does not enter directly into the utility function of the household as independent argument[12]. Utility is a function of consumption and leisure conditioned on household characteristics, $U(C, l; \theta)$, where θ is a vector of household characteristics important to utility. Goods consumed may be purchased, C^m, or produced by the household, C^a, and total consumption is defined as $C = C^a + C^m$. Utility is assumed concave, and is decreasing in time sick, increasing in leisure, and increasing in consumption.

Farm production links household labor time, hired labor working on the farm, land employed, and the health of health on labor to the amount of agriculture goods produced (staple food and livestock production), $Q^j = f^j\left[\phi(\Gamma)L^j, L^h; A^j\right]$, where Q^j is the amount of output. Thus, $= Q^j = Q^r + Q^g$. Also, $f^j[.]$ is a neoclassical production function, ϕ is a labor-aumenting health efficiency parameter, which varies across households according to their health status, L^h is hired labor, and A^j is land input used in agriculture and livestock production. Households in the Transamazon choose how much land to allocate to production. As part of the government policies for agriculture settlements and environmental protection, households have full rights for this land and they can lease it to other households at a well-definied land rental rate, but they are not allowed to sell the land and they must keep parts of their land with forest cover. Thus, $\sum A^j$ may be greater than or less than the fixed land endowment. To simplify the problem A^j is assumed to be fixed and exogenous. As before, j is an index for staple food $(j = r)$ and livestock $(j = g)$. Therefore, Q^rdescribes smallholder staple food production and Q^gdescribes smallholder livestock production. Notice that disease can affect production functions in two ways, through labor time available for production and

[12] We are focusing on the labor effect of sickness. The disutility of being sick is not central in our study. Also, time sick reduces income and therefore consumption in the utility function. The sickness impact captures the important disutility effects of sickness.

through quality of labor while working. In our data set, we know time spent sick and not working, and we have a variable indicating whether household members were sick.

Let there be a generic health production function designated as $\Gamma(.)$. Health is an intermediate input used in household production and has an impact on household's total endowment and labor efficiency. The health production function depends on labor, L^{ts}, health input, which is under control of the household, and vector of exogenous environmental factors that affect disease, ϑ. The health production function can be written as: $\Gamma = h(L^{ts};\ \vartheta)$. The health production function depicts how family care, health related goods such as medicine and medical services, and the environment affect household health. In general, health is increasing in labor and non-labor inputs, and decreasing in the characteristics of the environment that makes a given place prone to disease. The health production function has a direct impact on sick days not working $S(\Gamma)$, and a labor-augmenting efficiency parameter $\phi(\Gamma)$.

In order to clarify the impact of the health production function Γ on $\mathrm{S}(.)$ and $\phi(.)$, we rewrite the health production function as follows:

$$\Gamma = \begin{cases} S(\Gamma) = h(L^{ts}; \vartheta)\ for\ \kappa < \hat{\kappa} \\ \phi(\Gamma) = h(L^{ts}; \vartheta)\ for\ \hat{\kappa} < \kappa < 1 \end{cases} \tag{1}$$

Equation 1 shows that the severity of disease, measured by κ, can turn the health production function into 'sick while not working days' and 'sick while working with low efficiency days. In equation 1, $\hat{\kappa}$ is a threshold value for severity of disease. If the disease is serious a household cannot work, and in this case $\hat{\kappa} > \kappa$ and $\Gamma = S$. If disease is not so serious, then $\hat{\kappa} < \kappa < 1$ and a sick person can continue working. In this case, $\Gamma = \phi$.

The discussion above is important because our model groups individuals within a household. Thus, there will be cases in a household where a given person is sick while working and another household member is sick and not working. In any given scenario, the impact of disease enters the household problem in the time endowment constraint as well as in the full income constraint by changing labor efficiency. We will see this in detail in the discussion of the household maximization problem presented below.

Finally, the household participates in markets. Denote the market price of agricultural goods and livestock as p^j. As before, j is an index for staple food $(j = r)$ and livestock $(j = g)$. The wage rate of hired and family labor as w, and labor hired as L^h. The household has exogenous unearned income equal to y, which is unrelated to household production. Now, the household's problem is to maximize utility subject to economic conditions, with household time allocated freely to leisure, time working on farm, time working off the farm, and other inputs among productive activities. Formally, the household's utility-maximization problem is written as follows:

$$\max_{C,l} U[C, l; \theta] \tag{2}$$

subject to the following constraints:

$$M = \sum p^j \{f[\phi(\Gamma) L^j L^h; A^j] - C^j\} - wL^h + wL^{off} + y \tag{3}$$

$$T - S(\Gamma) = l + L^{off} + L^{ts} + L^j \tag{4}$$

$$\Gamma = h(L^{ts}; \theta) \tag{5}$$

In equation (2), M defines household full income. Rearranging the budget constraint, we get a more intuitive equation:

$$\sum C^j p^j + wl + wL^{ts} = y + \sum p^j \{f[\phi(\Gamma) L^j; L^h; A]\} + w[T(a) - S(\Gamma)] \\ = M \tag{6}$$

In equation (6), consumption of goods, leisure and time spent sick is equal to full income. Full income has three parts: exogenous income (y); non-maximized farm profit represented by $p^j\{f[\phi(\Gamma)L^j; L^h; A^j]\}$ and the value of household's time endowment $w[T(a) - S(\Gamma)]$. The Lagrangian for the household's maximization problem is:

$$l = U[C, T - S(\Gamma) - L^{off} - L^{ts} - L^j; \theta] \\ -\lambda \begin{bmatrix} M - p^j \sum \{f^j[\phi(\Gamma)L^j, L^h; A^j]\} \\ +wL^h + p^m C^m + p^a C^a + wL^{off} - y \end{bmatrix} \tag{7}$$

The first order conditions for labor allocation can be rearranged to obtain:

$$L^r = \frac{\partial U[.]}{\partial L^r} + \lambda p^r \frac{\partial f^r[.]}{\partial L^r} \phi(\Gamma) \tag{8}$$

$$L^g = \frac{\partial U[.]}{\partial L^g} + \lambda p^g \frac{\partial f^g[.]}{\partial L^g} \phi(\Gamma) \tag{9}$$

$$L^{ts} = \frac{\partial U[.]}{\partial S} - \frac{\partial U[.]}{\partial L^{ts}} + \lambda \left[p^a \frac{\partial f^a[.]}{\partial \phi} \frac{\partial \phi}{\partial L^{ts}} L^a + p^g \frac{\partial f^g[.]}{\partial \phi} \frac{\partial \phi}{\partial L^{ts}} L^g \right] \tag{10}$$

$$L^{off} = \frac{\partial U[.]}{\partial L^{off}} + \lambda w \tag{11}$$

where λ is the multiplier for the household's budget constraint.

