Staff Paper

Are Poor Farmers to Blame for Environmental Degradation? Results From the Peruvian Altiplano

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Abstract

Links between poverty and natural resource degradation are examined in the context of soil erosion, fertility loss and overgrazing in the Peruvian Altiplano. Multiple regression analysis of 1999 farm survey data examines 1) what agricultural practices affect natural resource degradation, and then 2) what factors affect farmers' choices of those agricultural practices. Soil erosion and fertility loss appear reduced by increased fallow in crop rotations. Overgrazing and range species loss are affected by changes in herd size and rotational grazing. The effect of investment poverty on natural resource outcomes is not clear. However, social and human capital variables both tend to favor the choice of more sustainable agricultural practices. Natural resource conservation policies that build on traditional social institutions may offer promise in areas with strong social fabric where farmers tend not to invest financially in natural resource conservation.

Key words: Poverty, overgrazing, erosion, soil fertility decline, deforestation, agricultural economics, Peru, peasant agriculture.

35 pages

ARE POOR FARMERS TO BLAME FOR ENVIRONMENTAL DEGRADATION?

RESULTS FROM THE PERUVIAN ALTIPLANO

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Introduction: Evolving thought on links between poverty and the natural environment

Perceptions of how poverty alleviation, agricultural intensification, and environmental outcomes have evolved importantly over the past four decades. The current evolution began with Boserup's (1965) attack on Malthusian thought. She argued that population does not *result* from limited carrying capacity of the land. Rather, population density is a key *cause* driving agricultural intensification which can leads to economic growth and sustained productivity increases. An important corollary of her thesis is that although environmental degradation may result from population growth, it is not a necessary result (Boserup, 1965, p. 22). This claim has been supported by a number of subsequent studies (Templeton and Scherr, 1999).

How can population growth cause both declines and gains in agricultural productivity and natural resource conservation? The economic rationale is that agricultural productivity (per land unit) follows a U-shaped curve in response to the abundance of land per worker. Land productivity falls and then rises again as growing population reduces the price ratio of labor to land (Templeton and Scherr, 1999). This theory is consistent with Hayami and Ruttan's (1985) theory of induced innovation, whereby technological change saves the scarce factor. As land becomes relatively more scarce, farming technologies evolve away from those that saved labor and capital toward those that save land. This intensification process leads to greater land productivity, often including investments in sustaining productivity over the long term.

If the good news is that environmental degradation need not occur, the bad news is that degradation still does occur in certain circumstances. Some authors have pinned the blame on poor farmers who intensify production with labor-led strategies, unable to afford such complementary capital inputs as fertilizers and conservation investments that might support sustainable intensification (Mink, 1993; Clay et al., 1998). This line of argument shifts the blame for environmental degradation from population to poverty. But poverty is not a simple substitute for population, since agriculturally-related environmental degradation often occurs in economically depressed rural areas that are experiencing out-migration (García-Barrios and García-Barrios, 1990; Zimmerer, 1993). This suggests a dynamic interplay between population and poverty whereby intensification may fail to occur if too many people "vote with their feet" and depopulate a region. The environmental effects may be especially severe if the emigrants are working-age adults (García-Barrios and García-Barrios, 1990).

As evidenced in the Northern Hemisphere, agricultural environmental problems are hardly confined to impoverished areas. Exceptions to the poverty-degradation causal chain in the developing world include rangeland productivity losses due to overgrazing by large cattle herds. Such cases have engendered a literature that pins the blame for degradation on the wealthy or on institutional or market failures (Duraiappah, 1999).

Lacking in most of the economic literature is careful examination of the natural resource base (Reardon and Vosti, 1997). Natural resources provide the setting that makes attractive their exploitation by humans. In agriculture, this is largely determined by the availability and quality of soils, moisture, warmth, and sunshine. Agriculturally related natural resource problems can be divided into two categories. *Resource depletion* encompasses problems of aquifer exhaustion, soil fertility mining, soil erosion, deforestation, and overgrazing (the latter two both being forms of biodiversity loss). *Resource contamination* encompasses water pollution (e.g., by agro-chemicals, fertilizers or excess manure runoff), land salination, pesticide and antibiotic residues in food, and – at the large scale – global warming. Either of these two classes of problem can result either from “mistakes” due to gaps in farmers’ information and knowledge or else from rational behavior by farmers with multiple objectives, including risk aversion. But if farmers are reasonably well informed and if maximizing consumption or net income is their primary objective, then it is reasonable to associate wealth with the contamination problems and poverty with the depletion problems.

If this conjecture is true, then neither population growth nor poverty leads simply to natural resource degradation. Instead, degradation will depend on the kind of farming practices and their natural resource setting. The severity of the environmental problem is likely to depend not only on its causes, but also on the vulnerability of the specific natural resource setting (Lutz et al., 1994). And in some settings, the agricultural determinants of natural resource problems may turn out to have little link to conventional definitions of poverty.

This research examines a unique ecoregional setting: the Altiplano around Lake Titicaca in South America. As in other parts of the Andes, the area has suffered out-migration in recent years (Zimmerer, 1993). The environmental degradation problems identified there include: 1) soil erosion, 2) soil fertility decline, 3) overgrazing, and 4) deforestation. These problems all fall into the resource depletion category, with its implicit link to poverty as a determinant. But they encompass not only the apparently poverty-related problem of soil mining, but also the seemingly wealth-related problem of overgrazing. For each of these problems, our objectives are to answer:

1) How are natural resource outcomes related to agricultural practices?
2) How does poverty affect the choice of those agricultural or forestry practices that degrade the natural resource base?

In the remainder of this paper, we present a conceptual model of linkages between poverty (as measured by farm assets), choice of farming practices, and natural resource outcomes. That model is examined empirically in search of links between low asset levels and natural resource degradation. We close by discussing how results for this eco-region and the relevant asset categories contribute to the state of knowledge on poverty-environment linkages.

A conceptual framework for poverty-environment linkages

The framework used here for understanding poverty-environment linkages proceeds through two stages, as illustrated in Figure 1. First, farmers choose their agricultural practices. Their choices are influenced by household asset levels, the external economic environment, and natural resource endowments. Second, their farming practices, in turn, combine with natural environment characteristics plus random environmental changes to create natural resource outcomes. Those outcomes, positive or negative, then shape farmers' subsequent choices in future periods.

