Does poverty constrain deforestation? Econometric evidence from Peru*

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Abstract

This paper investigates whether available evidence supports the common hypothesis that households living near tropical forests clear additional land over time because they cannot finance desired agricultural investments. I show that theoretically the effect of increases in income on land clearing is ambiguous. Using panel data, I investigate this hypothesis in Peru. In this sample income is positively correlated with land clearing, though at a decreasing rate, and, because of labor market constraints, land clearing is positively correlated with household size. Marginal increases in income are not associated with increased fertilizer expenditure. Policies to reduce both poverty and deforestation may exist, but small increases in incomes of the poorest are unlikely to reduce deforestation. Targeted support for the purchase of inputs and improvements in local labor markets may be more effective tools to raise incomes and reduce pressure on forests.

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1 Introduction

Agricultural expansion, primarily by smallholders, is the proximate cause of at least 50 percent of the deforestation in tropical forests (Barraclough and Ghimire [6]). Understanding how these households make agricultural production and investment decisions is critical if policy makers wish to influence the rate of tropical deforestation in a cost-effective manner. Equally important is the relationship between poverty and deforestation; governments are likely to be at least as concerned with increasing the incomes of rural households as slowing the rate of deforestation since the environmental benefits of tropical forests, as a reservoir of carbon or biodiversity for example, are overwhelmingly global in scope (Chomitz and Kumari [11]). In a recent review of the empirical deforestation literature, Angelsen and Kaimowitz [5] suggest that a lack of evidence on the impact of poverty on the deforestation decision is a shortcoming of existing research.

This paper investigates whether the poverty of households in the forest region of Peru exacerbates or constrains the rate at which these households clear forested land. The contention that poverty causes households to degrade the environment has been made in several contexts (e.g., United Nations [63], World Commission on Environment and Development [70]). In the case of deforestation, the story goes, households would like to invest in maintaining the quality of soil on existing cleared land, or increasing yields on this land, but are unable to do so because they cannot finance the necessary investments. As a result, they must clear additional forest for conversion to agriculture over time (World Bank [67], p. 134, Shortle and Abler [54]). Some authors have gone so far as to call this conceptualization of deforestation the "conventional wisdom" (Angelsen [4], Angelsen and Kaimowitz [5]). If this characterization of households' preferences and constraints is correct, then policies that raise the income or wealth of the poorest smallholders in forest regions, such as micro-credit programs, may generate that elusive policy outcome— a scenario in which, at least in some range, there is no uncomfortable trade-off between environmental protection and poverty reduction. This paper investigates whether available evidence supports this hypothesis.

Despite claims to the contrary, it is not obvious that a household at the forest margin that receives additional resources will choose to invest in the quality of land currently under cultivation instead of choosing to undertake additional conversion. From the household's perspective of maximizing its own welfare, forest clearing is an investment, and the choice depends on the relative price of intensification and clearing, the relative riskiness of the two strategies, the availability of hired labor, and other factors.[1] If the question is ultimately ambiguous from a theoretical perspective, empirical analysis is the best means of resolving this issue.[2] This paper addresses both of these considerations. I model the land-use decision taking into account key characteristics of smallholder agriculture to show that the effect of wealth on deforestation is theoretically ambiguous. I then investigate empirically the relationship between income and land clearing using panel data from the forest region of Peru, which has the second-largest area of tropical forest cover in Latin America, and the tenth-largest in the world (FAO [22]).

Empirical studies of the causes of land-use change have been performed in both the United States (US) and in developing countries. In the US, Plantinga [47], Stavins and Jaffe [59], and Schatzki [52] investigate how landowners have responded to economic incentives to convert land between agriculture and forestry uses. They use aggregated county-level data and derive an econometrically

[1] In other contexts, collective action and strategic interactions with neighbors might also affect the land-use decision. In the Latin American tropics, such concerns are of less importance. Forests are de facto open access resources (Angelsen [4]), though there are reserves in which indigenous people collectively manage forests. For an analysis of deforestation where forests are communally owned, see Foster, Rosenzweig, and Berhman [25].

[2] In the case of the relationship between poverty and deforestation, this point has been made elsewhere. See, for example, Lee, Ferraro, and Barret [37] and World Bank [68].

estimable equation from models of a land manager who faces complete markets. Because of the assumption of complete markets and the aggregated data used, the effect of poverty on the land-clearing decision cannot be tested directly. Similar research has been performed in developing countries (Pfaff [45], Chomitz and Grey [10], Deininger and Minten [18], Panayotou and Sungsuwan [43] and Cropper, Griffiths, and Mani [15]), where the assumption of complete markets may be more tenuous.

Investigating the relationship between poverty and the land-clearing decision requires taking the household as the unit of analysis, but studies such as this one using household-level panel data remain rare. With the exception of Shively [53], and Foster, Rosenzweig, and Berhman [25], most previous research on the causes of land-use change in the tropics using household-level data has relied on cross-sectional data (Faris [23], Godoy et al. [26]) or constructed panel data gathered using systematic oral recall techniques (Coomes, Grimard, and Burt [13], Bergeron and Pender [8]).[3] The use of panel data is critical to ensure that results are not driven by unobserved ability bias. Neither Shively nor Foster, Rosenzweig, and Berhman use data from Latin America, where the majority of tropical forest is located (FAO [22]).

By focusing on the relationship between poverty and agricultural production and investment decisions, this paper also contributes to empirical microeconomic research on the behavior of rural smallholders in poor countries. In contrast to much of the land-use literature, this research emphasizes the incomplete markets that rural smallholders face and the implications of these incomplete markets for agricultural decisions. Poverty can and does affect the agricultural production and

[3] Constructed panel data that relies on recall may be quite accurate when agents are asked to recall the timing and circumstances of major events (e.g., the birth of a child). However, this data is vulnerable to systematic error when agents are asked to recall the timing of regular or incremental activities.

investment decisions of the rural poor (Fafchamps, Udry, and Czukas [21], Fafchamps and Pender [20], Rosenzweig and Wolpin [49], Morduch [39], and Udry [62], among others), and labor market imperfections can affect land use (Angelsen [4]). In general, however, the implications of poverty for environmental externalities remains a relatively unexplored topic (Udry [61]).

In this analysis, I take as my benchmark the so-called conventional wisdom on the relationship between poverty and deforestation, which, as a short-hand, I call the "poverty-deforestation hypothesis." For clarity, define a "strong" version of the poverty-deforestation hypothesis as the following: increases in household income will be negatively correlated with land clearing and will be positively correlated with the use of inputs that increase or maintain yields. If this hypothesis is correct, the coefficient on income in a (properly specified) regression in which the dependent variable is the change in a household's cleared land holdings will be negative, and the coefficient on income in a regression in which the dependent variable is the use of inputs that increase yields or maintain soil quality (e.g., fertilizer or pesticide) will be positive and significant. A "weak" version of the poverty-deforestation hypothesis might predict that the coefficient on income in both the land-clearing and input-use regressions will be positive and significant, but the income elasticity of land clearing will be smaller than the income elasticity of input use.

In this paper, I am unable to accept either a strong or weak version of the poverty-deforestation hypothesis. Instead, I provide evidence that land clearing is positively correlated with income, but at a decreasing rate, while in contrast there is little evidence of a positive correlation between fertilizer use and income at the margin. There is mixed evidence of a positive correlation between pesticide use and income.

Rather than the relationship predicted by the poverty-deforestation hypothesis, a finding of this paper is that the land-clearing decision depends on household size. Because of labor supply constraints, households with more members per unit of cultivated land are more likely to clear land at any income level, and large households may be particularly likely to spend increases in income or credit on land clearing. In addition, permanent income is positively correlated with land clearing but not with fertilizer expenditure intensity. Taken together, the results of this paper provide evidence that mutually-reinforcing policies to reduce both poverty and deforestation may exist, but marginal increases in the incomes of poor smallholders at the forest margin will be unlikely to reduce deforestation. More promising interventions to increase incomes of the poor while minimizing associated increases in deforestation are likely to be targeted support for the acquisition of capital inputs that forestall yield declines, or improvements in the functioning of local labor markets. Increased off-farm labor opportunities can raise incomes and encourage households to value their own labor supply at an outside wage rate, enabling them to substitute intensive techniques for extensive production more efficiently.

The remainder of this paper is organized as follows: Section 2 sets out the intuition of the poverty-deforestation hypothesis to show that the effect of poverty on deforestation is ambiguous. A richer model of the land-use decision is presented in section 3 to show that households' expected borrowing constraints are taken into account when making land-clearing decisions. In section 4 the data are described and the estimation procedures discussed. Basic results are presented in section 5 along with a series of robustness checks in which I examine labor market constraints, borrowing constraints, and differential effects of permanent and transitory income. Section 6 contains concluding remarks.

2 The "poverty-deforestation hypothesis"

Before developing a more complete model of the smallholder's land-use decision, it is worth investigating the simplest version of a model of the interaction between poverty and deforestation to gain intuition about this problem. I show in this subsection that poverty and credit constraints can indeed result in a situation in which increasing household incomes slows deforestation. However, even this extremely simple model is sufficient to show that the effect of poverty on deforestation is theoretically ambiguous and depends on the relative profitability of intensification (or sustainable agriculture) and clearing. Therefore, in the case of deforestation, claims of mutually-reinforcing environment and development policies must be justified on the basis of empirical evidence rather than theory.

To gain intuition about how poverty may interact with deforestation, consider the following scenario: A household lives for 2 periods, $P1$ and $P2$, and begins with wealth W. The household cannot borrow, but can save at a certain rate of interest. All wealth is consumed at the end of $P2$. The household has at its disposal two equal-sized plots of forested land (j and k). The household can cultivate these plots using one of two techniques, A and B, with associated yields A and B and production costs c_A and c_B. The cost of clearing one plot of land is c and is independent of the production technique used. At the beginning of each period, the household makes its clearing and production decisions.

To understand the poverty-deforestation hypothesis, put some restrictions on the available production techniques. Assume that $A > B$, and $c_A < c_B$, but using technique B allows a plot to be farmed a second time. If technique A is used, the plot is degraded and must be abandoned. In any single period the "sustainable" production technique B is more costly than A and the yield from

Table 1: Representation of household's land-use options

Option 1	P1	P2	Option 2	P1	P2	Option 3	P1	P2	Option 4	P1	P2
Plot j	A		Plot j	A		Plot j	B	A	Plot j	B	A
Plot k	F	A	Plot k	A		Plot k	F	A	Plot k	B	A

A exceeds the yield from B.

Table 1 shows several of the household's options in this model to highlight the ambiguous relationship between land use and poverty. I denote land in forest with the letter F and cleared abandoned land with a blank cell. The letters A and B denote cultivated land using one of the possible techniques.

Given the structure imposed upon the production cost parameters, option 1 is clearly the least costly strategy in period 1. Absent the ability to borrow, households with the lowest wealth will have no choice but to pursue this strategy. As wealth increases, whether option 2 or option 3 is preferable depends on parameter values; option 4 is the choice that requires the largest investment up-front. When option 4 is chosen the most output is generated, but if environmental externalities were considered, this might not be the socially preferred outcome.

Now consider a policy that increases initial effective wealth holdings for the poorest households, such as a micro-credit program, but not so much that option 4 becomes feasible. If the poverty-deforestation hypothesis holds, then as W increases, households selecting option 1 will switch to selecting option 3; increasing wealth does not increase environmental degradation in period 1. If households selecting option 1 prefer to select option 2 as wealth increases, there is a short-run trade-off between deforestation and income increases that might be achieved through policies such as micro-credit programs. Theoretically, there is no way of determining which outcome is most likely. The decision will depend on the relative yields of A and B, the relative production costs c_A

and c_B, the cost of clearing land, and the interest rate. Household size and labor availability would also affect this decision if the possibility of an imperfect labor market were introduced.

I show in section 3 that in a more complete model of the household at the forest margin the relationship between wealth and land use remains ambiguous. This model supplies testable propositions.

3 Land clearing with borrowing constraints

Consider a household at the forest margin that is a member of a larger local economy of fixed population and that is subject to income shocks.[4] The households in this community hold land at the forest frontier and are the primary agents of deforestation.[5] For simplicity, assume that each household produces agricultural output and is unable to borrow. The labor market is imperfect; the household can hire labor, but dedicates all home labor to producing output and/ or clearing land for future agricultural production. This implies that hired labor comes from outside of the

[4] By fixing the total population, I abstract from migration to the region, often considered a key determinant of deforestation. To the extent that migration increases the sale value of land, the model does not capture these effects because, as explained below, I assume that land sales are not possible in the short-run. Empirically, migration from outside the region to the forest is relatively less important in Peru since the end of the Maoist insurgency in the early 1990s, which created strong incentives for out-migration from the Andean highlands (McClintock [38]). The same is true in the Brazilian Amazon since changes in policy enacted in the 1990s (De Almeida and Campari [16]). Nonetheless, the effects of migration are accounted for implicitly in econometric estimation to the extent that increases in population density affect the rural wage rate and thus the cost of hiring labor (Cropper, Griffiths, and Mani [15]).

[5] Smallholders are the primary agents of deforestation in the Peruvian tropics. Rights to logging exploitation have been granted by the government, but generally to a small domestic forestry sector, and this logging has been extractive, rather than extensive (Sjoholt [55]). This is likely to be largely attributable to the fact that commercial volume (high-value species) are around ten percent of total volume (FAO [22]). Nonetheless, the construction of logging roads has been important in the extension of the economic frontier since 1960. Lands made accessible by the construction of logging roads tend to be rapidly incorporated into agricultural production (Santos-Granero and Barclay [50]).