Note that optimal labor allocation takes into account the marginal cost of time as the value of the marginal product of labor in each activity. Households use labor in agriculture so that the marginal disutility of labor equals to the marginal product of labor in agriculture taking into account the impact of disease on labor efficiency. The same reasoning goes into the allocation of labor to livestock production. Labor allocated to off farm employment is different because the impact of disease on labor efficiency is not taken into account given the difficulties in monitoring efficiency by employers. Thus, labor is allocated to off farm production up to the point where the marginal disutility of labor working off farm equals the wage rate times the budget constraint. The household vector of time spent taking care of sick people in the household is employed so that the marginal disutility of labor, net of improvements to health, equals the marginal productivity benefit from increased health in production of staple food and livestock.

The first order conditions above indicate that our household model is non-separable. A non-separable model implies that a household decisions regarding production are affected by consumption behavior. Thus, each decision depends on the household's preference, resource stock and health status. The literature shows that it is not possible to work out the comparative statistic of a non-separable model without overly restrictive assumptions (Singh, et al., 1986). Nonetheless, Jacoby (1993) and Thornton (1994) showed that the first order conditions provide enough information to develop reduced forms of each decision and explanatory variables important for the econometric specification.

Thornton (1994) shows how to derive the household labor supply using the results from the first order conditions, and we apply his procedure to our problem. We assume there is a vector of optimal input choices that satisfies the first order conditions found in equations (8) to (11). This optimal input vector is used to determine the maximum farm production function. Net farm income is defined as the maximum amount of profit net of the value of the optimal inputs used in production. Finally, the maximum profit is substituted back into the full income constraint. This transformed model is solved for conditional consumption demand and all optimal decisions are reinserted into the full income constraint. The conditional labor supplies are derived using Hotelling's lemma applied to the new full income constraint. The household's choices found through this procedure are a function of exogenous income, preferences related variables, disease, prices and costs relevant to the problem. Applying this procedure to our problem, we find the following:

$$L^i = L\left(p^j, y, c, \hat{p}^d, \widehat{w}^{off}, \widehat{w}^j, S, A^j, \theta, \vartheta \right) \tag{12}$$

$$Q^j = f^j\left[\phi(\Gamma)L^j, L^h; A^j\right] \tag{13}$$

$$\widehat{w}^j = \frac{\partial Q^j(.)}{\partial L^j} \tag{14}$$

where the index i represent agriculture, livestock, land clearing, time taking care of sick people. p^j is price of staple food when $j = r$, p^j is price of livestock when $j = g$, w^{off} is off farm wage rate, $\widehat{w}^r$ is the staple food shadow wage, which is the same as the opportnity cost of time, and Q^j is the estimated production function. All other variables ae the same as before.

4.3 Econometric Specification

The econometric specification of the household model above follows by developing reduced form of each decision that can be used with our data to investigate te interaction of disease, labor markets, and labor activities. As indicated before, non-separability means we cannot easily solve for closed form solutions of each labor allocation choice. Eaca labor allocation decision also depends implicitly on household preferences and resources stocks. The comparative statics of such a system have been shown to be unsolvable (Singh et al, 1986). Despite this limitation, we can still use the model above to obtain insights into estimable equations and the explanatory variablesthat should be present in each equation. In addition, our goal is to jointly estimate a system of four labor share equations. Our labor share model is similar to standard models of commodity of factor demand such as the Almost Ideal Demand System (AIDS).

To achieve this goal we rely on multiple estimation stages. First, we estimate the opportunity cost (shadow price) of household labor employed in staple food and livestock production, clearing land, working off farm, and taking care of sick people. The returns to labor are an important variable guiding the household's decision-making process with respect to labor allocation. Therefore, our first step is to estimate a production function. Our second step is to use the estimated production function and derive the shadow wage of labor in staple food production, livestock and land clearing. The estimated shadow wage of labor in staple food production is used as a proxy for the opportunity cost of time allocated to livestock production and taking care of sick people and the wage rate is the opportunity cost of time for those households who engaged in off farm labor markets. After estimating the opportunity cost of labor employed to each activity, we compute the shadow wage of labor for households that do not participate in a given activity using data on the explanatory variables determining the shadow wage for participating households.

Conceptually, non-participation means that the return from a given activity is smaller than the household's labor shadow wage. Thus, ignoring non-participation can lead to biased estimates of labor supply (Heckman, 1974). To solve this problem Shively and Fisher (2004) and Fisher, Shively, and Bucola (2005) computed the missing shadow wage jointly with participation using the method of preferred maximum likelihood and replacing the missing values for the fitted shadow wages (Nawata and Nobuko, 1996). However, the estimated shadow wages may not be an accurate estimation of the true opportunity costs faced by households that do not participate in a given activity, especially for households living in places where markets for factor of production are weak. Here, we estimate the shadow wage of non-participants taking into account local market conditions. Our last step is to estimate the system of labor share equations, taking care of endogenous regressors when needed. The details of our estimation strategy for each step is presented below. The appendix provides details on methods used to estimate the production function, shadow wage, and non-participation.