In order to diagnose the specific agricultural practices and household assets that determine outcomes of the two stages, the problem is best examined backwards, beginning with outcomes and searching for their determinants. The first step is to identify the agricultural practices that affect natural resource outcomes. The following equation converts the processes from Figure 1 into algebraic form for natural resource characteristic i (NR_i):

$$NR_{it+1} = NR_{it} + f(x_t, z_{Nt}) + \varepsilon_{it+1} \tag{1}$$

Equation (1) states that the status of natural resource i at time t+1 depends on its status in the previous period as well as changes wrought by a vector of agricultural practices (x_t) as conditioned by other natural characteristics (z_{Nt}) and random effects (ε_{t+1}). Equation (1) can be restated in terms of change in natural resource status by subtracting NR_{it} from both sides of the equation to yield difference equation:

$$\Delta NR_i = f(\Delta x, \Delta z_N) + e \tag{2}$$

Natural conditions (z_N) include land characteristics such as elevation, slope, aspect and soil type, as well as other location and climate characteristics governed by geography. These characteristics cannot be changed, so for public policy purposes, it does no particular good to know that erosion is more severe on steep slopes. What does matter for the design of natural resource policy are the farming practice variables (x) that are chosen by human decision makers.

Once a particular farming practice has been determined to affect natural resource status, the second stage question is which factors govern the choice to adopt that practice. As modeled here, this microeconomic decision emerges from the household's attempt to optimize its perceived welfare subject to limitations imposed by the available economic and natural resources, as well as the parameters imposed by the larger economy. In simplified form, the household's problem can be modeled as follows:

$$\begin{aligned} &\max_x U(c, y^c) \\ &\textit{subject to} \\ &y = y(L_a, x | k, z) \\ &p_c c \le p_y (y - y^c) - p_x x - p_{ah} L_{ah} + p_{\ln} L_n \\ &L = L_{af} + L_n \end{aligned} \tag{3}$$

The model in Equation (3) states that the farm household chooses the agricultural practices x that will maximize the expected utility from consuming marketed consumption good c and home produced good y in quantity y^c. The maximization is constrained by the technology for producing good y on the farm, specifically its requirements in agricultural labor (L_a) and agricultural practices (x), as conditioned by farm level capital (k, in various forms) and other natural and external economic characteristics (z). It is assumed that the production function for y is differentiable, increasing, and concave. We do not assume that production function y() is separable in inputs x. A budget constraint states that no more of c can be purchased at price p_c than the household can afford with net income from sales of y (after subtracting home consumption y^c , the cost of production practices ($p_x x$), and the cost of hired farm labor ($p_{ah}L_{ah}$) plus income from nonfarm employment ($p_{ln}L_n$). Finally, the labor available for on-farm production work (L_a) must either come from the family (L_{af}) or from hired labor (L_{ah}). Family labor may be devoted either to on-farm agricultural work (L_{af}) or to non-farm work (L_n). The solution to this constrained optimization problem yields a reduced-form input demand equation for farming practice x_{ji}, the specific practice x_j associated with the state of natural resource i in Equations (1-2).

$$x^*_{ji} = x^*_j(p, x_{(j)}, k, z) \tag{4}$$

The optimal input demand function for x_{ji} in Equation (4) depends on the prices (p) of output y, inputs x, and labor L_a and L_n, the levels of other agricultural practices $x_{(j)}$ other than x_j, farm capital (k), and conditioning factors (z) related to economic infrastructure, natural characteristics, and the household's management knowledge and information.

Of particular interest in this study will be the levels of assets, k, which measure poverty. Reardon and Vosti (1995) make a useful distinction among categories of assets that allows them to distinguish between "welfare poverty" and "investment poverty." The former definition is based on human survival, usually measured in nutritional intake requirements. But for natural resource management, the more relevant definition is "investment poverty," the level below which it becomes impossible “to make minimum investments in resource improvements to maintain or enhance the quantity and quality of the resource based – to forestall or reverse resource degradation” (p. 1498).

A very wide range of asset categories can be relevant to natural resource management. In citing natural resources, human resources, and physical and financial resources, Reardon and Vosti (1995) go far beyond conventional accounting definitions of “assets.” Such definitions would measure capital assets (k) as physical and financial assets, including land, equipment, buildings, livestock, financial assets and other inventories with marketable value. People are, of course, a key productive resource whose value as a productive asset depends on their number as well as their “quality” as superficially measured by age, health and education. In the simple household model in Equation (3), the z variable accounts for such broader asset categories as natural resource characteristics and institutional setting. An additional asset category meriting consideration is social capital. The degree to which people in a community care about one another may ameliorate other conventional resource constraints such as market access or credit limitations (Bebbington, 1997). Social capital may also allow a community to impose social norms to discourage individual behavior that undermines the long-term interests of the community as a whole. Such an internalization of economic externalities may include natural resource conservation.

In the absence of excessively limiting assumptions, the variety of agriculturally related natural resource issues makes it impossible to derive *a priori* analytical results from a conceptual model like this one. Hence, insights must come from empirical evaluation of the natural resource and farming conditions in specific agro-ecological settings.

Data and empirical models

Research setting

The empirical analyses presented here focus on soil erosion, soil fertility decline, and overgrazing in the Peruvian Altiplano. The Altiplano lies at altitudes of 3800 to over 4500 meters in the broad Lake Titicaca basin formed by the Andes mountains across the Peru-Bolivia border. The data come from a survey of 265 farms conducted during April to June, 1999, at the end of the 1998-99 agricultural season. The study took place in the watershed formed by the Ilave and Huenque rivers on the south side of Lake Titicaca in southeastern Puno Department. This watershed was chosen for having documented problems of soil erosion (PELT, 1993). Peruvian census data shows that district-level poverty in the zone ranged from 63 to 95 percent of households with at least one Unmet Basic Need (INEI, 1994).

The survey employed a clustered, stratified sampling design. Strata were defined based on four agro-ecological zones that vary with distance from Lake Titicaca (AUTHORS, 1999a; Tapia, 1996). The flat, Lakeside zone has a frost-free cropping season of 5-6 months and 700-750 mm. of rainfall annually. Farming in the Lakeside zone is characterized by intensive potato-based crop rotations that include rising shares of forage crops to supplement the lake reeds traditionally used for livestock feed. Official measures of poverty are lowest in the Lakeside zone. Moving up and away from the lake, the Suni zone is next, with a frost-free season ranging from three to five months and slightly less rainfall than the Lakeside zone. Frost risk depends upon landscape position, leading to a distinction between the Suni A and Suni B zones, where the former has more "lake effect" and is less prone to night-time frosts. Potatoes can be grown in the Suni A zone, whereas they are a very risky crop in the Suni B zone. Consequently, households in the Suni B zone rely more heavily on rangefed livestock production and less on crops than their counterparts in the Suni A zone. Moving higher and farther yet from Lake Titicaca, the Dry Puna zone has a frost-free season under three months and precipitation under 600 mm annually. Agricultural production systems in the land-abundant Dry Puna are overwhelmingly oriented toward grazing, predominantly sheep and alpacas. The Dry Puna has the highest levels of poverty as officially defined.