The settlement of these newly "available" lands is done in almost all cases by small farmers. The Peruvian government has not encouraged large-scale ranchers or agribusiness to locate in the forest as was done in the eastern Brazilian Amazon in the 1970s (Hecht [28]). Indeed, ranching is less important in Peru than in other parts of the tropics in Latin America. The portions of the forest in Peru that are on the slopes of the Andes are not suitable for this activity. Most large plantations are planted in coffee, and most cattle are not raised for sale in markets (Sjoholt [55]).

community, or from a labor pool that does not engage in deforestation itself.[6]

Agricultural output in period t, a_t, is produced according to the production function:

$$a_t = A_t T_t (F_{t-1} + 1)^{\eta_1} L_t^{A\eta_2} + \epsilon_t^a, \tag{1}$$

where A_t is an index that measures total factor productivity, T_t is cleared land, $F_{t-1}$is fertilizer, or other yield-maintaining inputs (the specification captures the fact that this is not an essential input so that $F_{t-1} = 0$ does not imply $a_t = 0$), L_t^A is labor allocated to agriculture, and ϵ_t^a is a random shock with known mean and variance.

As is standard in models of deforestation in Latin America (e.g., Pfaff [45]), I assume that there is no revenue stream associated with holding forested land, and land sales are impossible in the short run.[7] Clearing forested land for agriculture is irreversible and costly. Cleared land is created by the household by dedicating labor to this task in a manner suggested by Southgate [56]. That is:

$$T_t = T_{t-1} + \frac{L_{t-1}^T}{d}, \tag{2}$$

[6] Imperfect markets for wage labor in the Peruvian forest have been documented by Collins [12] and Bedoya Garland [7]. Farmers in the forest region can and do recruit seasonal wage labor in the Andean highlands; in general, the harvest seasons of the forest and the highlands do not coincide (Santos-Granero and Barclay [50]). However, Jacoby [31] provides evidence of imperfect labor markets in the highlands as well.

[7] In practice, land sales are uncommon in this region because they were not legal until 1993 (Hopkins [29]). In addition, because households often lack formal title to their land, forested land is difficult to sell. Instead, households "sell" cropped land with weak title by characterizing the sale as a sale of the planted crops and the associated output, rather than as a sale of the land itself (Santos-Granero and Barclay [50]). In a similar frontier context, Alston, Libecap, and Schneider [3] report that in the forest region of Brazil, "having title is perceived as an advantage by settlers, as it broadens the range of potential purchasers."

where L^T_{t-1} is labor allocated to land clearing, and d is the labor intensity of clearing. By definition $\frac{L^T_{t-1}}{d}$ is the change in the amount of cleared land controlled by the household between periods $t-1$ and t. Since land sales are not possible, $T_{t-1} \leq T_t$.

The following relationship holds for the household's own labor supply:

$$\bar{L}_t^T + \bar{L}_t^A = \bar{L}_t. \tag{3}$$

The sum of the household's labor inputs in clearing, $\bar{L}_t^T$, and production, $\bar{L}_t^A$, equals total household labor available, $\bar{L}_t$.

Denote hired labor, which must be paid a wage w, as l^T_t for clearing and l^A_t for agricultural production. By definition, $L^A_t = \bar{L}_t^A + l^A_t$ and $L^T_t = \bar{L}_t^T + l^T_t$. This completes the labor balance equations. Note that because home labor has no outside value it will not be priced by the household at the wage w.

Just as labor can be hired at a wage w, fertilizer can be purchased by the household at the price p^f and output can be sold at a price p^a, so agricultural profits in any year are:

$$y_t = p^a a_t - p^f F_t - w(l^T_t + l^A_t). \tag{4}$$

Because of the labor market imperfection that the household faces, $\frac{\partial y_t}{\partial \bar{L}_t^T} \leq 0$. Supplying labor to land clearing weakly reduces current profits because hired labor or capital must substitute for home labor if yields are not to decline. For the largest households, per unit of land, this derivative will approach zero, since the marginal product in agriculture of the labor reallocated to clearing is low and may be zero.

This household consumes c_t each period. Since by definition the household cannot borrow, consumption plus expenditure on fertilizer and hired labor cannot exceed cash on hand, x_t, in any period:

$$\begin{aligned} c_t + p^f F_t + w(l_t^T + l_t^A) &\leq x_t \\ c_t &> 0, \text{ for all } t \\ x_t &\geq 0, \text{ for all } t. \end{aligned} \tag{5}$$

Cash on hand evolves according to the following equation:

$$x_{t+1} = R(x_t - c_t) + y_{t+1}, \tag{6}$$

where R is a gross rate of interest and y_{t+1} is agricultural profits, as defined above.

The household chooses its productive inputs, F_t and L_t^A, to maximize the expected discounted value of its consumption stream. That is, given a subjective discount factor β and an expectations operator E_t the household's problem is to find the value function v that solves:

$$\max_{\{L_{t-1}^A, F_{t-1}\}_{t=0}^{T-t}} E_{t-1} \sum_{k=0}^{T-t} \beta^k u(c_{t+k}) \tag{7}$$

$$\text{subject to } c_t \in [0, x_t],\ x_t \geq 0,\ x_{t+1} = R(x_t - c_t) + y_{t+1} \text{ for all } t;\ x_0 \text{ given,}$$

taking into account the previously specified production function and labor balance equations.

As shown by Morduch [39], it is possible to work backwards and examine the consumption decision that is predicated on optimal production choices to understand the solution to this problem. That is, think of the household as finding the value function V_t such that:

$$\begin{aligned} V_t(x_t) &= \max_{\{c_t\}} [u(c_t) + \beta E_t V_{t+1}(R(x_t - c_t) + y_{t+1} + \lambda_t(x_t - c_t - p^f F_t - w(l_t^T + l_t^A)))], \\ \text{s. t. } c_t &\in [0, x_t],\ x_t \geq 0,\ x_{t+1} = R(x_t - c_t) + y_{t+1} \text{ for all } t;\ x_0 \text{ given.} \end{aligned} \tag{8}$$

Here, the household chooses consumption, given optimal production choices. The problem is again solved taking into account the previously specified production function and labor balance equations, where λ_t is the Lagrange multiplier on the borrowing constraint.

Standard techniques can be used to solve for the household's optimal consumption path. The optimal consumption level in period t, c_t^*, must satisfy the following first-order conditions for an interior optimum:

$$
\begin{aligned}
u'(c_t) &= \beta R E_t V'_{t+1}(x_{t+1}) + \lambda_t \qquad (9)\\
(x_t - c_t) &\geq 0 \text{ if } \lambda_t = 0\\
(x_t - c_t) &= 0 \text{ if } \lambda_t > 0,
\end{aligned}
$$

in which the marginal utility of consuming current output is set equal to the marginal utility of allocating it to capital and enjoying augmented consumption next period. In the case in which borrowing constraints do bind, $\lambda_t > 0$, because households are constrained from borrowing more, but not from saving more.

By the envelope theorem, lifetime utility (as defined in equation 8) is maximized when, at the optimal level of consumption, the marginal value of current inputs equals the marginal utility of dedicating the input to production and allocating its (in this case negative) return to consumption. This implies that:

$$
E_{t-1}\frac{\partial V_t(x_t(c_t^*))}{\partial \bar{L}^{T}_{t-1}} = E_{t-1}\frac{\partial y_t}{\partial \bar{L}^{T}_{t-1}} u'(c_t^*) = 0, \qquad (10)
$$

where $E_{t-1}\frac{\partial V_t(x_t(c_t^*))}{\partial \bar{L}^{T}_{t-1}} = 0$ at the optimum, or else the household would have reallocated its labor supply. I can combine the first-order condition and this condition to identify the optimal consumption path.

By combining equations 9 and 10, at the optimum:

$$E_{t-1}[\beta R(\frac{\partial y_t}{\partial \underline{L}^T_{t-1}} V'_{t+1}(x_{t+1}))] = -E_{t-1}[\frac{\partial y_t}{\partial \underline{L}^T_{t-1}} \lambda_t], \tag{11}$$

where the land clearing decision enters implicitly through $\frac{\partial y_t}{\partial \underline{L}^T_{t-1}}$. The optimal labor allocation decisions will be made taking into account expected borrowing constraints and lifetime utility (a similar result has been shown by Morduch [39], and Zeldes [71]).

Just as predicted by the poverty-deforestation hypothesis, limitations on consumption-smoothing, and thus poverty, matter when explaining the land-clearing decision. The right-hand side of this equation is equal to zero when borrowing constraints do not bind and $\lambda_t = 0$. However, the key result is that neither the right-hand side nor the left-hand side of this equation can be signed because there is no a priori means of determining the sign of $\frac{\partial y_t}{\partial \underline{L}^T_{t-1}}$ either on average (in the case of the right-hand side), or when $\lambda_t > 0$ (in the case of the left-hand side). The sign of this derivative cannot be determined because there are at least two off-setting effects. When additional labor is allocated to clearing in period $t-1$, income in that period (weakly) declines and fewer resources are available for fertilizer purchases. However, additional land is available for cultivation in period t, increasing agricultural output.

Because the sign of $\frac{\partial y_t}{\partial \underline{L}^T_{t-1}}$ cannot be determined, it must be the case that if this equation were rearranged so that $\frac{L_t^T}{d}$ (the increase in cleared land between periods t and $t+1$) were on the left-hand side, the predicted relationship between income at time t and the land-clearing decision would be ambiguous. The relationship depends on the relative magnitude of $\frac{\partial y_t}{\partial \underline{L}^T_t} \leq 0$, $\frac{\partial a_{t+1}}{\partial T_t + 1} \geq 0$, and $\frac{\partial F_t}{\partial y_t}$, (which may be positive or negative). Whether the benefits of clearing outweigh the (labor) costs of clearing and the benefits of intensification depends on whether a household, given its expected borrowing constraints, receives the greatest benefit at the margin from increasing land under cultivation or increasing yields on currently cleared land by purchasing fertilizer. However, $\frac{\partial y_t}{\partial \bar{L}_t^T}$ will approach zero as the size of the household's own labor supply $(\bar{L}_t)$ grows large relative to total land holdings. This suggests that for larger households, per unit of land, the positive effect of $\frac{\partial a_{t+1}}{\partial T_{t+1}}$ is more likely to dominate.

This model yields the following testable propositions:

Proposition 1 *The predicted relationship between income and the land-clearing decision is theoretically ambiguous and must be determined empirically.*

Proposition 2 *If imperfect labor markets exist, households with more labor per unit of land will be more likely to respond to increases in income by clearing land.*

3.1 Other considerations

This model does not consider explicitly the dynamics of tenure security that may affect land use in the tropics. In practice, at the margin of tropical forests, households have differing degrees of tenure security, and within a single household tenure security may differ across plots. Under such a regime land clearing may be partially a title establishment strategy (Angelsen [4]). In this model, I neglect such strategic considerations, assuming that households gain no benefits from forested land, and clear land as desired at a contiguous frontier as part of a dynamic utility maximization calculation. For purposes of empirical estimation however, I can imperfectly account for households' property rights status.

In Peru, formal title may be held for uncleared land. Households may apply for title to land at the frontier, and indeed such title is contingent upon the land being "in use" (Republic of

Peru [48], Legislative Decree numbers 667 and 838). However, when title is awarded it is given not only for currently cultivated land, but also for a larger plot that generally includes forested land (Republic of Peru, Legislative Decree numbers 667 and 838). Once this formal title has been given, the "clearing as title establishment" strategy may be less salient. Lacking detailed plot-level information on tenure security, it is impossible to control for these considerations in a precise fashion, but I can use a dummy variable in econometric estimation for whether farmers have full title to their land. I can also control for the prevalence of title in a household's region and the size of households' total forested and cleared land claims as crude measures of expectations regarding future titling prospects.

Titling policy in Peru makes it difficult to predict the relationship in the data between the imperfect measure of titling status and land clearing. Households with full title to all land may currently clear less because they have previously employed the clearing as title establishment strategy. On the other hand, receiving title may induce households to expand the scale of agricultural production, prompting clearing.

4 Data and empirical implementation

4.1 Data

The data used in this analysis are from the World Bank Living Standard Measurement Survey (LSMS) performed in Peru in 1994, with additional rounds performed by Cuanto SA and UNICEF in 1996 and 1997. While these surveys contain national data, only the households living in the forest region, henceforth "the Selva," will be considered here. In Peru, the Selva can be disaggregated into the Selva Alta (the High Forest), high-altitude sub-tropical forest along the eastern slopes of the Andes, and the Selva Baja (the Low Forest), humid tropical forest in the Amazon Basin. This sample contains households in both ecological zones. Within each year the survey data for the Selva are stratified by rural and urban samples and clustered. Between years, a pooled cross-section of households practicing agriculture in at least two survey years can be identified, as can a panel of households responding to the survey in all three years.[8]

Table 2 shows that the households in the panel of households are poor relative to the average income per capita in Peru of about $1,500 (World Bank [69]), with incomes of around $700 per capita. Non-labor and non-farm income make up about one-half of total income, suggesting that household incomes may be vulnerable to shocks in agriculture such as weather or pest infestations. Such shocks may be mitigated if households can borrow to smooth consumption, but if borrowing potential depends on households' asset positions,[9] the small asset stocks that most households hold suggest that this may be only a limited cushion.[10] Detailed definitions of each variable are in appendix B.

Table 3 shows that the households in this sample practice low-input agriculture, hire little

[8] The LSMS surveys make little attempt to follow households that move between survey periods. This means that the panel of households are mostly those found in the same dwellings over time.

Because of the way the panel is generated, selection bias, on either observable or unobservable characteristics, is a potential concern. Summary statistics for the larger cross section of data are in appendix A. While the hypothesis of equality of means between the cross-section and the panel can be rejected for most variables, tests for systematic differences in either the dependent variables of interest or the independent variables of interest that have been suggested by Alderman et al. [2] show that attrition does not bias the panel data regression results, and the coefficient on income in particular. This is consistent with findings for other household survey data from developing countries.