Following Shively and Fisher (2004) and Fisher, Shively, and Bucola (2005), the system of share equations can be defined as:

$$s_i^j = \alpha^j + \sum_k \beta^{j,k} log(p^k) + \sum_k \delta^{j,k}(H_k) + \gamma^j Z_i + \varepsilon_i \qquad (15)$$

Where i represents households, j and k represents indexes of activities (agriculture, livestock, deforestation, taking care of sick people, and working off-farm), p is the shadow wage, Z is a vector of household characteristics and H is a vector of health status variables. The parameters of interest are α, β, and δ. To ensure that equation (14) represents a system of labor equations consistent with economic theory and predicted labor shares that add up to one, we impose the following restrictions to the model:

$$\sum_{k} \beta^{j,k} = 0 \tag{16}$$

$$\sum_{jk} \beta^{j,k} = 0;\ \sum_{jk} \delta_i^{jk} = 0\ and\ \sum_{j} \gamma_i^j = 0 \tag{17}$$

$$\sum_{j} \varepsilon_i^j = 0 \tag{18}$$

$$\sum_{j} \alpha^j = 0 \tag{19}$$

Restriction (16) imposes homogeneity to the model so that labor shares become invariant to proportional changes in all prices. Restriction (17) requires that the individual effects of labor allocation of changes given explanatory variables be offsetting, such that the net effect of given change be zero. Restriction (18) requires that the error term across equations should be linearly dependent. Finally, restriction (19), together with adding up the restrictions, ensures that the predicted labor shares sum to one. Together the restrictions make the household labor allocation decisions be related across activities. Following Hayashi (2000) and Greene (1997), the restrictions are imposed by dividing the shadow wage of all activities by the shadow wage for off-farm work. We drop the off-farm equation to avoid the singular variance-covariance matrix that occurs because the labor share equations add to one. In order to ensure symmetric cross-price elasticities, we impose and test the following restriction:

$$\beta^{j,k} = \beta^{k,j} \tag{20}$$

We estimate the system of labor share equations with constrained maximum likelihood (ML), ensuring that outcomes are invariant to choice of equation dropped (Greene, 2000).

4.4 Data Description

Our data come from a household survey completed in 10 villages in Marabá, a Municipality in the State of Pará in the Brazilian Amazon, between May and November 2006. Research villages were selected to provide as much variation as possible in access to markets, disease, environment, and public health. Villages were located anywhere between 12 and 300 km away from the city of Marabá. In each village, households were randomly selected from lists obtained from the president of the village's local community association. Interviews were undertaken with the head of household, using a recall instrument based on smallholder decisions in pre-planting, planting, and harvesting seasons during past year. In total, 335 households were sampled and no households refused to answer survey questions.

Table 18 presents the data on household labor allocation by activity. Most of the household labor is employed in cattle ranching and staple food production. Time spent taking care of sick people and time working off-farm, however, also takes a substantial part of the household time endowment. In nearly 50% of the sample, households had at least one sick family member. Time spent on land clearing is small compared to other activities done by the household. On average, smallholders clear one to three hectares of land per year in order to produce crops or establish pasture for cattle ranching (Homma et al., 1992), but there is a narrow window of opportunity for productive land clearing. Thus, land clearing has to be done on a specific schedule and as quickly as possible. Last, labor markets do not function well in the region, leading to constraints in off- farm labor opportunities, which is reflected in the low number of days allocated to off-farm employment.

In addition, **Table 18** shows the participation rate in each household activity. Here livestock nearly reaches a 100% participation rate followed by staple food production with

73% and all other activities have a participation rate of 44%. These households have a high participation rate in each activity followed by a low to moderate allocation of labor days to activities. Thus, we have 44% participation rate for land clearing but this activity takes only 0.03 share of the total labor time endowment.

After correcting for selection, shadow wage for labor employed in land clearing is R$16, working off-farm is R$12, working with staple food production is R$8, and taking care of sick people is R$7.

Table 18. Mean and standard deviations of labor shares and participation by activity

Variable	Mean	Std. Dev.
Labor share by activity		
Staple food production	0.263	0.244
Land Clearing	0.035	0.053
Livestock production	0.354	0.292
Working off-farm	0.142	0.228
Taking care of sick people	0.200	0.265
Participation in each activity		
Staple food production	0.731	0.444
Land Clearing	0.961	0.193
Livestock production	0.442	0.497
Working off-farm	0.442	0.497
Taking care of sick people	0.439	0.497
Number of observations	335	

Descriptive statistics of the variables used in the estimation are reported in **Table 19**. The variables are presented for both households that had at least one sick household member and households with no sick people during the period sampled. In our sample, there are 146 non-sick households and 189 households with sick family members. On average, the price of staple food was about the same for sick and non-sick households, but the price of livestock for non-sick households was slightly higher. This difference in price of livestock may be caused by households ascribing more expected value to an asset that may soon be sold. Sick households had more credit and exogenous income compared to non-sick households. Sick households live further from local markets and had more pasture and larger agricultural area under cultivation. Furthermore, sick households have slightly more adults and children compared to non-sick households. In terms of education, non-sick household had more formal education. Overall, sick households spent 49 days sick while working and had nearly 1.5 people sick per household.