Within each of the four agro-ecological zone strata, two to three villages were selected as sample clusters to reduce the cost of transportation. Based on testimony of government officials in the area, villages were chosen such that one was relatively less and one relatively more poor than the norm for the zone. Within villages, an attempt was made to stratify households by apparent wealth level, in consultation with village leaders (AUTHORS, 1999b); however, records were not retained on the original asset classification of households. The sampling stratification scheme was designed to insure a broad range of asset levels across all four agro-ecological zones in order to test the research hypotheses about poverty-environment links.

Econometric models

The empirical approach was to examine each of the three major natural resource areas in two steps. First, regression analysis was applied to Equation (2) in order to answer the question, "Which farming or forestry practices are key determinants of this natural resource outcome?" Next, Equation (4) was analyzed for those farming or forestry practices that were important determinants of soil nutrient loss, erosion and overgrazing. Specifically, the second stage regressions sought to answer the questions, "Do asset levels matter in determining the choice of farming/forestry practices? If so, which assets matter most -- a) land, equipment, livestock, buildings, b) household labor, c) human capital (education), d) social capital?"

The survey’s clustered sample design embedded village clusters within the agro-ecological zone strata. Due to similarities that typically occur in a community, it was inappropriate to assume independent observations within village clusters (Deaton, 1997). Village-based cluster effects were factored into the natural resource regressions using binary village dummy variables. In the agricultural practices regressions, where other village-level variables were present, the cluster effect was captured by using random-effects regression models (StataCorp, 1999). Random effects econometric models assume that the error term has two parts, one at the cluster level and one that is independently distributed at the individual level. A correlation coefficient, rho, estimates the proportion of total variance accounted for at the cluster level.

In the paragraphs below, we first describe the natural resource models used to identify agricultural practices that were key determinants of natural resource degradation. Afterward, we describe the generalized asset model that was applied to each of the key agricultural and forestry practices to identify those assets that were major determinants of the choice of practices.

1. Soil nutrient loss

Soil nutrient loss is a major concern among farmers in the Ilave-Huenque watershed. Fifty-eight percent of farmer respondents blamed productivity losses on “lack of nutrients” or “tired land,” more than any other response. This binary dependent variable was the basis of a probit regression to identify causal factors. Because it applied chiefly to crop production, the analysis was confined to the three agro-ecological zones where crops are grown (omitting the livestock zone of the Dry Puna).

Explanatory variables in the model included dummies for agro-ecological zone and village, the change in proportion of fallow farmland over the past 20 years, the proportions of fields with vertical and contour furrows, and expenditures per hectare on fertilizers and pesticides (including fungicides). Quadratic forms of most explanatory variables were tested for inclusion in the model. Final model variables were selected on the basis of theoretical consistency, parsimony, and statistical Wald tests (not reported) (Lau, 1986). The base model situation (with values of dummy variables at zero) was a flat field in the Lakeside zone, where tillage was unrelated to slope gradient.

2. Soil erosion

As a process that occurs gradually over time, soil erosion is difficult to measure in a single visit survey. The soil erosion model used two measures of soil erosion. The first is a Likert scale that increases with loss in soil depth over the past 20 years (values ranged from 1 = major gain to 5 = major loss of soil). The second measure was the proportion of yield lost under typical growing conditions over the past 20 years. Because this value was reported only for those survey respondents who reported that yields had declined (89.3 percent of those living in the three crop production zones), the data are censored at zero. Consequently, the yield loss model was estimated using tobit regression; the soil depth model was estimated using ordered probit.

Like fertility loss, erosion also applies to the soil, so the same explanatory variables used in the soil nutrient loss probit model were repeated here. In addition, several environmental variables were added relating specifically to likelihood of erosion. These added variables included the proportion of farm fields in footslope and hillside positions (as proxies for slope characteristics), the proportion of fields planted to small grains (a crop cover with fibrous roots that tends to reduce erosion), and the estimated value of farm labor (a proxy for tillage and mechanical movement of soil). The Dry Puna zone was again omitted from these regressions on water-based soil erosion due to its lack of cropping activities.

3. Overgrazing

Overgrazing can result in both sparse pasture cover and loss of the range species preferred by livestock. The survey measured these two outcomes in distinct ways. All farmers were asked if they had observed a decline in agricultural productivity over the past 20 years. Those that replied “yes” (91.3 percent) were asked to name up to six causes, three for crops and three for livestock. A binary variable was created from those answers naming overgrazing or poor pasture quality as the reasons for productivity decline (35.4 percent of respondents). This variable was used as the dependent variable in probit regressions.

Loss of range species was measured by a separate question asking whether natural pasture species had disappeared. If so, the respondent was asked to name up to four and to identify up to three reasons for their loss. A new count variable was created for the number of species lost. This second measure of overgrazing was used as the dependent variable in a Poisson regression.

The overgrazing and the species loss regressions shared the same set of explanatory variables. The natural condition variables included binary variables for the presence of productivity-damaging range pests, drought, frost, sun and wind conditions. The farming practice variables included stocking rate (sheep-equivalent value units per hectare), forage crop availability (in hectares per sheep-equivalent value unit), and decrease in herd size over the past

20 years (Likert scale variable where 1=major increase and 5=major decrease). The agro-ecological zone and village binary variables were also included (with the Lakeside zone again serving as the default zone). A special model for the Dry Puna zone included rotational grazing, a practice not recorded in the other zones.

4. Deforestation

Most households surveyed cut trees or bushes for cooking fuel. Timber harvest affects the population, age and height of remaining trees. In small areas of the Lakeside zone, pines, eucalyptus, and other new tree varieties had been planted. In most areas, the trees were harvested without replacement, although harvesters typically leave rooted branches of bushy species such as tola[1] and queñua (*Polypsis incana*).