Most importantly, selection effects in this context depend on whether households are moving into the forest, and clearing more land, or moving out of the forest region. If missing households have moved further into the forest, as seems most likely given the low-input agriculture practiced, these households are clearing more land when they move out of the sample.

[9] This is reasonable in the case of the Peruvian Selva for the period considered here. The government institution that traditionally supplied credit to small farmers in Peru, the Banco Agrario, was dismantled in 1990. For small farmers, even land title is generally not sufficient collateral to access formal credit, and no credit is available for the purchase of land by small farmers (Lastarria-Cornhiel and Barnes [36]).

[10] In an attempt to account for depreciation, the survey requests that households give the current sale value of their assets. This means that even the reported asset stocks given here may be an over-statement if households do a poor job of this estimation exercise.

Table 2: Pooled cross-section: Household summary statistics

Household variables	1994		1996		1997	
	Obs	mean Std. dev	Obs	mean Std. dev	Obs	mean Std. dev
Age of household head	45	47.89 (13.17)	45	50.76 (12.78)	45	52.07 (13.06)
Level of education of household head	45	2.04 (0.82)	45	2.09 (0.79)	45	2.07 (0.81)
Number of members in household	45	5.67 (2.53)	45	5.58 (2.58)	45	5.56 (2.66)
Total adult equivalents in household	45	2.96 (0.77)	45	3.00 (0.83)	45	2.98 (0.90)
Total annual household income	45	3678.13 (3321.12)	45	4051.57 (2456.63)	45	4518.67 (4035.53)
Total annual household consumption	45	2628.32 (1987.42)	45	3468.60 (1736.53)	45	3467.64 (2331.62)
Annual household food consumption	45	1515.94 (938.63)	45	1857.44 (829.06)	45	1070.82 (536.04)
Annual non-labor income	45	931.56 (2044.43)	45	704.72 (1083.91)	45	935.79 (1244.08)
Annual non-farm labor income	45	171.77 (535.56)	45	974.29 (1594.57)	45	1023.08 (1499.59)
Revenue from agriculture (includes autocons.)	45	1756.11 (4753.59)	43	2077.27 (3879.80)	44	1572.26 (3471.88)
Value of durables (includes land)	42	2157.31 (3002.26)	44	1848.84 (2127.41)	45	1656.44 (2811.70)
Value of consumer durables (excludes land)	42	537.62 (1111.33)	44	339.88 (543.79)	45	245.40 (421.35)

Monetary values in 1994 dollars at Lima prices; exchange rate and inflation information in appendix B.

outside labor, and consume much of their agricultural production. The fraction of total imputed profits that comes from actual sales in markets is about one-half.[11] About one quarter of all households report using inputs such as fertilizer or pesticide, and each year about one half of households hire outside labor. Such inputs often need to be financed prior to a harvest, which may be difficult for households with a limited ability to borrow. This is consistent with the story that underlies the poverty-deforestation hypothesis.

The relatively low incidence of capital input use is likely to have implications for land use. Without regular fertilizer use in this region, yields of annual crops decline by as much as 75 percent over a period of 3 to 7 years (Jordan [32]) and permanent crops can be grown on a plot for perhaps 20 years (Collins [12]).[12]

Tracking land use in this sample is complicated by the fact that this data set follows households rather than plots of land. In addition, tenure security varies among plots claimed by a given

[11] Lacking data on prices, I calculate agricultural profits using "unit values," reported revenues per unit of output. The LSMS surveys ask households to report the total revenue received from the sale of each crop and the revenue that would have been received if the rest of the crop had been sold in the market. Profits can be estimated as total reported revenues from all uses of all crops less total reported agricultural input expenses, though this is likely to be an overestimate if households fail to report transportation costs or the shadow wage cost of household labor. As Deaton [17] points out, unit values differ from prices because they contain information about product quality. A test to determine whether the signal-to-noise ratio in unit value data is sufficient to gain information from this variable is regressing unit values for key crops against a set of regional dummies (prices should be equal within regions). The higher the R-squared in this regression, the more confident the analyst can be that unit values contain price information. Running these regressions for the most popular crops, including maize, yucca, banana, and coffee I find R-squareds in the range of 5 to 25 percent.

I also investigated whether the unit values contained information about prices by comparing published national agricultural price data (INEI [30]) with the LSMS unit revenues. With the exception of coca, the numbers and time trends are similar.

[12] Without the use of such inputs, yield declines can be forestalled by the use of fallow techniques, but in this sample relatively little use is made of fallow periods to replenish soil productivity. The cultivation intensity of the farming systems can be measured by calculating the ratio of cultivated land to cultivated and fallow land. In this sample, this ratio is fairly high, as many households report holding no fallow land at all. Boserup [9] suggests that such a ratio should approach one as farming systems become more intensive, but the low level of input-use and the relative abundance of land at the forest frontier makes this unlikely in this sample. A more likely explanation, implicitly suggested by the poverty-deforestation hypothesis, is that households cannot afford to take land out of cultivation and thus soils are depleted and eventually abandoned as productivity declines, resulting in little fallow land in households' portfolios at any point in time (Santos-Granero and Barclay [50]). Because soils are shallow in tropical forest regions, continuous land coverage may also be important as a means of avoiding soil erosion so even very unproductive land is planted in some crop (Upton [65]) and thus reported as cultivated.

Table 3: Pooled cross-section: Land-use variables summary statistics

Land-use variables	1994		1996		1997	
	Obs	mean Std. dev	Obs	mean Std. dev	Obs	mean Std. dev
Total land claim (hectares)	45	5.29 (8.83)	45	6.97 (13.32)	45	4.74 (6.72)
Total cleared land claim (hectares)	45	2.57 (3.31)	45	2.56 (2.87)	45	2.25 (2.78)
Hectares of land claim under cultivation	45	1.79 (1.82)	45	2.05 (2.12)	45	1.72 (1.96)
Change in cleared land claim (hectares)			45	−0.01 (4.16)	45	−0.30 (3.49)
Agricultural profits per ha. land	40	1728.65 (3943.15)	29	998.14 (870.50)	28	2932.30 (10885.07)
Fraction of profits from sales to market	45	0.44 (0.38)	43	0.45 (0.32)	44	0.38 (0.39)
Cultivation intensity index	45	0.81 (0.35)	43	0.82 (0.36)	43	0.72 (0.42)
Expend. on pesticide per ha. of land	40	3.30 (12.30)	29	7.92 (16.69)	29	3.86 (11.29)
Expend. on fertilizer per ha. of land	40	11.36 (25.44)	29	15.14 (29.10)	29	11.77 (35.28)
Expend. on hired labor per ha. of land	40	21.84 (57.36)	29	77.74 (127.52)	29	42.43 (63.01)
Fraction households using pesticide	45	0.13	34	0.26	38	0.26
Fraction households using fertilizer	45	0.27	34	0.26	38	0.18
Fraction households hiring labor	45	0.29	34	0.56	38	0.47
Fraction households with land title	45	0.51	45	0.69	45	0.69
Fraction households living in High Forest	45	0.49	45	0.49	45	0.49
Fraction households living in rural area	45	0.67	45	0.67	45	0.67

Monetary values in 1994 dollars at Lima prices; exchange rate and inflation information in appendix B.

household, but this mixed form of proprietorship cannot be further disaggregated in the data to parcels of land in different uses. This means that when a household's total reported land claim changes over time, it is not possible to determine whether this is a result of land sales and rental, land abandonment, or simply a change in what the household considers its "claim." Households are more likely to change their perceived claim to forested land than to cleared land since maintaining property rights to cleared land is easier than maintaining property rights to forested land. Thus, forested land claims and total land claims are measured with greater error than cleared land claims. This is not a negligible problem, since only around 50 percent of the households in the survey have full title to their land, though this fraction increases over time within the panel households.

Because it is difficult to interpret the households' reported total land claim, for empirical analysis I focus on changes in the cleared land controlled by a household. Cleared land includes land used for cultivation, fallow, animal pasture and other uses. Over time, households both increase and decrease their holdings of cleared land in this sample. If land sales do not occur, as I have argued is likely, increases in cleared land holdings are as a result of deforestation. Decreases in cleared land holdings may be a result of renting out land or abandonment, as well as, in theory, land sales.

4.2 Specification of a testable equation

This model presented in section 3 suggests that a reduced-form equation can be estimated of the form:

$$\Delta T^{ij}_{t-1,t} = \phi^{ij} + \varphi^{j} + \psi_t + \beta_1 y^{ij}_{t-1} + \beta_2 y^{ij2}_{t-1} + \beta_3 H^{ij}_{t-1} + u^{ij}_t . \tag{12}$$

In this specification, $\Delta T^{ij}_{t-1,t}$ is the change in cleared land claimed between periods $t-1$ and t for each household i in district j, y^{ij}_{t-1} is the household's income, and H^{i}_{t-1} is vector of control variables. u^{ij}_{t} is a, not necessarily homoskedastic, error term. The variables φ^{j}, ψ_{t}, and ϕ^{ij} are district, time, and household fixed effects, respectively. As previously discussed, the sign of the coefficient on income can not be theoretically determined.

The control variables in H^{i}_{t-1} include the household's asset holdings and its location (whether it is rural or urban, and whether it is located in the Selva Alta). I also control for the household's titling status, total land claim, and, to account for potential scale effects in agricultural production and labor supply constraints, the number of adult equivalents in the household. Controlling for the age of the household head is intended to provide, imperfectly, a measure of the age of the cultivated land. When estimated with household fixed effects, several of the control variables are sufficiently time invariant that they are removed from the right-hand side of the estimated equation. I also control for the district average profitability of agriculture. This may be important because households learn about the profitability of agriculture over time; they may gather additional information about the parameters determining their own production when their outcomes differ from the outcomes of their neighbors (Foster and Rosenzweig [24]).

The functional form of equation 12 does not reflect the fact that there is a limit on how much land a household may clear and how much land a household may claim. At the very least, each household is constrained by the total area of the forest region of Peru. This constraint is accounted for by district fixed effects, which would control for the total available forest in a household's local region in any period. However, the form of the equation does not explicitly constrain land holdings from falling below zero. This could be accomplished by making the dependent variable the percentage of a household's land claim covered in forest, but this is potentially problematic because the phenomenon of interest is land clearing, not farm size. If a household increases its claims to both forested and cleared land over time the ratio of cleared land to total land holdings might not increase, even if the household is engaging in deforestation. On the other hand, a household that withdraws a claim to forested land might show an increase in the percentage of its holding that is cleared, even if it did not clear land. As part of the series of robustness checks in section 5, I present evidence that the relationship between income and land clearing identified using equation 12 is not driven by the fact that the dependent variable is measured as a level, rather than as a ratio of total land holdings.

The use of household fixed effects is critical to avoid a spurious correlation between household income and land clearing that arises from unobserved household "ability." That is, suppose that the most entrepreneurial households have the highest incomes, but are also most likely to bring additional land under cultivation. Lacking a variable for "entrepreneurial tendencies" I may estimate an equation in which high income misleadingly appears to be correlated with land clearing. A similar concern exists for time-invariant measures of land quality like slope that are likely to be correlated with income and included in the error term. Controlling for household fixed effects alleviates this source of bias.[13]

Household fixed effects also account for households' time-invariant productivity. I expect households with higher average agricultural productivity to clear more land over time. Whether they are high-ability farmers, or holders of high-quality land, the most productive farmers should bring

[13] Precisely because the concern is correlation between unobserved variables and included independent variables, a random effects specification is inappropriate. That specification requires the assumption that household-specific effects are randomly distributed across households.

more land under cultivation, controlling for land quality, and subject to their ability to finance additional agricultural input purchases and the (primarily labor) cost of land conversion.[14] Since household fixed effects capture the household's productivity, the profitability of agriculture is fully accounted for in this specification. District fixed effects capture levels of prices, and technologies that are common to the household's local area, and time fixed effects account for changes in prices, weather, and other shocks that are common to the district. This means that equation 12 is properly estimated without a measure of lagged household profits.

The fact that, over time, households both increase and decrease their holdings of cleared land in this sample has implications for econometric estimation; using a variable of the form "change in cleared land holdings" that has been transformed by taking logs excludes those households that reduce their cleared land claims or do not change their claim. To account for this concern, I present econometric estimation results using variables in levels, as well as logs. While an estimation of equation 12 in levels imposes the assumption of an additive relationship among the right-hand side variables, a sample reduced to only those households that clear land may be subject to important biases.

Equation 12 reflects a potentially endogenous relationship between agricultural profits, and thus household income, and land clearing. Not only might more profitable farmers choose to clear addi-

[14]This conclusion is tempered by two considerations. First, because clearing land is an irreversible investment and agricultural income is uncertain, there is an option value to the possibility of delaying clearing (Pindyck [46], Dixit and Pindyck [19]). A history of higher profitability should ultimately prompt successful farmers to bring additional land under cultivation, but it may not be optimal to do so in the first period that clearing is possible (Schatzki [52]). The most successful farmers may optimally hold some forest at any given time because of option value considerations. Second, yields may decline relatively rapidly over time if farmers practice low-input agriculture on fragile soils. If land can be profitably farmed for only a relatively short period but claims to forested land can be successfully made, it may be optimal to hold some forested parcels in abeyance while information about the path of profits is gathered. Taken together, asset portfolio choice considerations and option value calculations suggest the hypothesis that, for a given level of risk aversion, high profitability in period $(t-1)$ (and previous periods), particularly relative to neighbors that experience the same weather shocks (Foster and Rosenzweig [24]), should be correlated with land clearing between periods $(t-1)$ and (t), not necessarily that the most profitable farmers should hold no forest at all.

tional land, but households that choose to clear land may sacrifice current land holdings, and thus income, to do so. If this phenomenon exists, in the data this would result in a negative correlation between income and land-clearing, as predicted by the poverty-deforestation hypothesis.[15] Thus, endogeneity concerns would bias results in favor of the poverty-deforestation hypothesis.