Table 19. Descriptive statistics of selected variables

Variable	Mean	Std. Dev.
Sick household (n=189)		
Price of Staple Food (R$ per sack)	47.15	22.03
Price of livestock (R$ per head)	200.83	263.49
Access to credit (R$ per year)	1,901.88	4,542.28
Exogenous income (R$ per year)	1,224.23	2,833.27
Distance to local markets (Km)	129.83	163.34
Number of adults in the household	2.50	1.97
Number of children in the household	1.53	1.72
Age household head	49.70	11.88
Agriculture plot size	3.44	4.47
Pasture area	24.19	30.86
Adult mean education (years)	4.41	2.53
Number of sick people in the household	1.40	1.55
Number of sick days while working	49.16	97.26
Non-Sick households (n=146)		
Price of Staple Food (R$ per sack)	42.85	21.66
Price of livestock (R$ per head)	163.15	120.33
Access to credit (R$ per year)	1,153.38	4,029.03
Exogenous income (R$ per year)	970.21	2,088.31
Distance to local markets (Km)	99.71	82.71
Number of adults in the household	2.33	1.863
Number of children in the household	1.31	1.78
Age household head	48.17	12.71
Agriculture plot size	2.85	3.33
Pasture area	22.97	25.46
Adult mean education (years)	4.48	3.036
All household (n=335)		
Price of Staple Food (R$ per sack)	45.28	21.94
Price of livestock (R$ per head)	184.41	213.81
Access to credit (R$ per year)	1,575.67	4,335.77
Exogenous income (R$ per year)	1,113.53	2,535.27
Distance to local markets (Km)	116.70	134.95
Number of adults in the household	2.43	1.92
Number of children in the household	1.43	1.75
Age household head	49.03	12.26
Agriculture plot size	3.18	4.02
Pasture area	23.66	28.60
Adult mean education (years)	4.44	2.76
Number of sick people in the household	0.79	1.36
Number of sick days while working	29.27	78.18

4.4 *Results and Discussion*

Regression results for the system of equations are presented in **Table 20**. The computed F-statistic of 138.28 is significant at the 95% confidence level, providing support for the hypothesis of joint significance of the explanatory variables. Parameter estimates of the staple food, land clearing, and livestock equations are obtained directly from the Maximum Likelihood estimation. Parameters of the off-farm employment equation are calculated from the adding-up restrictions. We use likelihood ratio (LR) statistic to test the symmetry restrictions. The 95% chi-square test statistic for two restrictions is 6.05, exceeding the calculated LR statistics of 1.45. Thus, we fail to reject the null hypothesis of symmetry. A Wald test is used to test the homogeneity and adding-up restrictions. The associated 95% chi-square test statistic in the presence of 8 restrictions is 15.22, compared to the Wald statistic of 222.12. The joint null hypothesis of homogeneity and adding-up is therefore rejected. Note that the use of predicted shadow wages prices/wages in the labor shares equations is akin to instrumental variable estimation. Robust standard errors in the table are calculated by adjusting White's (1980) heteroskedasticity-consistent covariance matrix estimator for the instrumental variable cases.

Table 20 includes results for each labor share equations. Given our interest in the impact of sickness on labor allocation, we focus the following discussion on the impact of the variables measuring sickness across different labor share equations. We find strong statistical support for the hypothesis that variables related to sickness affect choice of labor allocation to various activities. The number of sick days not working has a statistically significant negative impact on the share of labor allocated to agriculture, livestock, and working-off farm. Also, it has a positive impact on labor allocated to family members taking care of sick people and labor allocated to land clearing. The correlation of the variable number of days sick while working, which has to do with labor efficiency, was not statistically significant across the labor share equation indicating that labor efficiency is not a major driver of labor allocation.

A priori, one might expect households with sick family members to reduce labor allocated to economic activities and increase labor allocated to care for sick family member. As expected, results reveal a negative correlation between illness and labor allocated to agriculture, livestock, and working-off farm and a positive relationship between illness and labor allocated to taking care of sick household members. This argument is supported by the staple food equation, which show a statistically significant relationship between labor share equation staple food and shadow wage of taking care of sick family members. It was not expected, however, to find a positive and statistically significant relationship between illness and labor allocated to land clearing. A plausible explanation is that households with sick family members temporarily increase labor to land clearing (an intermediary input for staple food production) to generate more income associated with sales of agriculture production. This result is different from other results found in the literature where sick households allocate more labor to forest activity. This contention is further supported by the staple food equation, which shows a positive and statically significant correlation between labor share and shadow wage of land clearing.

The results also show a positive and statistically significant relationship between education and off-farm labor allocation. An explanation may be that education signals employers about worker's potential productivity, increasing the likelihood of being hired into attractive off-farm production and thus increasing labor allocated to off-farm activities. The results also show no statistically significant relationship between education labor share equations related to staple food, land clearing, livestock, and taking care of sick people, which is not surprising giving that high levels of education is not really important in the low technology context of farm production by small farmers in the Brazilian Amazon. To assess whether demographic labor allocations change with variables related to household demographic variables, we include variables related to age of the household head and number of children in the household. Our findings show a negative and statically significant relationship between the demographic variables and the labor share equation related to time taking care of sick people in the household and no impact of the other labor share equations.

We find no support for the hypothesis that the observed prices of livestock and staple food influence labor allocation. Our observed prices, however, may not have sufficient variation to estimate such a relationship precisely. On the other hand, the shadow wages estimated for agriculture are statistically significant and negatively correlated with the labor share equation for staple food production, land clearing, and working off-farm, and positively correlated with the labor share equation for livestock and taking care of sick household members. The shadow wage of taking care of sick people is statistically significant and positively correlated with labor share equation for staple food and statically and negatively correlated with the labor share equation taking care of the sick. The shadow wage of land clearing is statistically significant and positively correlated with the labor share equations for staple food and land clearing. The shadow wage for working off-farm is statistically significant and positively correlated with the labor share equations for land clearing and working off-farm, and it is statistically significant and negatively correlated with the labor share equations staple food, livestock, and taking care of sick people.