Households that answered affirmatively to the question, “Do you participate in the extraction of bushes and trees?” (58.8 percent) were asked to identify the forest species that is most important to the household. Next, the respondent was asked to compare the present with twenty years ago for the following: a) round-trip time required to collect a load of wood, b) height to which the tree or bush is allowed to grow before being cut, c) number of years required to reach that height, as well as d) what kinds of fuel were used for cooking.

The degree of forest resource degradation was measured by reported changes over 20 years in wood cutting time, tree height, and tree age at cutting. Explanatory variables included whether the household cut trees, whether it had reported using trees for fuel, whether it cooked with wood (all binary), the normalized value of wood collected, and the distance to a gravel road. In addition, the agro-ecological zone binary variables were included.

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[1] Various authors classify tola as *Baccharis* spp., *Diplostephium* spp., *Parastrephia lediphylla* (ONERN); and *Lepidophyllum cuadrangulare* (Gomez).

Choice of agricultural or forestry practices

The agricultural practice regressions used generalized least squares (GLS) and probit random-effects regression to compensate for the clustered sampling design. Where feasible, all models used the same set of explanatory variables, based on the input demand function in Equation (4). These variables include prices, complementary agricultural inputs, capital (fixed, human, and social), nonfarm income, management information, economic infrastructure, and natural resource capital. Given the distinct nature of the rangefed livestock-oriented Dry Puna zone, many of the farming practices regressions were either irrelevant or specific to the Dry Puna. Models specific to the Dry Puna used a more restricted set of variables.

Results

1. Agricultural practices are key determinants of natural resource status in the Altiplano

Results of the soil nutrient loss and erosion models highlight the importance of fallows and tillage practices (Table 1). The probability of a farmer experiencing soil nutrient loss over the past 20 years depended upon village, soil depth loss, soil texture, and farming practices. Soil depth loss contributed significantly to the probability of experiencing soil nutrient loss. The probability of soil nutrient loss was aggravated on sandy soils. The practices of tilling furrows (either contour or vertical) and use of pesticides both detracted from the likelihood of soil nutrient loss. Both these results are somewhat unexpected, as neither directly affects soil fertility.

Soil depth loss over the previous 20 years became the dependent variable in an ordered probit model of erosion determinants (Table 1). Perceived soil loss was much more likely in the hilly Suni A and Suni B zones than in the Lakeside area. The proportion of fields in fallow and fertilizer expenditures per hectare were both associated with reduced reported soil loss.

The yield loss tobit model echoed the important role of fallowing. Once again, the proportion of fallow fields had a highly significant effect reducing reported yield loss over a 20-year period. Curiously, the proportion of fields with vertical furrows was associated with reduced yield loss. Consistent with expectations, yield loss was worse on sandy soils but lessened on fields located at foot slope position (up to a maximum of 32% of fields, beyond which yield loss would increase). Foot slope fields benefit from sediment deposition from up slope locations. Yield loss was also mitigated by pesticide use and labor value (the latter typically linked to weeding and harvest tasks).

The overgrazing and range species loss regression models pointed to herd size changes over time and rotational grazing as the chief agricultural practices with important effects on pasture sustainability (Table 2). Of secondary note were stocking rate and improved pastures. Village dummy variables were nowhere significant and so were dropped from all models.

The poor pasture probit models examined determinants of the probability that farmers mentioned poor pastures as a major cause of reduced productivity over the past 20 years. In the overall sample, poor pastures were strongly associated with decreases in herd size and reports of drought damage. The correlation between poor pastures and herd size change is misleading, since decreases in herd size are more likely to be the result of poor pastures, rather than the cause. Due to the distinct characteristics of the Dry Puna zone, where livestock are raised extensively, a separate probit analysis was run for that zone. There an additional variable was available to indicate the presence or absence of rotational grazing, whereby pastoralists move livestock to new pastures according to the season of the year. Results for the Dry Puna again found drought to contribute to poor pastures. Rotational grazing significantly reduced the probability of poor pastures (as did reports of frost damage, which may have reduced herd sizes).

The results of the Poisson regression of range species loss had many parallels to those from the poor pasture probit. Reported loss of range species was worst in the Dry Puna zone. Drought, pasture pests and sun burn damage exacerbated the likelihood of range species loss. Unexpectedly, so did the availability of improved pastures and lake area where totora reeds could be harvested for forage. But since improved pastures replace cropping areas and the pasture grown in fallow land, the land available for native pasture species decreases proportional to the area with improved pasture. Near the lake, fallows are absent, crop plots are small, and animal feeding is based on aquatic plants. Certain native species (notably *llachu*) are being depleted by the excessive use.

The range species loss analysis was run separately for the Dry Puna zone. There, the stocking rate and drought damage both contributed to range species loss. The practice of rotational grazing again significantly reduced range species loss.

Of the deforestation determinants regressions, only the ones on change in cutting time and tree height were significant (Table 3). Tree cutting was the sole practice that contributed significantly to the increase in observed time required to go and cut wood over the past 20 years. Neither of the two practices analysed (tree cutting and cooking with wood) proved significant in influencing the observed reduction in reported tree height. Instead, the reduction in tree height was explained chiefly by location in the Dry Puna agroecological zone. All three models were tested for random effects, but finding no evidence, the results are reported based on ordinary least squares models. The regression on change in tree age at harvest remained insignificant even after outlier variables were dropped.[2]

To summarize the empirical responses to the first research question regarding agricultural and forestry practices as determinants of natural resource outcomes:

1. Fallow in crop rotations is strongly associated with reduced soil erosion and reduced long-term crop yield loss. (And soil erosion, in turn, is strongly linked to soil nutrient loss.)
2. Tilled furrows and pesticide use are associated with reduced soil nutrient loss; vertical furrows are also linked to reduced yield loss over time (contrary to expectations).
3. Herd size decrease over 20 years is associated with probability of poor pastures.
4. In the Dry Puna zone, rotational grazing is strongly associated with reduced probability of poor pastures and reduced number of range species lost.
5. Tree cutting was associated with reduction in reported tree height over 20 years.

2. Farming practices are linked to social and human capital, but not strongly explained by fixed capital assets; forestry practices are linked to fixed capital assets

The second stage analyses sought to determine what factors influence the choice of those farming practices linked to natural resource degradation (or sustainability). Of particular interest is the effect of poverty – and type of poverty – on choice of agricultural practices. The practices of interest (listed above) were fallowing cropland, vertical furrows, change in herd size, and (for the Dry Puna) the use of rotational grazing. These analyses were modeled using a single set of explanatory variables derived from the categories in input demand Equation (4).