To a limited extent, I can address this endogeneity problem by using information about the households' profits and income at period $t-2$ as well as period $t-1$. These lagged values can be used as instruments, though data limitations mean that this estimation can be performed for only the small panel of households that appear in the survey in all three years, without household fixed effects.

Instrumental variables techniques may be more important as a means of addressing measurement error in the income variables. Schady [51] has previously shown that income is badly measured, and underestimated, in the LSMS surveys in Peru. This measurement error leads to attenuation bias that is exacerbated when household fixed effects are included. In these surveys, consumption is better measured than income, and is strongly colinear with it. To address measurement error concerns, I present results using instrumental variables techniques where income is instrumented using consumption expenditures.

As an additional test of the poverty-deforestation hypothesis, I can investigate not only whether income is correlated with land clearing, but whether income is correlated with increases in capital input use. An equation similar to 12 can be estimated in which the dependent variable is a measure

[15] Clearing may not "pull" labor from cultivation in a climatic zone such as the Peruvian Selva where there is no seasonality effect analogous to the Indian monsoon and where many of the staple crops can be planted and harvested several times throughout the calender year (United Nations Conference on Environment and Development [64]). In practice there is a delay between clearing and planting because households must wait for the felled material (the "slash") to dry before it can be burned, but clearing and planting can still be done within the same year (Collins [12]).

of capital inputs expenditure in period t. The equation to be estimated is:

$$k_t^{ij} = \phi^{ij} + \varphi^j + \psi_t + b_1 y_{t-1}^{ij} + b_2 y_{t-1}^{ij2} + b_3 H_{t-1}^{ij} + e_t^{ij}, \tag{13}$$

in which k_t^{ij} is defined as expenditure on yield-enhancing or -maintaining capital inputs, per hectare of cleared land, in period t. e_t^{ij} is a, not necessarily homoskedastic, error term. In this case, endogeneity concerns are less important; there is no trade-off between current profits and expenditure decisions in the next period. Estimations results for this equation are also presented in the next section.

5 Results

5.1 Initial results

Table 4 presents the results of the estimation of equation 12 using OLS. I present results both with and without household fixed effects for both the pooled cross-section and balanced panel.[16] Using household fixed effects, identification relies on the observations in all three years of the survey.

Putting aside measurement error concerns for the moment, consider the coefficient estimates in the regressions presented in table 4. In the regressions without household fixed effects, there is no statistically significant relationship between income and land clearing. This may be partially a result of ability bias; when household fixed effects are included higher income in period $t-1$ is correlated with land clearing between periods $t-1$ and t, while the square of total income is

[16] Using total cleared land holdings in period t as the dependent variable in these regressions results in coefficient estimates of the same signs as those presented here.

Table 4: The land-clearing decision I: Variables measured in levels

Ordinary least squares estimates (1994-1997)			
Independent variables	Dependent variable: Δ cleared land$_{t-1,t}$		
District ave. profits per ha$_{t-1}$	-0.0001 (0.0002)	0.0001 (0.0001)	0.0002* (0.0001)
Size household claimed land holding$_{t-1}$	-0.1890** (0.0489)	-0.2193** (0.0606)	-0.3059** (0.0680)
Household total income$_{t-1}$	0.0003 (0.0002)	0.0004 (0.0003)	0.0005** (0.0002)
Household total income squared$^{(a)}_{t-1}$	-0.0001 (0.0001)	-0.0002* (0.0001)	-0.0002** (0.0001)
Value of household durable assets$_{t-1}$	-0.0003 (0.0003)	-0.0007 (0.0005)	-0.0017** (0.0004)
Age of household head$_{t-1}$	-0.0080 (0.0299)	0.0320 (0.0332)	
Adult equivalents$_{t-1}$	-0.4886 (0.3168)	0.8016** (0.3295)	
Household is in High Forest	0.3947 (0.6289)	3.0789 (3.3518)	
Household is rural$_{t-1}$	0.6965 (2.9230)	2.9369 (3.3913)	-2.7529** (1.1941)
Household has full title to land$_{t-1}$	-0.8331 (0.6043)	-0.4812 (0.8535)	0.5666 (1.0420)
Fraction farms in district with full title$_{t-1}$	0.4960 (2.2892)	2.5351 (3.1013)	5.4443* (2.7480)
Constant	1.9096 (3.0731)	-6.7214* (3.6152)	
Household fixed effects?	NO	NO	YES
R-squared	0.28	0.43	0.79
Regression degrees of freedom	19	12	8
Strata	2	2	2
Clusters	31	15	15
Groups		42	42
Observations	197	84	84

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

[a]For this variable, this coefficient and standard error are multiplied by 10,000.

negatively correlated with land clearing, implying that the relationship between income and land clearing is non-monotonic. Note that the coefficient on income-squared is much smaller than the coefficient on income. This is not the relationship predicted by the strong version of the poverty-deforestation hypothesis.

The variable that is intended to control for potential scale effects and labor supply constraints, the number of adult equivalents in the household, is not consistently significant in these regressions. This may be a result of the fact that households can hire labor, and thus the family's size is irrelevant to the land-use decision, or an indication that the important constraint is the ratio of family labor to the current land claim. In the next subsection, I investigate further whether households in this sample face a labor supply constraint that impacts their land-clearing decision and show that household members per unit of cleared land is positively and significantly correlated with land clearing.

The coefficient on the variable that measures the household's lagged asset holdings is negative in these regressions, and significant when household fixed effects are included. Households with large asset holdings may be relatively less credit-constrained than households with equally high incomes in any period but fewer assets. The negative sign of the coefficient on asset holdings may indicate that households that can borrow, to finance capital inputs in agriculture for example, choose to clear less land than households that are relatively more constrained. In subsection 5.5 I investigate this contention directly by including on the right-hand side of this regression a measure of the household's borrowing constraint developed by Morduch [39].

Other control variables are mostly insignificant in the regressions excluding household fixed effects. When household fixed effects are included, households with larger land holdings clear less land, households in districts with higher profits and more prevalent title clear more land, and households that move to rural areas clear less land. These results are intuitive; households with less land and who live in regions where agriculture is profitable and likely to result in title are more likely to clear. Households that move to rural areas need do less clearing; most clearing was done to establish a hold on agricultural land while the household was in an urban location. This phenomenon has been documented in the Peruvian Selva by Collins [12].

5.2 Addressing measurement error and endogeneity concerns

While the regressions presented in table 4 suggest that, in this sample, there is evidence against the strong version of the poverty-deforestation hypothesis, the robustness of these results must be tested. I begin this process by addressing measurement error concerns. Table 5 presents regressions that address the attenuation bias introduced by the fact that income is poorly measured by instrumenting for income using consumption. The results of this regression are more favorable to the poverty-deforestation hypothesis than those presented in table 4. While income is positively correlated with land clearing and the coefficient on income-squared has a negative sign, these coefficient estimates are not statistically significant.[17] Nonetheless, the conclusion that these regression results do not support the strong version of the poverty-deforestation hypothesis remains intact. The signs of the coefficients on all other variables remain unchanged from those in table 4.

In table 6 I again use instrumental variables techniques, but here my concern is the potentially endogenous relationship between income and land clearing. Here, the value of income at time $t-1$ is instrumented using its value at period $t-2$. This restricts the sample to those households in all

[17] A Hausman test suggests that the differences in the coefficients between the OLS and IV models are not systematic and that the hypothesis that OLS is less efficient than IV cannot be accepted at conventional levels of significance. Very similar results are found if the instrument is food consumption alone as opposed to total expenditures.

Table 5: The land-clearing decision I: IV estimates

Instrumental variables estimates (1994-1997)	
Independent variables	Dependent variable: Δ cleared land$_{t-1,t}$
District ave. profits per ha.$_{t-1}$	0.0002 (0.0001)
Size household claimed land holding$_{t-1}$	-0.3096^{**} (0.0604)
Household total income$^{+}_{t-1}$	0.0004 (0.0006)
Household total income squared$^{+(a)}_{t-1}$	-0.0001 (0.0001)
Value of household durable assets$_{t-1}$	-0.0017^{*} (0.0001)
Household is rural$_{t-1}$	-1.2523 (2.5399)
Household has full title to land$_{t-1}$	0.5449 (1.1607)
Fraction farms in district with full title$_{t-1}$	5.0634^{*} (2.9709)
Household fixed effects?	YES
R-squared	0.78
Regression degrees of freedom	8
Strata	2
Clusters	15
Groups	42
Observations	84

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

[a]For this variable, this coefficient and standard error are multiplied by 10,000.

[+]This variable instrumented using consumption expenditure to identify first-stage regression.

three years of the panel, but does not allow for the use of household fixed effects.

In this restricted sample, the coefficients on income are statistically insignificant though the point estimates are similar to those found earlier. These results might be consistent with the weak version of the poverty deforestation hypothesis, but since these results are subject to unobserved ability bias this is a relatively weak test.

Multiplicative or additive relationships?

To investigate whether the relationships shown in table 4 are driven by the fact that the variables are measured in levels, and thus that I have imposed the assumption of an additive, rather than multiplicative, relationship among the variables, I transform the data by taking logs. Table 7 presents the same basic regressions, using the transformed data.

In these regressions, the coefficient on income is positive in each regression, though significant only when income is instrumented for using consumption expenditures, indicating potential attenuation bias in the OLS estimates. The signs on most other variables are unchanged from the results found when the variables are measured in levels. This is additional evidence against the strong version of the poverty deforestation hypothesis, but not evidence against the weak version. These results are also evidence that the assumption of a constant-elasticity relationship between income and land-clearing is unwarranted. In section 5.4 I present a statistical test in favor of this finding.

Since the logarithmic results are consistent with the basic results, the remainder of the paper focuses on regressions where the variables are measured in levels. As discussed in section 5.4, the insignificant coefficient on the income variable in the OLS regression is likely a result of an incomplete characterization of the labor supply constraint that households face, rather than the selection bias that is introduced by taking logs.

Table 6: The land-clearing decision I: Balanced panel

Ordinary least squares and insturmental variables estimates (1994-1997)	
Independent variables	Dependent variable: Δ cleared land$_{t-1,t}$
	IV
District ave. profits per ha.$_{t-1}$	-0.0008 (0.0005)
Size household claimed land holding$_{t-1}$	-0.2402^{**} (0.0405)
Household total income$^{+}_{t-1}$	0.0012 (0.0020)
Household total income squared$^{+(a)}_{t-1}$	-0.0008 (0.0011)
Value of household durable assets$_{t-1}$	0.0010 (0.0011)
Age of household head$_{t-1}$	0.1469 (0.1529)
Adult equivalents$_{t-1}$	1.6403 (0.1.0733)
Household is in High Forest	-0.3646 (3.1949)
Household is rural$_{t-1}$	1.2854 (3.4568)
Household has full title to land$_{t-1}$	1.9695 (2.3808)
Constant	-13.1271 (16.5920)
Household fixed effects?	NO
R-squared	0.11
Regression degrees of freedom	13
Strata	2
Clusters	15
Observations	44

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. Regression includes time and district fixed effects.

**significant at 5% level; * at 10% level.

[a]For this variable, this coefficient and standard error are multiplied by 10,000.

[+]This variable instrumented using values of income at period $t-2$ to identify first-stage regression.

Table 7: The land-clearing decision I: Variables measured in logs

Log-linear estimates (1994-1997)			
Independent variables	Dependent variable: Δ log cleared land$_{t-1,t}$		
	OLS	OLS	IV
Log district ave. profits per ha.$_{t-1}$	−0.236 (0.338)	0.054 (0.359)	0.047 (0.373)
Log size household claimed land holding$_{t-1}$	0.097 (0.133)	−1.451** (0.277)	−1.478** (0.284)
Log household total income$^{+}_{t-1}$	0.130 (0.169)	0.413 (0.359)	0.659* (0.373)
Log value of household durable assets$_{t-1}$	−0.061 (0.086)	−0.316* (0.151)	−0.354* (0.157)
Log age of household head$_{t-1}$	0.840 (0.555)		
Log adult equivalents$_{t-1}$	0.046 (0.385)		
Household is in High Forest	0.266 (1.392)		
Household is rural$_{t-1}$	−0.020 (0.584)	4.625** (1.052)	2.766** (0.4819)
Household full title to land$_{t-1}$	−0.391* (0.222)	0.142 (0.294)	0.159 (0.299)
Fraction farms in district with full title$_{t-1}$	−0.789 (1.473)	1.738 (1.374)	1.884 (1.387)
Constant	−4.673 (4.178)		
Household fixed effects?	NO	YES	YES
R-squared	0.15	0.87	0.87
Regression degrees of freedom	16	7	7
Strata	2	2	2
Clusters	25	13	13
Groups		32	32
Observations	142	64	64

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

+In IV regression this variable instrumented using consumption expenditure to identify first-stage regression.

5.3 The use of purchased inputs

The results in the previous subsection are evidence in favor of the contention that increases in incomes are not correlated with decreased land clearing in the Selva of Peru. While this is not predicted by the poverty-deforestation hypothesis, this hypothesis cannot be rejected without investigating the correlation between the use of inputs that increase yields on previously cleared land and income. If analysis shows that high incomes are correlated with both additional input use and land clearing, this would be consistent with a weak version of the poverty-deforestation hypothesis. On the other hand, evidence that high incomes are uncorrelated with the purchase of yield-increasing or yield-maintaining inputs would be further evidence against the hypothesis.

In tables 8, 9, and 10 I present results from regressions that are similar to those presented in the previous subsection. In this case however, the dependent variable is no longer land clearing, but expenditure on purchased inputs, fertilizer, pesticide, and hired labor respectively, per hectare of cleared land. The results of these regressions suggest that income is not positively correlated with the additional use of capital inputs that increase yields; this is evidence against the weak version of the poverty-deforestation hypothesis.[18] Regression results using district fixed effects for the panel are similar to those for the pooled cross-section and are not shown.