Table 20. Constrained Maximum Likelihood Results for Labor Share Equations

	Staple Food		Land Clearing		Livestock		Taking Care Sick		Off Farm	
	Coef.	**Std. Err.**	**Coef.**	**Std. Err.**	**Std. Err.**	**Std. Err.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Std. Err.**
Shadow Wage Agriculture	-0.0897**	(0.0292)	-0.0356***	(0.00655)	0.0855*	(0.0343)	0.116***	(0.0256)	-0.0782**	(0.0242)
Shadow Wage Taking Care of Sick	0.162***	(0.0429)	0.0167	(0.00962)	-0.0792	(0.0503)	-0.164***	(0.0377)	0.0571	(0.0356)
Shadow Wage Land Clearing	0.0612*	(0.0300)	0.0415***	(0.00673)	-0.00846	(0.0352)	-0.0440	(0.0263)	-0.0425	(0.0249)
Shadow Wage Off Farm	-0.0439**	(0.0139)	0.0129***	(0.00311)	-0.0833***	(0.0163)	-0.0246*	(0.0122)	0.142***	(0.0115)
Observed Price of Staple Food	0.0277	(0.0261)	-0.00247	(0.00586)	-0.0321	(0.0306)	-0.0101	(0.0229)	0.0122	(0.0217)
Observed Price of Livestock	-0.00543	(0.0118)	0.00129	(0.00265)	0.0167	(0.0139)	0.0159	(0.0104)	-0.0303**	(0.00981)
Credit (R$)	-0.00281	(0.00367)	-0.000737	(0.000822)	0.00385	(0.00430)	0.00241	(0.00322)	-0.00178	(0.00304)
Exogenous Income (R$)	-0.00682	(0.00352)	-0.00102	(0.000789)	0.00792	(0.00413)	-0.00182	(0.00309)	0.00242	(0.00292)
Distance to local Markets	-0.0172	(0.0120)	-0.00229	(0.00268)	0.0395**	(0.0140)	-0.00665	(0.0105)	-0.0184	(0.00993)
Adults in the Household	-0.0209	(0.0306)	-0.00215	(0.00687)	0.102**	(0.0359)	-0.105***	(0.0269)	0.0170	(0.0254)
Children in the Household	0.00555	(0.0213)	0.00163	(0.00478)	0.0168	(0.0250)	-0.0478*	(0.0187)	0.00625	(0.0177)
Age household head	-0.00183	(0.0355)	-0.00928	(0.00798)	0.0380	(0.0416)	-0.0655*	(0.0312)	0.0370	(0.0295)
Agriculture area under cultivation (ha)	0.0826***	(0.0162)	0.00750*	(0.00363)	-0.0116	(0.0190)	-0.0398**	(0.0142)	-0.0333*	(0.0134)
Pasture size (ha)	-0.00418	(0.0111)	0.00286	(0.00249)	0.0331*	(0.0130)	-0.0131	(0.00975)	-0.00962	(0.00922)
Adult mean education	-0.00593	(0.0212)	-0.00518	(0.00476)	-0.0193	(0.0249)	-0.0245	(0.0186)	0.0766***	(0.0176)
Number of sick people in the household	-0.0576*	(0.0264)	0.0124*	(0.00591)	-0.190***	(0.0309)	0.299***	(0.0232)	-0.0593**	(0.0219)
Number of days working and sick	0.00679	(0.00714)	-0.00254	(0.00160)	-0.00432	(0.00838)	-0.00326	(0.00627)	0.00135	(0.00592)
Constant	0.288*	(0.118)	0.0311	(0.0267)	0.178	(0.139)	0.626***	(0.105)	-0.124	(0.0989)
R-Squared	0.2168		0.1644		0.2500		0.4884		0.3861	
RMSE	.2155168		.0482532		.2527202		.1890508		.1786304	
P>Chi2	0.00000		0.00000		0.00000		0.00000		0.00000	
N	335		335		335		335		335	

* Implies statistical significance at the 0.01 level
** Implies statistical significance at the 0.05 level
*** Implies statistical significance at the 0.10 level

4.5 Conclusions

The literature on deforestation largely ignores the impact of disease on smallholders' decisions related to land-use, even though land clearing might be linked to household health status. With little or no access to credit, and thus technology, the production process by which forests are converted into cleared land for agriculture or ranching is labor-intensive. It is understandable that illness could have a direct impact on total farm household labor. But illness may also result in a change in the labor allocation decisions by households to a new mix of production activities, and may require the purchase of wage labor support. Therefore, the local labor markets may provide an additional framework to link economic activities, labor markets, health, and land use.

In this chapter, we study the factors related to the demand for labor by jointly estimating a system of labor share equations applied to land clearing, staple food production, livestock, working off-farm, and time taking care of sick people in the household. Our empirical application examines the impact of disease on labor allocation, and we account for time lost by households taking care of sick members as a non-productive activity. In the context of this paper, disease can play an important role in household decisions because farm activities are performed inefficiently by sick households, and changes in household labor efficiency brings about a change in the relative price of competing uses for a household's time. We could have estimated a single-equation model of household's labor allocation. However, a single-equation demand for labor as applied by previous studies on labor allocation decisions by smallholders would miss important interactions among competing economic activities that require different level of labor efficiency. The system of equations we use in this paper better captures the trade-offs related to labor allocation among competing economic activities a household faces when dealing with disease.

Our results strongly support the hypothesis that health, or conversely sickness, influences the labor allocation decisons in smallholder households living on the forest frontier of the Brazilian Amazon. The number of sick days not working by family member has a statistically significant negative impact on the share of labor allocated to agriculture, livestock, and working-off farm and it has a positive impact on labor allocated to family members taking care of sick people and, surprisingly, labor allocated to land clearing. The negative health effect in each labor share equation related to economic activities (agriculture, livestock, and working off-farm) suggest that labor can be drawn away from the main economic activities undertaken on and off-farm and assigned to land clearing. These results seem counterituitve, however, it is important to notice that cleared land incorporated into agriculture and livestock production tend to be more productive than land already in production for few years. The slash-and-burn agriculture practices tend to degrade soil and reduce nutrients, impacting productivity within few years of production. We believe the slash-and-burn agriculture practices are a major driver of the results presented in the labor share equations. A household that needs to boost economic results from agriculture and livestock production to offset loses related to disease may tend to replace nutrient depleted land already in production with nutrient rich land incorporated into production through deforestation. In other words, it is possible that disease is a counter-intuitive but important driver of deforestation.