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[2] One household in the Lakeside zone with newly planted pine trees was dropped from the change in tree cutting time regression as a (negative) outlier. Two others in the Suni A zone were dropped from the change in tree age model. regression due to extreme values.

The categories of explanatory variables included prices and economic infrastructure, poverty level, capital (fixed, human, and social), labor, nonfarm income, natural resource capital, and other agricultural inputs. The price/infrastructure category included potato price and distance from village center to nearest paved road. Poverty level was measured as the sum of Unmet Basic Needs as defined by Peru's national statistical service (INEI, 1994). Fixed capital included cropped area, pasture area, vehicles owned, stores or farm buildings owned, well equipment, other agricultural equipment, home appliances, and total livestock (measured as sheep-equivalent value units [SEVU]). Farm labor was measured as the total adult family labor supply minus the person-years worked in non-farm employment during 1998-99. Credit and non-farm income were measured in cash amounts declared during the year from April 1, 1998, to March 31, 1999. Human capital measures were years of schooling by household head and number of household adults having completed secondary school. Social capital variables included whether the household head had held an official position in the community during the past five years, the number of association memberships by household members, village area devoted to *aynoca* land (where individual owners must follow community-dictated crop rotations), and village families using communal pastures. In addition, several of the same natural resource and agricultural practice variables were included as appeared in the natural resources regression models. Finally, in order to capture knowledge transfer in a setting where agricultural extension has disappeared, a dummy village-level binary variable was included for existence of a natural resource-oriented development project during the past ten years.

The results are as surprising for the relationships that are absent as the ones that are present. As shown in Tables 3 and 4, prices and economic infrastructure have no significant effect on the choice of these agricultural practices. Several fixed capital variables are significant, but in inconsistent ways that offer no clear support or contradiction of the opposing sides in the poverty-environment debate. The proportion of fields in fallow increases with well equipment units and decreases with non-farm income. The proportion of fields with vertical furrows decreases with Unmet Basic Needs. Livestock herd size decreases are boosted by store and building ownership but decreased by ownership of wells and other agricultural equipment and (tautologically) by livestock capital. Rotational grazing is more likely among owners of more livestock capital and less likely among store and building owners.

Among the garbled effects of fixed capital on adoption of sustainable agricultural practices, livestock capital offers the chief discernable pattern. Livestock-related management changes are closely linked to capital in the form of livestock numbers and the availability of water for them (via well equipment). However, the causal link between herd size and poor pastures remains unclear, and larger herds are associated with more sustainable rotational grazing. If these results are hard to interpret for management of livestock, they are even more so in crops. Overall, the results show no clear link between fixed asset ownership and choice of agricultural practices that degrade natural resources.

Social and human capital variables display a clearer link to the choice of sustainable agricultural practices. The social capital variables play positive roles in almost all cases. Land area under *aynoca* management is strongly associated with more cropland in fallow and less tree cutting. The *aynoca* is a traditional land management system under which villagers with fields in a designated *aynoca* area are obliged to follow an established crop rotation. The rotation typically includes a fallow period. Apart from the statistical analyses reported here, one explanation farmers mentioned for loss of soil fertility was that they had given up their *aynoca* fields; 14% of all respondents (including 35% of those in one village) blamed crop productivity loss on the abandonment of *aynocas*.

The other social capital variables also largely favored adoption of good land stewardship practices. Association memberships are associated with more land in fallow (good), but also reduced rotational grazing (not good). A public position held by the household head is associated with increased rotational grazing. However, household heads who held a public position were also linked to more tree harvesting.

Human capital too appears to promote the use of more sustainable agricultural practices. Use of fallow was more common among households with more adults who completed secondary school and in villages that had enjoyed a natural resources development project. Livestock herd size was less likely to decrease where the household head was better educated (and herd decreases were associated with poorer pastures). Likewise, tree cutting was less common where household heads held higher levels of education.

Forestry practices, by contrast, are clearly linked to asset poverty. As shown in Table 6, the probability of engaging in tree extraction was reduced by land holdings (for both crops and grazing) and access to credit. It was further reduced by access to public infrastructure in the form of paved or improved dirt roads. Among human capital variables, educational level of the household head reduced the likelihood of cutting trees. Social capital variables had mixed effects, but in communities with a larger area under joint *aynoca* crop management, the probability of tree cutting was reduced. The only forms of capital associated with more tree harvest were herd size and leadership experience, both of which have alternative explanations linked to information rather than capital. Herding brings household members into contact with woodlands, while community leadership may acquaint the leader with resources beyond the bounds of his or her own lands.

Discussion and conclusions

The link between certain agricultural practices and natural resource sustainability is clear. In the impoverished setting of the Peruvian Altiplano, soil nutrient loss and erosion were diminished by the use of fallow and, in some cases, by the use of vertical furrows. Overgrazing was reduced by rotational grazing. With the direction of causality unclear, overgrazing was also positively associated with decreases in herd size.

The three agricultural practices with clear natural resource impacts require either land (for fields in fallow rotation) or labor (for tillage or rotational grazing). None requires much investment capital. So it should not be surprising that fixed capital variables had little ability to explain adoption of these methods.

By contrast, deforestation in this area is chiefly caused by the search for fuel wood. Not cutting wood carries the financial opportunity cost of buying some other fuel for cooking and heating. As a result, the households poorest in land ownership, access to credit and community lands, schooling, and access to roads were those most likely to timber native forests.

Does the minor role of fixed capital assets in affecting soil and grassland resources mean that the debate over poverty and natural resource degradation is irrelevant in the Altiplano? Can policy makers conclude that deforestation is the only area where poverty is relates to natural resource degradation in this setting? Almost certainly not, but a firm conclusion can only be reached by studying a wider range of asset levels. Poverty was pervasive among the farm households surveyed. Seventy-two percent lacked a latrine, among other unmet basic needs.

Two-thirds earned less than Peru's monthly minimum wage of $100 per month. Since nearly everyone interviewed suffered "welfare poverty," not to mention "investment poverty," this study cannot draw conclusions about agricultural practices that are affordable only to the wealthy.

This study does offer insights about the adoption of natural resource-conserving agricultural practices in a setting where poverty is widespread. It demonstrates that relative improvements can be made in natural resource stewardship – even among the very poor. Awareness of sustainability problems and low-cost steps to address them, combined with closely-knit community structures are the key factors support good stewardship in such a setting. Traditional social institutions like the *aynoca* continue to play a valuable role in a setting where fallow rotations are the primary means of restoring soil fertility and preventing erosion.