Consider the case of fertilizer expenditures first. As shown in table 8, for this capital input, which is important for maintaining yields over time, the coefficients on the income variables in the household fixed effects regression are the opposite of those observed in the case of land clearing. In this case income is negatively correlated with expenditure on fertilizer, while the square of income

[18] The finding that the coefficient on income in the land-use regression is larger than the coefficient in the input-use regressions can be tested further using seemingly unrelated regression techniques. When a seemingly unrelated regression is performed, the conclusion that there is evidence against both the strong and weak versions of the poverty-deforestation hypothesis remains intact.

Table 8: The fertilizer-use decision: Variables measured in levels

Ordinary least squares estimates (1994-1997)		
Independent variables	Dependent variable (expenditure per unit of cleared land$_t$)	
	fertilizer$_t$	fertilizer$_t$
District ave. profits per ha.$_{t-1}$	-0.0473 (0.0306)	0.0009 (0.0013)
Size household claimed land holding$_{t-1}$	-4.8743 (4.1426)	0.8969 (0.8376)
Household total income$_{t-1}$	-0.0066 (0.0163)	-0.0042** (0.0017)
Household total income squared$_{t-1}^{(a)}$	-0.0016 (0.0050)	0.0014** (0.0006)
Value of household durable assets$_{t-1}$	0.0333 (0.0255)	0.0053 (0.0024)
Age of household head$_{t-1}$	3.5928 (5.3465)	
Adult equivalents$_{t-1}$	73.6584 (48.7564)	
Household is in High Forest	265.551 (335.444)	
Household is rural$_{t-1}$	306.801 (278.317)	
Household has full title to all land$_{t-1}$	-60.8005 (141.0161)	-52.4291* (28.3954)
Fraction farms in district with full title$_{t-1}$	367.173 (558.375)	-33.2884 (42.2862)
Constant	-459.369 (364.589)	
Household fixed effects?	NO	YES
R-squared	0.22	0.95
Regression degrees of freedom	18	8
Strata	2	2
Clusters	27	13
Groups		28
Observations	124	56

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

[a]For this variable, this coefficient and standard error are multiplied by 10,000.

is positively correlated with expenditure. This is the opposite of what would be predicted by the poverty-deforestation hypothesis in either its strong or weak versions.

Next, consider pesticide expenditures (table 9). In this case again, there is not a positive correlation between income and the purchase of the capital input. There is however a positive correlation between asset holdings and pesticide expenditures. As previously discussed, households with larger asset stocks are likely to be less credit-constrained than households with fewer assets. This correlation may simply reflect the fact that households using pesticide are more likely to grow permanent tree crops such as coffee or pineapple. These tree crops are an asset that households may factor into their estimates of the value of their total assets, resulting in a correlation between asset holdings and pesticide use. I investigate the role of credit constraints directly in subsection 5.5.

Finally, consider expenditures on hired labor. This regression, in table 10, is more difficult to interpret because hired labor may be used to clear land or to cultivate previously cleared land. Indeed, the point estimates of the coefficients on the income variables take the same sign as the coefficients on income in the land-clearing regressions. However, in this case the coefficients are insignificant when fixed effects are included. The next section examines the labor market in greater detail.

For each of these inputs the coefficient on land title is negative in the household fixed effects regressions. It is significant for both fertilizer and pesticide expenditures. This would be surprising if these capital investments had persistent effects on yields. Lack of property rights is often cited as a deterrent to capital investments. However, these inputs do not have significant long-term effects; as previously discussed, soils in the Selva need regular fertilizer applications to forestall

Table 9: The pesticide-use decision: Variables measured in levels

Ordinary least squares estimates (1994-1997)

Independent variables	Dependent variable (expenditure per unit of cleared land$_t$)	
	pesticide$_t$	pesticide$_t$
District ave. profits per ha.$_{t-1}$	0.0001 (0.0022)	−0.0041** (0.0011)
Size household claimed land holding$_{t-1}$	0.1047 (0.4077)	0.6657** (0.5690)
Household total income$_{t-1}$	−0.0032 (0.0037)	−0.0051* (0.0024)
Household total income squared$^{(a)}_{t-1}$	0.0016 (0.0011)	0.0015 (0.0009)
Value of household durable assets$_{t-1}$	0.0027 (0.0027)	0.0093** (0.0040)
Age of household head$_{t-1}$	−2.4372 (1.6376)	
Adult equivalents$_{t-1}$	1.7508 (7.8957)	
Household is in High Forest	21.7271 (32.1214)	
Household is rural$_{t-1}$	1.3343 (37.3753)	
Household has full title to all land$_{t-1}$	34.9592 (37.5429)	−10.2383* (5.2880)
Fraction farms in district with full title$_{t-1}$	19.6487 (34.5430)	−70.4953 (33.1941)
Constant	114.511* (60.6433)	
Household fixed effects?	NO	YES
R-squared	0.37	0.86
Regression degrees of freedom	18	8
Strata	2	2
Clusters	27	13
Groups		28
Observations	105	56

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

[a]For this variable, this coefficient and standard error are multiplied by 10,000.

Table 10: The hired-labor-use decision: Variables measured in levels

Ordinary least squares estimates (1994-1997)		
Independent variables	Dependent variable (expenditure per unit of cleared land$_t$)	
	labor$_t$	labor$_t$
District ave. profits per ha.$_{t-1}$	-0.1092 (0.0856)	-0.0193^* (0.0098)
Size household claimed land holding$_{t-1}$	-32.4756 (20.6097)	-0.3702 (3.5107)
Household total income$_{t-1}$	0.1218^* (0.0686)	0.0028 (0.0253)
Household total income squared$_{t-1}^{(a)}$	-0.0474^* (0.0250)	-0.0001 (0.0084)
Value of household durable assets$_{t-1}$	0.1637 (0.1248)	-0.0109 (0.0226)
Age of household head$_{t-1}$	12.2832 (8.6291)	
Adult equivalents$_{t-1}$	-39.2890 (82.9680)	
Household is in High Forest	-26.1809 (1245.03)	
Household is rural$_{t-1}$	396.573 (1035.34)	
Household has full title to all land$_{t-1}$	461.571 (373.298)	-150.113 (117.788)
Fraction farms in district with full title$_{t-1}$	2143.37 (2239.69)	177.051 (181.129)
Constant	-997.789 (992.281)	
Household fixed effects?	NO	YES
R-squared	0.42	0.72
Regression degrees of freedom	18	8
Strata	2	2
Clusters	27	13
Groups		28
Observations	124	56

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

[a]For this variable, this coefficient and standard error are multiplied by 10,000.

yield declines, and pesticides must also be annually applied. In the case of hired labor, it is again difficult to interpret this coefficient since we cannot track in the data how this labor is used.

Uncertainty regarding the use of hired labor is indicative of a more general concern. Households may be making investments that maintain yields, such as building terraces, that cannot be seen in the data. If this is the case, I may wrongly reject the weak version of the poverty-deforestation hypothesis, though not the strong version.

5.4 The labor market

In this section I investigate whether labor supply constraints affect the land-clearing decision. I begin by testing for a labor supply constraint, and then provide some evidence that larger households are more likely to use additional income to finance land clearing than smaller households. Additional evidence for this contention is presented in section 5.5.

Including as a variable in the basic regression the number of adult equivalents in a household per hectare of cleared land tests for a labor supply constraint. These results are shown in table 11. The OLS regressions show that households with more members per unit of land are more likely to clear land. This is expected only if households do not have access to a complete labor market. Indeed, households that hire labor are not more likely to clear land than households that do not do so.

Controlling for the household's labor supply constraint does not significantly affect the OLS coefficients on the income terms as compared to the results of the basic regression in the previous section. The coefficient on income is positive and statistically significant. This is additional evidence against the poverty deforestation hypothesis (in its strong version). However, to test the proposition

Table 11: The effect of labor supply constraints: Variables measured in levels

Ordinary least squares estimates (1994-1997)			
Independent variables	Dependent variable: Δ cleared land$_{t-1,t}$		
Adult equivalents per ha. cleared land$_{t-1}$	0.0052** (0.0017)		0.0664* (0.0355)
Dummy for hired labor$_{t-1}$		−0.2233 (0.9759)	0.3644 (0.8487)
District ave. profits per ha.$_{t-1}$	0.0001 (0.0002)	0.0002 (0.0002)	0.0003 (0.0003)
Size household claimed land holding$_{t-1}$	−0.1422 (0.1007)	−0.3385** (0.0377)	−0.1891 (0.1231)
Household total income$_{t-1}$	0.0008** (0.0004)	0.0004* (0.0002)	0.0008** (0.0003)
Household total income squared$^{(a)}_{t-1}$	−0.0003** (0.0001)	−0.0014** (0.0005)	−0.0003** (0.0001)
Value of household durable assets$_{t-1}$	−0.0011* (0.0005)	−0.0017* (0.0003)	−0.0013** (0.0005)
Household is rural$_{t-1}$	1.3142 (1.3552)	−11.6450** (2.2136)	−13.0839 (16.9357)
Household has full title to land$_{t-1}$	1.7141 (1.6087)	0.4269 (1.6091)	2.3600 (1.8796)
Fraction farms in district with full title$_{t-1}$	4.8431 (2.8349)	7.9728 (4.7793)	8.8380 (5.1527)
Household fixed effects?	YES	YES	YES
R-squared	0.82	0.82	0.84
Regression degrees of freedom	9	9	9
Strata	2	2	2
Clusters	14	14	14
Groups	37	37	33
Observations	74	74	66

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

[a]For this variable, this coefficient and standard error are multiplied by 10,000.

that larger households, per unit of land, are more likely to respond to increases in income by clearing land requires that I include a variable that is the interaction between the household's income and its labor supply constraint. These results are shown in table 12. A positive coefficient on this interaction variable would be evidence in favor of this proposition. In the IV regression the coefficient on this variable is positive, but is insignificant. Similar results are obtained when the variables have been transformed by taking logs.

How robust is the finding that the relationship between income and land clearing is non-monotonic when the I account for the household's labor supply constraint?[19] First, this relationship remains if additional controls for lagged fertilizer and hired labor expenditures per hectare are included. It is virtually unchanged if a control for lagged agricultural profits per hectare is included. The relationship also remains intact if attention is restricted only to households' non-farm labor income and non-labor income. That is important because this income is less endogenous than income earned from a household's own farm.

Variability in the household's labor supply constraint in this regression comes almost entirely from changes in cleared land holdings, as opposed to changes in household size, since the time series of data is short. If the household's labor supply constraint is characterized as adult equivalents per hectare of cleared land in 1994 and household fixed effects are excluded, the income coefficients are

[19] A statistical test of the finding that, once the household's labor supply constraint is accounted for, the relationship between income and land clearing is initially positive but declining is a Wald test of the joint hypothesis that the coefficients on income and income squared are both equal to zero. This is because when the regression is run without the income squared term, the estimated coefficient on income is not statistically different from zero. When this test is performed the F statistic is $F(2, 11) = 3.79$. The hypothesis that both coefficients are equal to zero can be rejected at the 6 percent level. A stronger test relies on the point estimate of the coefficient on income when the income squared term is excluded. When the regression is run without the income squared term, the point estimate of the coefficient on income is -0.000064 (t-statistic 1.09). A Wald test of the hypothesis that the coefficient on income equals -0.000064, and the coefficient on income squared is equal to zero results in an F statistic of $F(2, 11) = 3.35$. The joint hypothesis can be rejected at the 7 percent level. The relationship between income and land clearing is statistically different than that which would be predicted by the strong version of the poverty deforestation hypothesis.

very similar to those in the first regression in table 11. However, the coefficient on the labor supply constraint is no longer significant.

The findings in the subsection imply that the correlation between income and land clearing depends crucially on the household's ability to supply labor to clear and cultivate additional lands. That is, the poverty-deforestation hypothesis is not so much incorrect as incomplete. Larger households are more likely to clear land at any income level. There is only mixed evidence that these households are more likely to use additional income to bring more land under cultivation. The positive coefficient on the interaction term in the IV regression would be consistent with Proposition 2, and would suggest that households with low income per capita are so marginalized that any increases in income are spent on land clearing, but given that the coefficient on household size is negative in this regression, this is only weak evidence in favor of this proposition. I provide more evidence that labor supply constraints affect land clearing both directly and indirectly, through the income effect, in section 5.5.