In addition, the labor share questions show positive own price effects, indicating that households respond to production and economic incentives. In similar fashion, the negative cross-price variables in the labor share equations demonstrate that labor can be relocated among economic activities through economic return incentives. Unlike the results presented elsewhere, off-farm work opportunities are not effective in reducing labor allocated to land clearing. It reduces labor allocated to staple food and livestock production. However, it increases labor allocated to land clearing (Blufstone, 1995; and Shively, 2001). The economic return to staple food production, however, tend to reduce labor allocated to land clearing. For smallholders in the Brazilian Amazon, the best way to reduce pressure on forest is to keep agriculture land productive through investment in agriculture innovation and technical assistance to keep land already cleared productive.

Finally, the results presented have implications for development and conservation policies. It is tempting to consider labor allocated to off-farm work and land clearing as substitutes. In the case where labor allocated to work off-farm and land clearing are substitutes, then, policies could be designed to improve off-farm labor while land clearing by smallholders. The results presented here, however, suggest that there are important complementarities between labor allocated to land clearing and off-farm work. These complementarities hint that policies that deepen the off-farm labor market may in-fact encourage land clearing by smallholders. The results also show that illness reduce labor allocated to all economic activities, including off-farm work. Given the negative relationship between agriculture return and land clearing labor share equation, a higher return to agriculture reduces the land clearing labor share, this result provides evidence that agriculture innovation and technical assistance policies may have an important impact on forest conservation.

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APPENDIX

Appendix B

Shadow wages and participation

As indicated by Shiveley et al 2004, “prices” relevant to labor supply functions are shadow wages or opportunity ocsts observed by the household. In other words, the returns they forego by substituting out one economic activity into another. In this context, the decision not to supply labor is as important as the decision to supply labor to a given economic activity. When a household does not participate in an activity, it probably because household’s perceived shadow price for labor in that activity exceeds the observed return. Therefore, a common problem we face in the case of non-participation is that we cannot observe the opportunity cost of those households that do not engage in a given activity. Nonetheless, we know that there is an opportunity costs observed by the household, and not observed by the econometrician. Thus, ignoring non-participation can lead to biased estimates of labor supply (Heckman, 1974).[13] To solve this problem Shively and Fisher (2004) and Fisher, Shively, and Bucola (2005) computed the missing shadow wage jointly with participation using the method of preferred maximum likelihood and replacing the missing values for the fitted shadow wages (Nawata and Nobuko, 1996). Below, we detail the procedure for correcting non-participation for each economic activity.

Our first step is to estimate a farm-level production function for staple food and livestock production (**Table** A2.1 and A2.2). Fitted value of outputs are, then, retained for

[13] References for the Appendices are listed in Chapter 4.

each household and combined with the observed level of labor input and the estimated parameter for labor to generate a shadow value of labor used on each farm activity (staple food, land clearing, and livestock), namely for staple food production (agriculture): $\widehat{w}^a = \frac{\partial Q(.)}{\partial L^a} = \frac{\widehat{\beta}^{L^a} Q^a}{\partial L^a}$.

Appendix C

Labor Participation and Shadow Wages

The household production involves two decisions. First, the household observes the returns from production and based on its own perception about the opportunity cost of the household's labor time it makes a decision on participation in a given activity and the desired number of days it should allocate. In a previous section, we have already computed the shadow wage of labor in staple food production. Now, we have to compute the shadow wage of non-participants in staple food production, and in this manner estimate participation and shadow wage jointly. In our selection model, the estimated shadow wage is the the dependent variable and the regressors can be grouped into farm characteristics (distance to local markets), household demographics (household head age, adult mean education, and number of adults and children in the household), and health status variables (number of sick people and number of days sick while working). Health status is used in the selection and wage equation because both group of variables are likely to have an influence on the decision to participate in staple food production as well as on the returns to labor. The estimated coefficients are then used to predict the shadow wage of non-participants. The missing shadow wages of non-participants households in staple food production are replaced by the computed shadow wage of non-participants.

One problem is that in cattle ranching smallholders in the Amazon use a traditional production system, which requires low input use and little labor time in management. So, when we run the livestock production function, we get labor as a non-significant variable.

Another problem is that labor time spent taking care of sick people is only the household's own labor. In our sample, nobody was hired to take care of sick family members. In this case, there is no observation of a market wage rate at all and the proxy for the opportunity cost of time for the household is the endogenous shadow wage. Therefore, we use the shadow wage from staple food production as the opportunity cost of time for the household's labor time spent on livestock production and taking care of sick people in the household. However, even after replacing the missing shadow wage for the shadow of wage from staple food production there are cases in which the household did not choose to participate in livestock production yet is taking care of sick family members. So, the shadow wage from staple food production is likely different from the household's own perception of its opportunity cost of time. In these cases, we correct for self-selection as we did for non-participation in staple food production. In the end, the shadow wages from these three activities are slightly different because the wage rate necessary to make a household participate in any of these activities may vary.

Table A1.2 Maximum Likelihood Results for Agriculture Participation and Shadow Wage Regresions

	Staple Food (0/1)	**Shadow Wage (R$/Day)**
Constant	0.696**	0.1.936**
	(0.249)	(0.956)
Number of people in the household	-0.744*	-0.420*
	(0.304)	(0.153)
Number of adults in the household	0.399	-
	(0.269)	
Number of children in the household	0.309	-
	(0.194)	
Number of sick people in the household	0.369*	0.420**
	(0.153)	(0.146)
Number of days sick and not working	0.026 ***	0.019
	(0.429)	(0.039)
Distance (km)	-	0.227***
		(0.054)
Age of household head (years)	-	-0.231
		(0.230)
Adult mean education (years)	-	-0.279*
		(0.106)
N	321	321

Note: White's robust standard errors appear in parenthesis. Coefficients marked with asterics are significant different from zero at a 90%, 95% and 99% confidence level.