The long slow emigration from the Andean highlands gives ample evidence that residents view life chances elsewhere as more favorable. Continuing emigration may leave Altiplano agriculture stagnating in a low-productivity equilibrium where the relative price of labor to land never triggers the kind of investments that raise land productivity beyond the bottom of Templeton and Scherr's (1999) U-curve. Unspoken in the literature about intensification is that as economies develop, some regions see agricultural intensification while others see agricultural abandonment. The latter can also offer environmental benefits, as witnessed by the reforestation of the eastern United States in the past 70 years. The fact that Altiplano farmers are not making significant investments in agricultural conservation may be due to their poverty, but it may also be due to a belief that their scarce funds are better invested elsewhere – perhaps not in agriculture and perhaps not in the Altiplano. Only dramatic changes in market access and local employment opportunities are likely to change this in a fundamental way. The results here show that even incremental changes in market and credit access can reduce deforestation. But the effects for agricultural natural resources may be hidden by a low-level poverty equilibrium.

In the absence of dramatic changes in market access and employment opportunities, the policy lesson from this research is that incremental natural resource benefits can be had at very low cost. In areas where the social fabric is strong and capital is scarce, natural resource policies should focus on diffusing knowledge about natural resource stewardship using affordable practices. Traditional social norms and institutions such as the *aynoca* already provide incentives for sustainable farming. These institutions should be understood and built upon if the objective is to encourage marginal changes to effect better stewardship using traditional practices.

References

AUTHORS, 1999a. “Using Farm Data to Validate Agro-ecological Zones in the Lake Titicaca Basin, Peru.”

AUTHORS, 1999b. “Descripción Preliminar de la Zona y Metodología de Colección de Datos para el Estudio sobre la Pobreza Rural y el Deterioro Ambiental: Cuenca del Lago Titicaca (Subcuenca de los Ríos Ilave y Huenque).”

Bebbington, A., 1997. “Social capital and rural intensification: Local organizations and islands of sustainability in the rural Andes.” Geographical Journal 163, 189-197.

Boserup, E., 1965. The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure. New York: Aldine.

Clay, D., T. Reardon, and J. Kangasniemi, 1998. "Sustainable Intensification in the Highland Tropics: Rwandan Farmers' Investments in Land Conservation and Soil Fertility." Economic Development and Cultural Change. 46, 351-378.

Deaton, A., 1997. The Analysis of Household Surveys: A Microeconomic Approach to Development Policy. Baltimore: Johns Hopkins.

Duraiappah, A. K., 1998. "Poverty and Environmental Degradation: A Review and Analysis of the Nexus." World Development. 26, 2169-2179.

García-Barrios, R. and L. García-Barrios, 1990. "Environmental and Technological Degradation in Peasant Agriculture: A Consequence of Development in Mexico." World Development. 18, 1569-1585.

Hayami, Y. and V. W. Ruttan, 1985. Agricultural Development: An International Perspective. 2nd edition. Baltimore: Johns Hopkins University Press.

INEI (Instituto Nacional de Estadística e Informática del Perú), 1994. Perú: Mapa de Necesidades Básicas Insatisfechas de los Hogares. Tomo I: A nivel Provincial y Tomo II: A nivel Distrital. Lima.

Lau, L.J., 1986. "Functional Forms in Econometric Model Building." In Z. Griliches and M. D. Intrilligator, eds., Handbook of Econometrics. Amsterdam: Elsevier. Pages 1515-1564.

Lutz, E., S. Pagiola, and C. Reiche, 1994. "The Costs and Benefits of Soil Conservation: The Farmers' Viewpoint." The World Bank Research Observer. 9, 273-295.

Mink, S. D., 1993. Poverty, Population and the Environment. World Bank Discussion Paper No. 189. Washington, DC: World Bank.

Morgan, R.P.C. 1996. Soil Erosion and Conservation. 2nd edition. Longman: Kuala Lampur, Pages 137, 138.

PELT (Proyecto Especial Binacional Lago Titicaca), 1993. Plan Director Global Binacional de Protección de Inundaciones y Aprovechamiento de los Recursos del Lago Titicaca, Río Desaguadero, Lago Poopo, y Lago Salar de Coipasa (Sistema T.D.P.S.). Comisión de las Comunidades Europeas y las Repúblicas de Perú y Bolivia. Puno, Perú, y La Paz, Bolivia.

Reardon, T. and S. A. Vosti, 1995. "Links Between Rural Poverty and the Environment in Developing Countries: Asst Categories and Investment Poverty." World Development. 23, 1495-1506.

Reardon, T. and S. A. Vosti, 1997. "Policy Analysis of Conservation Investments: Extensions of Traditional Technology Adoption Research." In Stephen A. Vosti and Thomas Reardon, eds., Sustainability, Growth, and Poverty Alleviation: A Policy and Agroecological Perspective. Baltimore: Johns Hopkins University Press. Pages 135-145.

Scherr, S. J., 1998. "Poverty-Environment Interactions in Agriculture: Key Factors and Policy Implications." Paper prepared for the United Nations Development Programme and the European Commission expert workshop on Poverty and the Environment, Brussels, Belgium, January 20-21, 1998.

StataCorp, 1999. Stata statistical software: Release 6.0. College Station, TX: Stata Corporation.

Tapia, M.E., 1996. Ecodesarrollo en los Andes altos. Lima: Fundación Friedrich Ebert.

Templeton, S. R. and S. J. Scherr, 1999. "Effects of Demographic and Related Microeconomic Change on Land Quality in Hills and Mountains of Developing Countries." World Development. 27, 903-918.

Zimmerer, K. S., 1993. "Soil Erosion and Labor Shortages in the Andes with Special Reference to Bolivia, 1953-91: Implications for 'Conservation-with-Development'." World Development. 21, 1659-1675.