To test whether these results are driven by the choice of the functional form, consider the following equation:

$$\tau_t^{ij} = F(y_{t-1}^{ij}, H_{t-1}^{ij}, \varphi^j, \psi_t, \phi^{ij}). \tag{14}$$

Table 13 presents results in which the function $F(\cdot)$ in equation 14 is assumed to be the logistic cumulative distribution function. That is, the dependent variable in the OLS regressions below is $\ln(\tau_t^{ij}/(1-\tau_t^{ij}))$ where τ_t^{ij} is the fraction of a household's land claim covered in cleared land. The results of this estimation show that the conclusion that there is evidence against the strong

Table 12: Additional evidence on the effect of labor supply constraints: Variables measured in levels

Ordinary least squares and insturmental variables estimates (1994-1997)		
Independent variables	Dependent variable: Δ cleared land$_{t-1,t}$	
	OLS	IV
Adult equivalents per ha. cleared land$_{t-1}$	0.0814* (0.0456)	−0.0050 (0.0920)
Adult equiv. per ha. cleared$_{t-1}$*income$_{t-1}^{+(a)}$	−0.0005 (0.0003)	0.0001 (0.0002)
District ave. profits per ha.$_{t-1}$	0.0002 (0.0002)	0.0001 (0.0002)
Size household claimed land holding$_{t-1}$	−0.1435 (0.1001)	−0.1396 (0.1173)
Household total income$_{t-1}^{+}$	0.0007** (0.0003)	0.0009 (0.0006)
Household total income squared$_{t-1}^{+(b)}$	−0.0003** (0.0001)	−0.0003** (0.0001)
Value of household durable assets$_{t-1}$	−0.0011* (0.0005)	−0.0001 (0.0002)
Household is rural$_{t-1}$	1.2208 (3.0637)	−1.6519 (7.2003)
Household has full title to land$_{t-1}$	1.8141 (1.7138)	1.7681 (2.0092)
Fraction farms in district with full title$_{t-1}$	5.2297 (3.2790)	4.7064 (3.8450)
Household fixed effects?	YES	YES
R-squared	0.82	0.81
Regression degrees of freedom	10	10
Strata	2	2
Clusters	14	14
Groups	37	37
Observations	74	74

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample.
All regressions include time and district fixed effects.
**significant at 5% level; * at 10% level.
[a,b]For this variable, this coefficient and standard error are multiplied by 100 (for a) or by 10,000 (for b).
[+]In IV estimation this variable instrumented using consumption expenditures and consumption* adult equivalents per ha. of cleared land to identify first-stage regression.

version of the poverty deforestation hypothesis when the household's labor supply constraint is accounted for is not driven by the use of a dependent variable that measures changes in the level of cleared land holdings. In these regressions, income is positively correlated with the share of a household's land that is cleared, though the relationship does not appear to be non-monotonic. When a quadratic income term is included, the coefficient on income alone is insignificant. Note that the sign of the coefficient on household size, per unit of land, is the opposite of that shown in table 11. This finding suggests that larger households hold a larger fraction of their holding in forest; this is not inconsistent with a positive correlation with land clearing. Similar results are found when the independent variables are transformed by taking logs.

While a measure of the household's labor supply constraint is consistently significant in regressions in which the dependent variable is land clearing (or some variant of this), the same is not true in regressions in which the dependent variable is capital input expenditure. As table 14 shows, including the interaction between income and the household's labor supply does not change the conclusion that higher incomes are not positively correlated with expenditure on capital inputs. In the case of fertilizer, initial increases in income are correlated with less fertilizer expenditure per hectare of land. There is also some evidence that households with many members per hectare of land are less likely to use fertilizer, though this effect is less strong for high-income families. These results are the opposite of those found in the land-clearing regressions, and again contrary to the prediction of the poverty-deforestation hypothesis.

5.5 The credit market

In this subsection, I test directly for the effect of borrowing constraints on the land-clearing and input-use decisions. This is a broader measure of households' ability to finance agricultural in-

Table 13: Additional evidence on the labor supply constraint: Testing the functional form

Ordinary least squares estimates (1994-1997)

Independent variables	Dependent variable: $\ln(\tau_t^{ij}/(1-\tau_t^{ij}))$	
Adult equivalents per ha. cleared land$_{t-1}$	-0.0290^{**} (0.0020)	-0.0300^{**} (0.0030)
District ave. profits per ha.$_{t-1}$	0.0004^{*} (0.0002)	0.0005 (0.0003)
Size household claimed land holding$_{t-1}$	0.0630 (0.0390)	0.0540^{*} (0.0300)
Household total income$_{t-1}$	0.0004^{*} (0.0002)	-0.0003 (0.0003)
Household total income squared$_{t-1}^{(a)}$		0.0002^{**} (0.0001)
Value of household durable assets$_{t-1}$	0.0001 (0.0007)	-0.0004 (0.0004)
Household is rural$_{t-1}$	-13.4500^{**} (2.6878)	-12.2310^{**} (3.2590)
Household has full title to land$_{t-1}$	-1.4840 (1.8640)	-1.8530 (2.0110)
Household fixed effects?	YES	YES
R-squared	0.84	0.86
Regression degrees of freedom	8	8
Strata	2	2
Clusters	13	13
Groups	33	33
Observations	66	66

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

[a]For this variable, this coefficient and standard error are multiplied by 10,000.

Table 14: The effects of labor supply constraints: Input expenditure

Ordinary least squares estimates (1994-1997)			
Independent variables	Dependent Variables (expenditure per unit of cleared land)		
	fertilizer_t	pesticide_t	hired labor_t
Adult equivalents per ha. cleared land_{t-1}	−21.7312 (13.4751)	9.1101 (7.8108)	−139.098* (74.5699)
Adult equiv. per ha. cleared_{t-1}*$\text{income}_{t-1}^{(a)}$	0.0216* (0.0012)	−0.0085 (0.0082)	0.0105 (0.0062)
District ave. profits per ha._{t-1}	0.0003 (0.0022)	0.0048* (0.0017)	−0.0020 (0.0104)
Size household claimed land holding_{t-1}	1.2622 (0.9884)	0.5002 (0.4579)	2.7606 (4.6919)
Household total income_{t-1}	−0.0109** (0.0044)	0.0026 (0.0049)	−0.0190 (0.0411)
Household total income $\text{squared}_{t-1}^{(b)}$	0.0024** (0.0009)	0.0001 (0.0001)	0.0037 (0.0106)
Value of household durable assets_{t-1}	0.0100** (0.0039)	0.0080** (0.0029)	0.0234 (0.0302)
Household is rural_{t-1}	35.6412 (26.2734)	−10.3820 (22.8463)	−115.801 (185.809)
Household has full title to land_{t-1}	−59.4689** (28.3081)	−7.8376 (6.5533)	−159.986 (110.613)
Fraction farms in district with full title_{t-1}	−70.2911 (60.6707)	−62.2994 (38.1748)	407.896 (331.037)
Household fixed effects?	YES	YES	YES
R-squared	0.93	0.86	0.73
Regression degrees of freedom	9	9	9
Strata	2	2	2
Clusters	13	13	13
Groups	27	27	27
Observations	54	54	54

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

[a,b]For this variable, this coefficient and standard error are multiplied by 10 (for a) or by 10,000 (for b).

vestments than income alone. To do this, I rely on a test for borrowing constraints developed by Zeldes [71] and a definition of risky production behavior developed by Morduch [39]. Given Morduch's definition of risky behavior, I provide additional evidence for the contention that the relationship between income and land clearing depends on household size.

Following Morduch's [39] methodology, In appendix C I derive a noisy measure of the household's borrowing constraint. With this imperfect measure of a household's ability to smooth consumption and to finance investment, I can estimate the following reduced-form equation:

$$\Delta T_{t-1,t}^{ij} = \delta_1 \Phi_t^{ij} + \delta_2 H_{t-1}^{ij} + \varphi^j + \psi_t + \varepsilon_{it}, \qquad (15)$$

where Φ_t^{ij} is the estimate of the household's borrowing constraint, ε_{it} is a, not necessarily homoskedastic, error term and all other variables defined as above.[20] I also present regressions in which an interaction between the borrowing constraint and adult equivalents per hectare of cleared land is included on the left-hand side of the regression as a means of testing proposition 2. In the case of capital inputs, I present probit estimates of the binary decision of whether to use fertilizer or pesticide.

Morduch [39] shows that, in an equation of this form, the coefficient on Φ_t^{ij} can be predicted in the case of production decisions that raise incomes in good times (when households receive a positive exogenous shock) and lower incomes in bad times (a negative exogenous shock). Even for production choices in which the up-side potential outweighs the possible losses in the event

[20] Morduch estimates this equation without household fixed effects and with very few agricultural controls. However, he has land quality data, which is included on the right-hand side.

of a negative shock, households that expect greater lifetime borrowing constraints will choose to undertake less of the risky activity. That is, we expect that $\delta_1 > 0$ for activities that more constrained households do more.

It is not clear that the choices that are the subject of this paper fit this definition of risky activity well. However, based on previous regressions, there is some evidence that increases in income are positively correlated with land clearing for the largest families. From the Euler equation, we know that as incomes increase, borrowing constraints decline. Thus, if the effects of income on land-use change work through borrowing constraints, we would expect that when we use a direct measure of borrowing constraints we find that large households that receive a reduction in borrowing constraints clear more land. That is, proposition 2 predicts a negative coefficient on the variable that is the interaction between household size and the borrowing constraint measure.

Perhaps the production decision most amenable to Morduch's test is pesticide application. Using pesticide is beneficial in the event of a negative exogenous shock (infestation) but may be of little value in other years. Based on Morduch's definition of risky production choices, the coefficient on the measure of borrowing constraints is predicted to be positive in a probit regression for pesticide use. Households that expect to face borrowing constraints will be more likely to use pesticide, controlling for other considerations. On the other hand, tree crops, which require pesticides, may be assets against which households can borrow so pesticide users appear less constrained.

The results of the estimation of equation 15 are presented in table 15. The direct effect of borrowing constraints is positive, that is, more constrained households clear land, but the interaction effect of borrowing constraints and family size is negative. The negative sign on the interaction term means that, while more constrained households clear land, the effect is dampened for large households. These large households continue to clear relatively more land than small households as constraints are relaxed. This is further evidence that the land-clearing decisions of large and small households differ. The signs of these coefficients are consistent with the proposition derived from the model that large households are most like to respond to increases in income, or reduced borrowing constraints, by clearing land because these households have surplus home labor that they price below the local wage rate. However, the magnitude of the coefficients suggests that, for reasonable values, the direct income effect may dominate the indirect effect.

Turning to the effect of borrowing constraints on the use of inputs, in table 16 I present results of probit estimates for the fertilizer- and pesticide-use decisions. The results of this estimation show that bigger families (per unit of land) are less likely to invest in an input to intensify agricultural production. There is little clear relationship between fertilizer use and borrowing constraints, which is the opposite of what would be predicted by either the strong or weak version of the poverty deforestation hypothesis. However, there is clear evidence that more constrained households are more likely to use pesticides. As noted above, pesticide application is most beneficial when households experience a negative shock of infestation. In good times, it is less useful.

By using a direct measure of the household's borrowing constraint, rather than a measure of income, the evidence in this section provides additional support for the claim that the simple version of the poverty-deforestation hypothesis can be rejected for this sample. This section provides evidence that the relationship between poverty and land clearing depends on household size, as predicted by proposition 2. These results also support the contention that larger households, per unit of land, are less likely to use purchased inputs.

Table 15: The effect of borrowing constraints on the land-clearing decision: Variables measured in levels

Ordinary least squares estimates (1994-1997)				
Independent variables	Dependent variable: Δ cleared land$_{t-1,t}$			
Borrowing constraint$_{t-1}$	1.5090* (0.9109)	1.2000 (0.8653)	1.4525 (0.9198)	1.2026 (0.9658)
B. constraint$_{t-1}$*Adult eq. per ha.$_{t-1}$			−0.0003** (0.0001)	−0.0003 (0.0002)
Adult equivalents per ha. cleared$_{t-1}$	−0.0010 (0.0019)	−0.0017 (0.0022)	0.0005 (0.0022)	−0.0009 (0.0026)
District ave. profits per ha.$_{t-1}$	−0.0002 (0.0001)	0.0001 (0.0002)	−0.0001 (0.0001)	0.0001 (0.0002)
Size household claimed land holding$_{t-1}$	−0.1821** (0.0475)	−0.1908** (0.0532)	−0.1313** (0.0593)	−0.1643 (0.1618)
Age of household head$_{t-1}$	−0.0260 (0.0345)	−0.0221 (0.0293)	−0.0502 (0.0424)	−0.0140 (0.0244)
Household is in High Forest	−6.9235** (1.2535)	−1.9415 (2.1663)	−7.9274** (1.4278)	−4.1651** (0.8490)
Household is rural$_{t-1}$	3.0883* (0.6917)	−0.3965 (2.3893)	0.9076 (0.6894)	0.3041 (2.4889)
Household has full title$_{t-1}$	−0.5681 (0.7105)	0.0590 (0.9880)	−0.5008 (0.7809)	0.5306 (1.1868)
Fraction farms in district with full title$_{t-1}$	−3.7501 (1.7770)	−1.7414 (2.4238)	−2.1495 (2.2211)	−0.8084 (2.8685)
Constant	9.4312** (1.1678)	0.1240 (3.1680)	11.6988** (1.5189)	1.7829 (2.8398)
Household fixed effects?	NO	NO	NO	NO
R-squared	0.20	0.36	0.14	0.17
Regression degrees of freedom	17	18	11	10
Strata	2	2	2	2
Clusters	30	26	14	13
Observations	188	70	188	70

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.
**significant at 5% level; * at 10% level.

Table 16: The effect of borrowing constraints on input use: Variables measured in levels

Probit estimates (1994-1997)		
Independent variables	Dependent variables	
	Fertilizer use_t	Pesticide use_t
Borrowing constraint_t	0.0507	0.7617^{**}
	(0.2555)	(0.3025)
Adult equivalents per ha. cleared land_{t-1}	-0.0044^{**}	-0.7908^{**}
	(0.0017)	(0.1433)
District ave. profits per ha._{t-1}	0.0004^{**}	-0.0001
	(0.0001)	(0.0001)
Size household claimed land holding_{t-1}	0.2344^{**}	-0.0596
	(0.0782)	(0.0148)
Age of household head_{t-1}	0.0137	0.0059
	(0.0210)	(0.0152)
Household is in High Forest	0.7082	2.8228^{**}
	(0.9194)	(1.1492)
Household is rural_{t-1}	2.5713^{**}	1.1257
	(1.1864)	(0.7180)
Household has full title to land_{t-1}	-0.4758	-0.3976
	(0.4373)	(0.4691)
Fraction farms in district with full title_{t-1}	10.1988^{**}	-1.2961
	(3.2637)	(0.7180)
Constant	-6.4535^{**}	-0.2537
	(1.8079)	(0.9245)
Household fixed effects?	NO	NO
R-squared	-	-
Regression degrees of freedom	13	13
Strata	2	2
Clusters	16	17
Observations	83	108

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample.
All regressions include time and district fixed effects.
**significant at 5% level; * at 10% level.