Appendix D

Off Farm Labor Market, Land Clearing, and Shadow Wages

As mentioned earlier in this section, the shadow wage of labor applied to on farm production is smaller than the prevailing market wage for most of the seasons in the Brazilian Amazon. Thus, at times the household labor supply is greater than on-farm labor demand. However, off-farm labor opportunities are limited. In this case, working off-farm is not a choice for most of the households. Then, by default the shadow wage from staple food production is the opportunity cost of labor for those households not able to find work. In this case, we use the predicted shadow wage from staple food production to replace the opportunity cost of time that is missing for those households that did not participate in the off-farm labor market.

Last, we used the fitted value of staple food production together with the marginal contribution of leased land to find a proxy for the return of labor to land clearing. The return of leased land is a combination of household fitted staple food production, the estimated coefficient on leased land, and the level of leased land used by households in production. Assuming that leased land is a perfect substitute for land cleared on the household's own farm leads to the implication that the returns to land clearing should be directly related to the values for leased land. Finally, using this proxy for shadow price of land clearing we can compute, as before, the shadow value of land clearing for those that cleared land in the survey period. For those households that did not cleared land, we corrected for selection by estimating jointly the shadow wage together with participation in land clearing activity. As before, the missing shadow wages of non-participants households in land clearing are replaced by the computed shadow wage of non-participants.

Appendix E

Estimated production functions for stasple and livestock.

Tables A2.1 and A2.2 report the results of fitting both ordinary least squares (OLS) and instrumental variables (2SLS) for staple food and livestock production, respectively. In the estimated staple food production function, we can see that output is statistically signicant and increasing for adult male labor, agricultural land, leased land, and improved seeds. Note that OLS and 2SLS coefficients differ for most parameters. For instance, the hired labor coefficient is large and signicant in the OLS regression, but small and insignicant in the 2SLS regression, indicating that unobserved endogenous factors are the driving force behind the OLS results. Also, none of the health-related variables are important to staple food production. Because OLS estimates are inconsistent, the following analysis will be based on the 2SLS estimated results.

In the estimated production function for livestock, we can also see that output is statistically significant and increasing for most of the inputs: capital, pasture area, leased land, use of improved seeds, and livestock immunization. Again, we observe differences between the parameters estimated by OLS and 2SLS. The adult male labor coeffcient is large and highly signifcant in OLS and insignificant in 2SLS. Hired labor follows the opposite pattern where it is negative for both OLS and 2SLS. However, it is significant only in the 2SLS results. These results are reasonable because the traditional livestock production system in the region uses extensive technology with low labor input and little management time, thus, the family labor coefficient is insignificant. When they have to hire labor, it has a negative effeect on production. Again, the OLS estimates are inconsistent, so the proceeding analysis will be based on the 2SLS estimated results.

Comparing the responsiveness of output to labor between staple and livestock production systems, we observe that the coefficient on labor devoted to staple food positive and signicant while it is not statistically significant for livestock production function. This indicates staple food production is the activity that best measures the opportunity cost of time faced by smallholders in the study area. Also, it makes sense to observe the coefficient on land devoted to livestock is two times larger than the coefficient on land devoted to staple food production. Livestock production requires large amounts of land converted to pasture and cattle has a higher aggregated value when compared to staple food. Frequently, early in the morning adult male labor take the herd to the selected pasture and let it graze until the afternoon when the herd is taken back to the corral. In between, most of the staple food production activities are undertaken on other land units. The descriptive statistics for the shadow wage of labor is reported in **Table 5**. The mean value of the shadow wage is R$10. In addition, **Table 5** reports the impact of disease on the estimated shadow wage. The male shadow wage for sick households is R$10. This value is nearly two times greater than the average male shadow wage for non-sick households, which is around R$6. These results, together with the fact that sick household supply slightly more labor to land clearing and to farming, suggest that the impact of disease on the shadow wage is positive. This indicates that the behavior of the households sampled is similar to cases 2 and 4 from our theoretical section. In both cases, we saw that the shadow wage is positive whenever the impact of disease on labor-augmenting health efficiency parameter and days sick no working is compensated by non-sick household members.

Table A2.1 Staple food Production in the Brazilian Amazon

Variables	Instrumental Variable	Ordinary Least Squares
Ln Adult Male Labor (Days)	0.31530** (0.1560)	0.32824*** (0.0718)
Ln Adult Female Labor (Days)	0.07211 (0.1340)	0.07994 (0.0698)
Ln Agriculture Plot Size (ha)	0.16862**(0.1850)	0.23987*** (0.1760)
Ln Hired Labor (R$)	0.10220 (0.0647)	0.17340*** (0.0472)
Ln Capital (R$)	0.18361*** (0.0997)	0.16784** (0.1010)
Ln Distance to Nearest Market (km)	-0.00117 (0.1270)	-0.00944 (0.130)
Ln Value Leased Land (R$)	0.08230* (0.0507)	0.07938* (0.0570)
Ln Value Improved Seeds (R$)	0.11932** (0.0473)	0.11062* (0.0493)
Adult Mean Education (years)	-0.03196 (0.5820)	-0.02763 (0.6130)
Age Household Head (years)	1.42819 (0.2560)	1.49344 (0.278)
Age Household Squared (years)	-1.77750 (0.0023)	-1.81565 (0.00251)
Experience (years)	-1.08691 (0.2100)	-1.16299 (0.2250)
Experience Squared (years)	1.43784 (0.0029)	1.49083 (0.00235)
Ln Days Sick	0.03751 (0.0874)	0.02625 (0.0674)
Sick in the Pre-Planting Season (yes & no)	0.02732 (0.3490)	0.02874 (0.3560)
Sick in the Planting Season (yes & no)	0.01453 (0.3220)	0.01550 (0.3310)
Sick in the Harvesting Season (yes & no)	-0.03950 (0.4110)	-0.03903 (0.4230)
Observations	335	335
F	9.053	8.658
R^2	0.341	0.351
RMSE	2.196	2.239