Table 1: Soil nutrient loss, soil loss and 20-year yield loss regression results, cropped zones of Ilave-Huenque basin, Puno, Peru, 1999

Variable	Unit of measure	Nutrient Loss (probit)		Soil loss (ordered probit)		Yield loss (tobit)	
		Coef.	z-stat.	Coef.	z-stat.	Coef.	t-stat.
Location & Natural factors (z)							
Village 9(Lake)	Binary	0.945	2.04 **				
Zone: Suni A	Binary	-0.645	-1.34	1.753	4.64 ***	-0.037	-0.49
Village 1(Suni A)	Binary	1.015	1.82 *				
Village 4 (Suni A)	Binary	0.231	0.59				
Zone: Suni B	Binary	0.501	0.86	1.154	2.57 ***	0.017	0.27
Village 6 (Suni B)	Binary	-0.737	-1.63 *				
Village 10 (Suni B)	Binary	-0.870	-1.87 *				
Footslope	Proportion of fields			0.140	0.59	-0.381	-1.90 *
Sq. footslope	Proportion of fields					0.614	1.97 *
Slope	Proportion of fields			0.582	0.81	0.162	1.67
Sandy soil	Proportion of fields	0.912	2.02 **	-0.133	-0.35	0.138	2.58 **
Soil depth loss	Likert (5 levels)	0.565	2.88 ***	n.a.		n.a.	
Management factors (x)							
Fallow fields	Proportion of fields	-1.193	-1.37	-1.365	-1.81 *	-0.340	-3.27 ***
Small grains	Prop. of planted area			-0.445	-0.88	0.080	1.13
Vertical furrows	Proportion of fields	-0.999	-2.26 **	-0.398	-1.18	-0.089	-1.88 *
Contour furrows	Proportion of fields	-1.501	-1.63 *	-0.368	-0.44	0.078	0.63
Fertilizer	Kg/ha	0.001	0.57	-0.002	-1.80 *	0.000	-0.21
Pesticides	Kg/ha	-0.026	-2.02 **	-0.008	-0.57	-0.009	-2.03 **
Sq. Pesticides	Kg/ha			0.001	1.33	0.000	1.94 *
Labor value	New soles			0.000	-0.62	0.000	-2.31 **
Sq. labor value	New soles					0.000	1.95 *
Constant		-0.793	-1.02			0.474	7.70 ***
Regression diagnostics:							
	Observations (n)	181		173		172	
	Chi-square	36.69		41.98		51.61	
	P-value	0.001		0.000		0.000	

Note: Asterisks denote coefficient significance at 0.10 (*), 0.05 (**), and 0.01 (***) levels.

Table 2: Overgrazing and range species loss regression results, Ilave-Huenque watershed, Puno, Peru, 1999

Variable	Unit of measure	Poor pasture models				Range species loss models			
		All zones (probit)		Dry Puna (probit)		All zones (poisson)		Dry Puna (poisson)	
		Coef.	z-stat.	Coef.	z-stat.	Coef.	z-stat.	Coef.	z-stat.
Location & Natural factors									
Zone: Suni A	Binary	0.070	0.2			-0.257	-0.87		
Zone: Suni B	Binary	0.284	0.78			0.234	0.80		
Zone: Dry Puna	Binary	0.519	1.32			0.706	2.37 **		
Pasture pest damage	Binary	-0.153	-0.37	-0.540	-0.79	0.600	2.79 ***	-0.010	-0.03
Drought damage	Binary	0.435	2.33 **	0.784	1.72 *	0.348	2.60 ***	0.923	3.15 ***
Frost damage	Binary	-0.174	-0.78	-1.607	-2.20 **	-0.058	-0.37	0.025	0.09
Sun damage	Binary	0.079	0.32	-0.010	-0.02	0.288	1.91 *	0.088	0.43
Wind damage		-0.042	-0.11	-0.144	-0.27	0.241	1.20	0.371	1.47
Management factors									
Stocking rate	Sheep-equiv. units / ha.	0.000	1.23	0.037	0.92	0.000	0.75	0.038	2.15 **
Forage availability	Cereal has./ SEV unit	0.029	0.04	926.52	0.32	0.460	0.92	358.63	0.23
Herd decrease	Likert (5-levels)	0.175	2.38 **	0.061	0.41	0.047	0.96	-0.016	-0.19
Rotational grazing	Binary			-0.837	-2.12 **			-0.420	-2.02 **
Pasture area	Hectares	-0.002	-1.64	-0.002	-1.46	-0.001	-1.96 **	0.000	-0.67
Improved pastures	Proportion of pasture area	-0.723	-1.33	4.896	0.42	1.326	4.54 ***	-0.706	-0.16
Lake reed pasture	Proportion of pasture area	-0.119	-0.26			0.638	1.86 *		
Constant		-1.296	-3.02 ***	-0.157	-0.21	-0.637	-1.97 **	-0.197	-0.43
Regression diagnostics:									
	Obs. (n)	248		61		248		61	
	Chi-square	26.5		21.1		78.0		28.5	
	P-value	0.022		0.032		0.000		0.003	

Note: SEVU=sheep-equivalent value unit.

Note: Asterisks denote coefficient significance at 0.10 (*), 0.05 (**), and 0.01 (***) levels.

Table 3: Deforestation regression results, Ilave-Huenque watershed, Puno, Peru, 1999

Variable		Change in cutting time (OLS)			Change in tree height (OLS)			Change in tree age (OLS)	
	Unit of measure	Coef.	t-stat.		Coef.	t-stat.		Coef.	z-stat.
Location & Natural factors									
Zone: Suni A	Binary	-0.088	-0.45		-0.164	-1.47		-0.317	-0.43
Zone: Suni B	Binary	0.202	1.07		0.113	1.06		-0.034	-0.05
Zone: Dry Puna	Binary	-0.287	-1.30		0.331	2.64	***	0.274	0.33
Management factors									
Cuts trees	Binary	1.162	3.81	***	0.254	1.46		0.909	0.78
Cooks with wood	Binary	-0.253	-0.82		-0.097	-0.55		0.464	0.39
Constant		-0.027	-0.21		0.001	0.02		0.049	0.10
Regression diagnostics:									
	Obs. (n)	246			246			246	
	Adj. R-square	0.184			0.172			0.031	

Note: SEVU=sheep-equivalent value unit.

Note: Asterisks denote coefficient significance at 0.10 (*), 0.05 (**), and 0.01 (***) levels.

Table 4: Determinants of cropping practices: Random effects regression results, cropped zones of Ilave-Huenque basin, Puno, Peru, 1999.