5.6 Permanent vs. transitory income

Just as sections 5.4 and 5.5 show that large and small families differ in their land-clearing decisions, it is possible that permanent and transitory income affect the land-clearing decision differently. Households that receive a windfall of extraordinary income may be more inclined to respond by purchasing inputs such as fertilizer or pesticide than by clearing additional land. Increases in permanent income on the other hand may be more likely to induce clearing; households can anticipate the ability to finance larger-scale production on an on-going basis. In this section, I test to see if there is evidence against the poverty-deforestation hypothesis when attention is restricted to permanent income.

The most effective means of testing whether permanent and transitory income have differential effects on land clearing and the use of inputs would be to develop a direct measure of transitory income, as done by Paxson [44] and Alderman [1]. Such measures usually rely on rainfall data, which is not available at a sufficiently disaggregated level for the Selva region of Peru to take this approach. Another means of separating permanent and transitory income has been developed by Musgrove [40]. Permanent income is unobservable, but with several assumptions, including the requirement that the mean of transitory income is zero, instrumental variables techniques can be used to estimate the effect of permanent income on land clearing.

To estimate the correlation between permanent income and land clearing, suppose that equation 16 defines the true relationship:

$$\Delta T_{t-1,t}^{ij} = \varphi^{j} + \psi_{t} + \gamma_1 \omega_{t-1}^{Pij} + \gamma_2 \omega_{t-1}^{Tij} + \gamma_3 \tilde{H}_{t-1}^{ij} + v_t^{ij}. \tag{16}$$

The variables φ^j and ψ_t are district and time fixed effects respectively, ω_t^{Pij} is permanent income, ω_t^{Tij} is transitory income, and $\tilde{H}_{t-1}^{ij}$ is a vector of control variables. v_t^{ij} is an error term. By taking advantage of the relationship between observable total income and unobservable permanent income, $\omega_t^{Pij} = \omega_t^{ij} - \omega_t^{Tij}$, equation 16 can be written as:

$$\Delta T_{t-1,t}^{ij} = \varphi^j + \psi_t + \gamma_1 \omega_t^{ij} + \gamma_3 \tilde{H}_{t-1}^{ij} + (\gamma_2 - \gamma_1)\omega_t^{Tij} + v_t^{ij}. \tag{17}$$

In estimation, transitory income is absorbed into the error term, and instrumental variables techniques can be used to estimate γ_1, provided that there is at least one instrumental variables that is correlated with permanent income but that is orthogonal to transitory income and not directly related to land clearing. Following Musgrove [40], an available instrument is the age and education level of the household head.[21]

For purposes of estimation, Musgrove [40] defines the income term as total income less income that can be *ex ante* classified as transitory income. This makes the income term less noisy. In the context of the LSMS data sets I do this be subtracting "extraordinary income" from total income. Extraordinary income is now an element of the error term, and must be exogenous to the instruments for the estimation strategy to be valid.

By changing the measure of income used in the regression, and imposing assumptions on the distribution of transitory income, the coefficients on income in an IV regression can be interpreted

[21] So far, there is no evidence of a direct relationship between land clearing and the age of the household head. I argued earlier that this was being used as a proxy for the age of land holdings, not that it directly affected land clearing. In the case of eduction of the household head, this instrument could be invalid if schooling taught farmers particular agricultural techniques or induced farmers to value the existence of forest for non-pecuniary reasons. Since most household heads have only primary education, this is unlikely. More seriously, it could be invalid if education makes individuals less myopic and more willing to substitute future for current consumption (Deaton [17]).

as the coefficients on permanent income. The results of these regressions are presented in tables 17. In this table, the variables are measured in levels, but similar results are obtained when the variables are transformed by taking logs. Note that these regressions do not include household fixed effects; many of the determinants of permanent income are time invariant and would be absorbed by these variables if they were included. In addition, these results must be interpreted carefully because in the formulation of the estimated equation it is difficult to distinguish genuine measurement error from transitory income (Deaton [17]).

The most important finding in table 17 is that the coefficient on permanent income is positive and significant in the regression for the panel of households while the coefficient on income squared is not significantly different from zero. In the analogous regression using total household income rather than permanent income neither coefficient is statistically different from zero. This would suggest that permanent income is more strongly correlated with land clearing than total income. However, these results may be driven by unobserved ability bias. Household fixed effects cannot be included in this regression since many of the determinants of permanent income are likely to be time invariant.

Table 18 shows that permanent income is not significantly correlated with increased fertilizer expenditure. There is some suggestion that it is negatively correlated with pesticide expenditure. Restricting attention to permanent income does not change the conclusion that the strong and weak versions of the poverty deforestation hypothesis can be rejected in this sample.

This section suggests that land clearing is positively correlated with permanent income, just as it is with total income. The effect of transitory income is not driving the results of the earlier sections of this paper. Increases in permanent income are not positively correlated with fertilizer

Table 17: The effect of permanent income on land use: Variables measured in levels

Instrumental variables estimates (1994-1997)

Independent variables	Dependent variable: Δ cleared land$_{t-1,t}$	
Permanent income$^{+}_{t-1}$	0.0001	0.0005*
	(0.0002)	(0.0003)
Permanent income squared $^{(a)+}_{t-1}$	−0.0001	−0.0002
	(0.00001)	(0.0001)
Adult equivalents per ha. cleared land$^{(a)}_{t-1}$	0.0267	−0.0012
	(1.7328)	(0.0022)
District ave. profits per ha.$_{t-1}$	−0.0001	0.0001
	(0.0001)	(0.0002)
Size household claimed land holding$_{t-1}$	−0.1516**	−0.1769**
	(0.04479)	(0.0479)
Value of household durable assets$_{t-1}$	−0.0004	−0.0006
	(0.0004)	(0.0005)
Household is in High Forest$_{t-1}$	1.0341	2.7961
	(2.3447)	(4.3578)
Household is rural$_{t-1}$	−1.4219	0.0353
	(1.8861)	(3.0557)
Household has full title to land$_{t-1}$	−0.4554	0.1928
	(0.6028)	(0.9209)
Fraction farms in district with full title$_{t-1}$	−1.6130	0.6737
	(0.5527)	(3.4786)
Constant	0.7659	−2.0351
	(3.4039)	(3.4176)
Household fixed effects?	NO	NO
R-squared	0.28	0.49
Regression degrees of freedom	19	11
Strata	2	2
Clusters	30	14
Observations	178	75

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

[+]This variable is total income less extraordinary income and is instrumented using age and education level of household head. If the exclusion restrictions for IV estimation are satisfied, the coefficient reported here may be interpreted as the coefficient on permanent income.

[a]For this variable, the coefficient and standard error are multiplied by 10,000.

Table 18: The effect of permanent income on the input-use decision: Variables measured in levels

Instrumental variables estimates (1994-1997)

Independent variables	Dependent variables (expenditure per unit of cleared land)			
	fertilizer_t	fertilizer_t	pesticide_t	pesticide_t
Permanent income^{+}_{t-1}	0.0036 (0.0273)	0.0450 (0.0552)	−0.0027 (0.0052)	−0.0029* (0.0015)
Permanent income squared $^{(a)+}_{t-1}$	−0.0112 (0.0091)	−0.0193 (0.0210)	0.0024 (0.0021)	0.0012** (0.0006)
Adult equivalents per ha. cleared land_{t-1}	0.0712 (0.2869)	−0.1662 (0.1658)	−0.1318** (0.0251)	−0.0295* (0.0137)
District ave. profits per ha._{t-1}	−0.0587 (0.0388)	−0.0177 (0.0193)	0.0024 (0.0027)	−0.0038** (0.0008)
Size household claimed land holding_{t-1}	−7.0474 (5.8823)	1.3678 (2.2550)	−0.1807 (0.2597)	0.1775 (0.2110)
Value of household durable assets_{t-1}	0.0782 (0.0546)	0.0534 (0.0624)	−0.0086* (0.0042)	0.0051* (0.0025)
Household is in High Forest_{t-1}	286.796 (202.960)	398.002 (427.114)	−4.4556 (56.1419)	44.9692** (13.6115)
Household is rural_{t-1}	378.178 (268.306)	409.407 (492.882)	−28.4029 (43.5960)	40.2839 (17.4165)
Household has full title to land_{t-1}	−41.774 (129.898)	−27.9615 (23.5203)	29.3813 (34.5271)	−14.7392** (5.3745)
Fraction farms in district with full title_{t-1}	174.631 (603.176)	−221.933 (242.767)	94.8508 (50.5039)	−39.1820* (17.1524)
Constant	−171.669 (409.212)	−365.310 (576.990)	−61.1227 (54.1315)	28.3795 (21.0886)
Household fixed effects?	NO	NO	NO	NO
R-squared	0.20	0.05	0.31	0.55
Regression degrees of freedom	15	10	15	10
Strata	2	2	2	2
Clusters	24	13	24	13
Observations	115	55	115	55

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. All regressions include time and district fixed effects.

**significant at 5% level; * at 10% level.

[+]This variable is total income less extraordinary income and is instrumented using age and education level of household head. If the exclusion restrictions for IV estimation are satisfied, the coefficient reported here may be interpreted as the coefficient on permanent income.

[a]For this variable, the coefficient and standard error are multiplied by 10,000.

expenditure intensity. Of course, households may use increases in permanent income to fund other investments that maintain soil quality, such as terrace construction, but this cannot be observed in the LSMS data.

6 Conclusion

This paper analyzes the interaction between poverty and land-use change in the Peruvian Selva. I take as a benchmark the claim that reductions in poverty will be correlated with less land clearing, as households are able to make desired investments in intensification on previously cleared plots. In contrast to this so-called conventional wisdom, I show that, while households do take expected lifetime borrowing constraints into consideration when making land-clearing decisions, the relationship between poverty and deforestation is theoretically ambiguous.

In empirical analysis, I show that, in the Peruvian Selva, the correlation between income and land clearing is non-monotonic. Progressively large increases in income are not correlated with proportional increases in land clearing. Rather, the positive correlation between income and land clearing falls as incomes grow large. In contrast, the correlation between income and fertilizer expenditure per hectare, a crucial outlay to maintain yields on cleared lands, becomes positive and significant as incomes grow very large. This result remains when attention is restricted to permanent income.

Another robust result is that land clearing depends critically on the availability of labor for land clearing as households are constrained in their ability to hire labor and earn off-farm wages. Larger households, per unit of land, are more likely to clear land at any income level. A less robust but suggestive result is that, contrary to the simple story that is presented as the conventional wisdom, when the incomes of larger families (per unit of land) are increased (or their borrowing constraints are relaxed), they are more likely to respond by clearing land. Even controlling for labor availability, there is little evidence that fertilizer use is positively correlated with income, and the evidence is mixed in the case of pesticide.

The findings of this paper suggest that for households with relatively high incomes, who are perhaps still absolutely poor, the poverty deforestation hypothesis may indeed be an accurate characterization of households' preferences. At some income level, the income elasticity of land clearing is smaller than the income elasticity of fertilizer use. However, this is not true at the margin, and is not true for the poorest households in the sample, which would likely be the intended target of policies intended to raise incomes. This result is consistent with the existence of an "environmental Kuznets curve" for deforestation, (Kuznets [27], Panayotou [42], Grossman and Krueger [35]) a non-linear relationship between an environmental "bad" and income. That the qualitative relationship takes this form can be seen from the regression results alone. Using the first regression in table 11, the marginal effect of income and land clearing becomes negative after incomes increase beyond \$900 per capita (assuming households have 5.7 members).[22]

Identifying policies that can raise incomes and assist in achieving environmental goals requires identifying the incentives and constraints that inform agents' choices. In the case of this work, the policy implications of these findings depend critically on whether poor households' land-clearing decisions are a first-best choice, or a second-best solution that is chosen taking labor-supply con-

[22] This is much lower than the income level identified by Cropper and Griffiths [14] using national-level data from all countries of about \$5,400 per capita, suggesting that the dynamics of deforestation are locally-specific (a point emphasized by Koop and Tole [34]) and depend to a large extent on incentives for migration to the forest. That is, once households are established in the forest region and have cleared their initial holding, incentives to clear diminish significantly. Such a conclusion is consistent with Pfaff's [45] finding that initial migrants to a region are responsible for much more clearing than later migrants or intra-regional population growth.

straints into account. The fact that households' own labor supply is statistically correlated with their land-use decision is one piece of evidence for the conclusion that the observed decisions may not be the result of a first-best solution. Evidence in favor of proposition 2, that larger households are more likely to use increases in incomes to clear land, is addtional evidence for a second-best solution. Evidence for proposition 2 in this paper is less robust than evidence for proposition 1 (which would be consistent with either a first-best solution or a second-best solution), but it is found when households' ability to finance production is measured by an estimate of their borrowing constraint, as opposed to their income alone. The leads to the conclusion that the balance of evidence supports the finding that the poorest households' land-clearing behavior may not be a first-best solution, and that relaxing households' labor supply constraints may be an appropriate policy intervention.

In summary, the findings of this paper suggest that small increases in income for the poorest smallholders in the Peruvian Selva will not reduce the rates at which these households clear land, and are unlikely to increase their use of purchased inputs that increase yields, such as pesticide and, especially, fertilizer. Policies that would result in large income increases for these households are likely to be difficult to undertake or infeasible. More promising interventions to increase incomes of the poor while minimizing associated increases in deforestation are likely to be targeted support for the acquisition of capital inputs that forestall yield declines, or improvements in the functioning of local labor markets. Increased off-farm labor opportunities can raise incomes and encourage households to value their own labor supply at an outside wage rate, enabling them to substitute intensive techniques for extensive production more efficiently. This conclusion is consistent with Shively's [53] finding that, in the Philippines, increases in labor demand have led to small but statistically significant reductions in rates of forest clearing by smallholders.