Table A2.2 Livestock Production in the Brazilian Amazon

Variables	Instrumental Variable	Ordinary Least Squares
Ln Adult Male Labor (Days)	0.1009 (0.3110)	0.2773*** (0.0444)
Ln Adult Female Labor (Days)	0.0341 (0.1010)	0.0268 (0.0363)
Ln Hired Labor (R$)	-0.1274** (0.0563)	-0.0305 (0.0368)
Ln Capital (R$)	0.1560* (0.1100)	0.1418** (0.0756)
Ln Distance to Nearest Market (km)	-0.0112 (0.1290)	-0.0099 (0.1280)
Ln Area of Pasture (Ha)	0.2992*** (0.1350)	0.2839*** (0.1130)
Ln Value Leased Land (R$)	0.0390 (0.0435)	0.0687** (0.0303)
Ln Fencing (R$)	0.0492 (0.0218)	0.0250 (0.0199)
Ln Value Improved Seeds (R$)	0.0746* (0.0283)	0.0926** (0.0261)
Ln Lot Size (ha)	-0.0422 (0.2190)	-0.0589 (0.2250)
Ln Value of Animal Immunizations (R$)	0.4613*** (0.0897)	0.3906*** (0.0365)
Adult Mean Education (years)	0.0819 (0.6790)	0.0437 (0.5450)
Age Household Head (years)	-0.8747 (0.1590)	-0.8174 (0.1640)
Age Household Squared (years)	0.5925 (0.0014)	0.5325 (0.0015)
Experience (years)	0.6160 (0.1470)	0.5398 (0.1440)
Experience Squared (years)	-0.3713 (0.0014)	-0.2905 (0.0015)
Ln Sick People in the Household	0.1139 (0.9740)	-0.0739 (0.279)
Ln Days Sick	-0.1399 (0.2740)	0.0468 (0.0801)
Sick in the Pre-Planting Season (yes & no)	-0.0793 (0.2670)	-0.0761 (0.26000)
Sick in the Planting Season (yes & no)	0.0858 (0.3430)	0.0594 (0.2360)
Sick in the Harvesting Season (yes & no)	-0.0306 (0.3090)	-0.0434 (0.2840)
Observations	335	335
F	7.053	15.01
R^2	0.341	0.652
RMSE	2.196	1.372

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 *Conclusion*

Most of those people living in rural areas of the Brazilian Amazon are smallholder farmers. Typically, they employ cleared forest and their own labor to plant and produce crops, tend pasture for cattle ranching, and collent non-timber forest products. Their work often relies on strength and endurance, and therefore on good health. However, the impact of health on farm production, labor decisions, and welfare of these smallholders has not been rigorously studied examined in the Amazon. Because sickness directly reduces labor time available and indirectly impacts labor quality if sick family members must work, farm activities may not be performed efficiently by households whose members are sick. This relationship has been found in many studies set in Africa and Asia, but has yet to be considered in Latin America, to our knowledge.

How illness changes household decisions also depend critically on labor markets in the rural areas. With complete markets, households can simply hire labor freely at the market wage to compensate for the loss of household labor time due to disease, although their income might be lower. When markets are incomplete, however, labor cannot be freely hired (a market wage may not even exist), and sick households are fully subject to both direct and indirect impacts of disease. Given the importance of labor markets, we cannot therefore generalize labor market characteristics across countries and regions.

The core of this dissertation is a set of essays (listed as Chapters 2, 3 and 4) that use data from a household survey conducted in Brazilian Amazon to examine whether household health is an important factor in determining labor allocation and household agriculture productivity. More precisely: **Essay I** examines how labor and production by migrant smallholders in the Brazilian Amazon is impacted by disease. The impacts of illness on household decisions depend critically on labor market function in the rural areas of the tropics. Results from a formal statistical labor market tests shows that labor markets do not work well in the study area. In particular, we find that staple food and livestock labor demands are affected importantly by factors other than price and biophysical characteristics of the land itself. These results collectively raise questions about the ability of households to smooth the impact of disease by allocating labor to economic activities, such as cattle grazing, that are not labor intensive. These results also suggest the importance of both modeling households across seasons and incorporating health effects into household models for the Brazilian Amazon. These results are important both in specification of future smallholder household economic problems and in targeting policies that better alleviate poverty and encourage more sustainable use of forest and land resources in similar tropical regions.

Essay II investigates the role of health as a productive input and non-input factor of production. By using a non-neutral stochastic production approach, the impact of health is decomposed into direct effect on the production function and indirect effects on the technical inefficiency. The findings of the essay suggest that household health status have significant impacts on rural household production. The most important policy implication is that careful designing of agriculture development and rural settlements programs is important, and the provision of health care should be tied to these development projects.

Finally, our results show that most of the farmers in the sample produce below the production frontier. This finding indicates that there is a lot of scope to increase agricultural output without requiring the introduction of new technologies. Efficiency gains would raise output and farm profits, as well as improve competitiveness. Consequently, there is a clear rationale for supporting smallholders so that they can achieve higher efficiency from the technology already available to them. The mechanisms to improve efficiency are well known by policy makers and include effective education and extension services, credit availability, input supplies (particularly high-quality seeds), output marketing, and market information, among other factors.

Essay III examines the demand for labor applied to land clearing, staple food production, livestock, working off-farm, and time taking care of sick people in the household. Specifically, the empirical application examines the impact of disease on labor allocation, accounting for time lost by households taking care of sick members as a non-productive activity. Disease plays an important role in household decisions because farm activities are performed inefficiently by sick households and changes in household labor efficiency brings about a change in the relative price of competing uses for a household's time.

The results strongly support the hypothesis that health, or conversely sickness, influences the labor allocation deceions in smallholder households living on the forest frontier of the Brazilian Amazon. The number of sick days not working has a statistically significant negative impact on the share of labor allocated to agriculture, livestock, and working-off farm. Also, it has a positive impact on labor allocated to family members taking care of sick people and labor allocated to land clearing.

Overall, the results of the three studies presented in this dissertation deliver strong evidence for joint policy design between conservation, labor markets, agricultural production, and health. Studies and policies that ignore the links between these aspects of household life and production on the frontier risk being wrong with possible unintended negative consequences either for household welfare or deforestation.