Further research is needed to support this policy conclusion. First, plot-level data should be collected, such as is available from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for India and Burkina Faso, to track land-use decisions more accurately, as well as other investments not captured by the LSMS data. Such data is also critical if an accurate understanding of the interaction of titling, land clearing, and poverty is to be gained. Second, to determine how effective targeted interventions to assist households in purchasing fertilizer or pesticide are likely to be, future research might investigate how effective current yield-maintaining technologies are and what barriers to their adoption exist. Additional research into the labor markets in this region is also needed; one reason that the evidence in this paper on proposition 2 is only suggestive may be because labor markets differ significantly in the Selva Alta and Selva Baja. The sample size here is too small to investigate this possibility.

An application of the results developed in this paper that is an avenue for further research is to simulate how changes in relative prices affect deforestation and link these estimates with a simulation model of carbon sequestration. As shown by Stavins [58], drawing on the analyses of Stavins and Jaffe [59] and Stavins [57], this revealed-preference approach to estimating the marginal cost of carbon sequestration has the advantages of (1) being based on actual behavior, as opposed to engineering studies, and (2) yielding a marginal cost function instead of point estimates. Few such revealed preferences estimates of the marginal cost of carbon sequestration have been developed for Latin American tropical forests (see, Kerr, Pfaff, and Sanchez [33]), despite the fact that the marginal cost of sequestration through retarded deforestation is likely to be lower than the marginal cost through forestation, which suggests that sequestration efforts should be focused in the tropics (Newell and Stavins [41]).

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A Cross-sectional data summary statistics

Tables 19 and 20 present summary statistics for the cross section of data of which the balanced panel is a subset. Some households' responses to various questions are missing from the survey.

Table 19: Balanced panel: Household summary statistics

Household variables	1994		1996		1997	
	Obs	mean Std. dev	Obs	mean Std. dev	Obs	mean Std. dev
Age of household head	164	44.86 (13.38)	166	46.98 (13.31)	45	52.07 (13.06)
Level of education of household head	164	2.26 (0.98)	166	2.20 (0.95)	45	2.07 (0.81)
Number of members in household	164	6.07 (2.60)	166	5.84 (2.50)	45	5.56 (2.66)
Total adult equivalents in household	164	3.10 (0.83)	166	3.06 (0.79)	45	2.98 (0.90)
Total annual household income	164	3644.00 (3252.51)	166	4006.88 (2798.39)	45	4518.67 (4035.53)
Total annual household consumption	164	2800.06 (2326.32)	166	3478.01 (2148.27)	45	3467.64 (2331.62)
Annual household food consumption	164	1562.65 (918.96)	166	1991.31 (1065.78)	45	1070.82 (536.04)
Annual non-labor income	164	769.11 (1856.25)	166	525.99 (755.70)	45	935.79 (1244.08)
Annual non-farm labor income	164	129.90 (376.91)	166	917.35 (1369.56)	45	1023.08 (1499.59)
Revenue from agriculture (includes autocons.)	162	1947.27 (4341.63)	166	1616.22 (2468.40)	44	1572.26 (3471.88)
Value of durables (includes land)	153	2413.33 (4890.35)	161	2558.25 (4847.59)	45	1656.44 (2811.70)
Value of consumer durables (excludes land)	153	485.93 (1028.26)	161	750.72 (3668.02)	45	245.40 (421.35)

Monetary values in 1994 dollars at Lima prices; exchange rate and inflation information in appendix B.

Table 20: Balanced panel: Land-use variables summary statistics

Land-use variables	1994		1996		1997	
	Obs	mean Std. dev	Obs	mean Std. dev	Obs	mean Std. dev
Total land claim (hectares)	164	6.59 (10.70)	160	9.67 (22.53)	45	4.74 (6.72)
Total cleared land claim (hectares)	164	3.85 (6.00)	166	3.95 (7.96)	45	2.25 (2.78)
Hectares of land claim under cultivation	164	2.18 (2.66)	165	2.55 (6.54)	45	1.72 (1.96)
Change in cleared land claim (hectares)			164	0.14 (7.93)	45	−0.30 (3.49)
Agricultural profits per ha. of land	137	1574.65 (4704.98)	119	1231.78 (2368.21)	28	2932.30 (10885.07)
Fraction of profits from sales to market	154	0.46 (0.36)	142	0.45 (0.32)	44	0.38 (0.39)
Cultivation intensity index	163	0.73 (0.37)	143	0.78 (0.37)	43	0.72 (0.42)
Expend. on pesticide per ha. land	146	6.18 (20.69)	100	17.87 (66.97)	29	3.86 (11.29)
Expend. on fertilizer per ha. land	146	11.87 (32.29)	100	60.62 (303.46)	29	11.77 (35.28)
Expend. on hired labor per ha. land	146	23.69 (75.74)	100	177.33 (872.75)	29	42.43 (63.01)
Fraction households using pesticide	161	0.29	101	0.29	38	0.26
Fraction households using fertilizer	161	0.30	101	0.28	38	0.18
Fraction households hiring labor	164	0.35	101	0.47	38	0.47
Fraction households with land title	161	0.43	165	0.60	45	0.69
Fraction households in High Forest	161	0.41	165	0.41	45	0.49
Fraction households living in rural area	164	0.70	166	0.69	45	0.67

Monetary values in 1994 dollars at Lima prices; exchange rate and inflation information in appendix B.

B Data description

Variables from household survey

- Age of household head- Age of person self-identified as head of household.
- Level of education of household head- Takes values of 1 = none, 2 = primary, 3 = common secondary, 4 = technical secondary, 5 = tertiary but not university, 6 = university, and 7 = other.
- Number of members of household- Number of individuals taking the majority of their meals at the dwelling.
- Number of adult equivalents- Adjusted number of members to account for economies of scale in household. Weights are based on Deaton [17].
- Household income- Total income from all sources including estimate of imputed income from auto-consommation.
- Total consumption - Estimated value of expenditure and auto-consommation by household in the last 12 months.
- Total food consumption- Estimated value of expenditure and auto-consommation on food (including alcohol and tobacco) in the last 12 months.
- Non-labor income- Income from rent, transfers, extraordinary sources, and pensions.
- Non-farm income- Income from work for others, as opposed to imputed income from work on own land.

- Revenue from agriculture- Calculated as sum of self-reported estimate of agricultural revenues if all output had been sold. Note that revenue from agriculture + non-farm income + non-labor income $\leq$ total income. Total income also includes income from animal husbandry, forestry, and sale of secondary agricultural products (e.g., corn meal or cheese).

- Estimate of value of durables- Self-reported estimate of how much durable assets could be sold for at time of survey. This number is the sum of the value reported for various consumer durables, urban property, agricultural property and stores or businesses. Table reports value including and excluding land. Responses including land are difficult to interpret because land sales are likely to be difficult or impossible as discussed in footnotes 7 and 9 in the body of this chapter.

- Total land claim- Survey asks for the total amount of land that a household claims. Land rented out is not included in this number, but land rented in is included.

- Total cleared land claim- Hectares of claimed land not covered in forest.

- Hectares of land under cultivation- Land planted for agriculture. Total land holding is disaggregated into land under cultivation, land lying fallow, land used for pasture, land covered in forest and land used for other purposes at time of survey.

- Change in cleared land claim- Cleared land claim$_t$$-$cleared land claim$_{t-1}$.

- Agricultural profits per hectare- Sum of self-reported estimate of agricultural revenues if all output had been sold, less sum of self-reported estimate of agricultural expenses, divided by land under cultivation. This number may be overestimated if reported expenses exclude transportations costs and shadow price of household labor. See footnote 11 in the body of this chapter.

- Cultivation intensity index- Measure of cultivation intensity calculated as (cultivated land) ÷ (cultivated land+ fallow land). It equals 1 if no land is lying fallow and becomes smaller as the amount of land lying fallow increases.

- Fraction of profits from sales to market- Fraction of calculated profits coming from actual sale of products in markets.

- Expenditure on pesticide per hectare of land- Self-reported expenditure divided by reported cleared land.

- Expenditure on fertilizer per hectare of land- Self-reported expenditure divided by reported cleared land.

- Expenditure on hired labor per hectare of land- Self-reported expenditure divided by reported cleared land.

- Fraction of households using pesticide- Total number of households reporting that they used pesticide in the last year to perform agricultural work, divided by number of households responding to agricultural section of questionnaire.

- Fraction of households using fertilizer- Total number of households reporting that they used fertilizer in the last year to perform agricultural work, divided by number of households responding to agricultural section of questionnaire.

- Fraction of households hiring labor- Total number of households reporting that they hired labor in the last year to perform agricultural work, divided by number of households responding to agricultural section of questionnaire.

- Fraction of households with full title to land- Households are asked to characterize their property rights to their land as one of the following: 100 percent proprietorship, over 50 percent proprietorship, a form of proprietorship, awardee, lease or rent, and other. Summary tables present fraction of households claiming 100 percent proprietorship over their land holding and regressions use this distinction as well.

- Fraction of households living in High Forest- Uses definition of Selva Alta used by World Bank [66].

- Fractions of households living in rural areas- Households classified as rural or urban by survey; urban areas defined as those with more than 2,000 inhabitants.

Inflation rates

- All monetary values deflated to 1994 soles using inflation rates of 10.2 percent (1995), 11.8 percent (1996), and 6.5 percent (1997), as reported by Instituto de Estadistica e Informatica [30]. To account for the fact that surveys were performed mid-year, inflation rates adjusted linearly.

Exchange rates

- One dollar = 2.2 soles at time of survey in 1994.

- One dollar = 2.4 soles at time of survey in 1996.

- One dollar = 2.7 soles at time of survey in 1997.

C Derivation of credit constraint measure

One means of testing for missing credit or insurance markets is to rely on the exclusion restrictions implied by a Euler equation (Zeldes [71]). This equation states that, if households are able to smooth consumption through recourse to credit or insurance markets, then changes in consumption between periods should not be related to income in the initial period. Rather, these changes should be related only to demographic variables that characterize the life-cycle phase of the household. There is a wealth of evidence that the geographic correlation of risks in rural agriculture and the lack of collateral assets among the poor will make consumption smoothing difficult to achieve for households engaged in agriculture in poor countries (e.g., Townsend [60], Paxson [44]).

To test for the presence of credit constraints, following Morduch [39] I estimate the following equation:

$$\ln(c_{t+1}/c_t)^{ij} = \psi_t + \phi^{ij} + \xi_1 \ln(y)_t^{ij} + \xi_2 D_t^{ij} + \zeta_t^{ij}. \tag{18}$$

The dependent variable is the change in log consumption (c) for household i in district j at time t. As before, ϕ^{ij} and ψ_t are household and time fixed effects respectively, D_t^{ij} is a vector of demographic variables that affect the household's place in the life-cycle and ζ_t^{ij} is an error term. The exclusion restriction implied by the Euler equation is that the coefficient on lagged income (y_t^{ij}) is equal to zero if the household is able to smooth consumption. The prediction is that the restriction is more likely to be satisfied for groups that hold more assets and likely to be violated for groups that hold fewer. When the exclusion restriction is violated, the coefficient on income is negative because an increase in current income is positively correlated with a loosening of the liquidity constraint. As a result, consumption rises relative to its future level, lowering the expected growth in consumption.[23] This is derived explicitly by Zeldes [71].

As suggested by Morduch [39], a noisy measure of a household's borrowing constraint is:

$$\Phi_{hit} = \ln(c_{t+1}/c_t)_{hi} - \ln\widetilde{(c_{t+1}/c_t)}_{hi}\rfloor_{\xi_1=0}, \tag{19}$$

where $\ln\widetilde{(c_{t+1}/c_t)}_{hi}\rfloor_{\xi_1=0}$ is calculated by estimating equation 18 for households with above average income, setting the coefficient on income to zero. Using the estimated coefficients from this regression, optimal consumption growth is estimated for all households. The difference between this estimate of optimal consumption growth and actual consumption growth is a noisy measure of a household's borrowing constraint.

Table 21 shows the results of the estimation of equation 18. To test whether violation of the exclusion restriction depends on asset holdings, and as a means of developing a measure of households' credit constraints, the income variable is interacted with dummies for asset holding categories.[24][25] This is Morduch's [39] test for the presence of credit constraints.[26]

[23] Because the household is constrained it will always receive more utility from consuming the additional income rather than saving it.

[24] The sample is split into four groups (quartiles) based on mean self-reported value of asset holdings. More asset-rich households are less likely to face liquidity constraints.

[25] This test is performed by Morduch using land holdings as a measure of assets. This is not appropriate in this case because property rights to land are imperfect and land may not be in fixed supply. In the Peruvian case, when this equation is estimated using land holdings as a measure of asset position the coefficient on income is signifcant only for the most land-rich (!) households.

[26] An F-test (1, 16) of the equality of the coefficients on income for the households with the largest durables holdings and the households with "medium" durables holdings is not rejected at the 99 percent confidence level. (F-stat is 0.90, as compared to a critical value of 7.56).

Table 21: Euler equation estimate

Ordinary least squares estimates (1994-1997)	
Independent variables	Dependent variable: Δ log food consumption$_{t,t+1}$
Log small durables holdings income$_t$	-0.867 (0.858)
Log medium durables holdings income$_t$	-0.563^{**} (0.213)
Log large durables holdings income$_t$	-0.285^{**} (0.140)
Dummy for full property rights to land$_t$	-0.098 (0.279)
Change in adult-equivalent family size$_{t,t+1}$	0.194 (0.127)
Dummy for whether household is rural$_t$	1.913 (6.435)
Age of household head (lag)	-0.014 (0.017)
R-squared	0.63
Regression degrees of freedom	8
Strata	2
Clusters	13
Groups	44
Observations	88

Notes: Standard errors in parentheses are robust and adjusted for stratification and clustering of sample. Regression includes household and time fixed effects.
**significant at 5% level; * at 10% level.