Variable	Unit of measure	Fallow		Vertical Furrows	
		Coef.	z-stat.	Coef.	z-stat.
Prices					
Price of potato	Peru soles/kg #	-0.029	-0.29	-0.037	-0.16
Physical assets and income					
Unmet basic needs	Sum	0.027	1.42	-0.076	-1.70 *
Cropped area	hectares	0.012	0.89	0.017	0.56
Pasture area	hectares	0.000	1.18	0.001	0.88
Vehicles owned	Units	0.008	0.48	0.007	0.17
Store/warehouse	Units	0.030	1.37	-0.017	-0.34
Well equipment	Units	0.079	2.81 ***	0.011	0.18
Other ag. equipment	Units	0.001	0.09	-0.001	-0.07
Home equipment	Units	0.007	1.04	-0.024	-1.48
Total SEVU's	Sheep value units	0.000	-0.42	0.000	0.49
Nonfarm income	Peru soles	.000007	-2.28 **	-0.000	-1.25
Family labor & local infrastructure					
Family agric. labor available	Person-years	-0.015	-1.60	0.011	0.53
Credit	Peru soles	0.000	-0.59	0.000	0.84
Distance to paved road	Minutes on foot	0.119	1.04	-0.115	-0.43
Human capital					
Education of HH head	Years	-0.007	-0.83	0.009	0.47
Adults with high school	Units	0.030	2.20 **	-0.045	-1.42
Social capital					
Position of HH head	Binary	-0.004	-0.15	-0.019	-0.34
Association memberships	Units	0.027	2.07 **	0.037	1.23
Aynoca area	hectares	0.001	2.65 ***	0.000	0.58
Families using communal pastures		-0.001	-1.18	-0.002	-0.87
Natural & conditioning factors					
Suni A zone	Binary	0.188	3.85 ***	0.025	0.22
Suni B zone	Binary	0.364	5.42 ***	-0.223	-1.44
Footslope	Proportion of fields	-0.004	-0.06	0.265	1.82 *
Slope	Proportion of fields	-0.082	-1.13	0.102	0.61
Sandy soil	Proportion of fields	0.025	0.63	0.031	0.98
Fertilizer	Kg/ha	0.000	-0.97	-0.000	-0.04
Pesticides	Kg/ha	-0.001	-0.75	0.001	0.23
Natural Resource project	Binary	0.161	2.34 **	0.152	0.96
Constant		-0.227	-1.76	0.701	2.35 **
Regression diagnostics:					
	Nbr. of observations	178		179	
	Nbr. of groupings	8		8	
	Chi-square	314.1		40.01	
	P-value	0.000		0.008	
	rho	0.00		0.00	

Note: SEVU=sheep-equivalent value unit.

Note: Asterisks denote coefficient significance at 0.10 (*), 0.05 (**), and 0.01 (***) levels.
#During 1998-99, the exchange rate of Peru’s nuevo sol was approximately US$1 = S/. 3.20.

Table 5: Determinants of livestock management practices: Random effects regression results, Ilave-Huenque basin, Puno, Peru, 1999.

Variable	Unit of measure	Herd Decrease (ordered probit)		Rotation Grazing (probit) – Dry Puna	
		Coef.	z-stat.	Coef.	z-stat.
Physical assets and income					
Unmet basic needs	Sum	0.170	1.24	0.419	0.82
Cropped area	hectares	0.146	1.48		
Pasture area	hectares	0.000	-0.06	-0.001	-0.68
Vehicles owned	Units	0.021	0.18		
Store/warehouse	Units	0.233	1.65 *	-1.093	-2.40 **
Well equipment	Units	-0.710	-3.31 ***		
Other ag. equipment	Units	-0.106	-2.36 **	-0.181	-0.87
Home equipment	Units	-0.029	-0.62	0.526	2.44 **
Total SEVU's	Sheep value units	-0.002	-2.61 **	0.004	2.27 **
Nonfarm income	Peru soles	0.000	-0.74	0.000	0.21
Family labor & local infrastructure					
Family agric. labor available	Person-years	-0.086	-1.34	0.117	0.61
Credit	Peru soles	0.000	-1.01		
Distance to paved road	Minutes on foot	-0.086	-0.14		
Human capital					
Education of HH head	Years	-0.235	-4.11 ***	-0.227	-1.07
Adults with high school	Units	0.113	1.23		
Social capital					
Position of HH head	Binary	0.018	0.11	1.505	2.47 ***
Association memberships	Units	-0.041	-0.47	-0.916	-2.87 ***
Aynoca area	hectares	-0.001	-0.54		
Families using communal pastures		0.003	0.73		
Natural & conditioning factors					
Suni A zone	Binary	0.040	0.15		
Suni B zone	Binary	0.226	0.52		
Dry Puna zone	Binary	0.498	1.04		
Natural Resource project	Binary	-0.040	-0.15		
Constant				-1.625	-1.85 *
Regression diagnostics:					
	Nbr. of observations	258		61	
	Nbr. of groupings	n.a.#		3	
	Chi-square	78.37		18.21	
	P-value	0.000		0.077	
	Rho	n.a.#		0.00	

Note: SEVU=sheep-equivalent value unit.

Note: Asterisks denote coefficient significance at 0.10 (*), 0.05 (**), and 0.01 (***) levels.

The herd decrease model was run as an ordinary ordered probit, since software for random-effects ordered probit was unavailable (StataCorp, 1999). However, the other random effects models showed no appreciable village-level error component, suggesting that the likely effect of not applying random-effects regression is negligible.

Table 6: Determinants of tree cutting: Random effects regression results, Ilave-Huenque basin, Puno, Peru, 1999.

Variable	Unit of measure	Cuts trees (probit)	
		Coef.	z-stat.
Physical assets and income			
Unmet basic needs	Sum	-0.404	-1.53 *
Cropped area	hectares	-0.559	-3.18 ***
Pasture area	hectares	-0.008	-1.87
Vehicles owned	Units	-0.078	-0.34
Store/warehouse	Units	-0.274	-0.95
Well equipment	Units	0.143	0.41
Other ag. equipment	Units	-0.059	-0.74
Home equipment	Units	-0.036	-0.39
Total SEVU's	Sheep value units	0.005	1.91 *
Nonfarm income	Peru soles	0.000	-0.63
Family labor & local infrastructure			
Family agric. labor available	Person-years	0.191	1.54
Credit	Peru soles	-0.001	-1.96 **
Distance to paved road	Minutes on foot	-3.061	-3.08 ***
Distance to improved road	Minutes on foot	-8.325	-2.06 **
Human capital			
Education of HH head	Years	-0.212	-1.97 **
Adults with high school	Units	-0.119	-0.68
Social capital			
Position of HH head	Binary	0.631	2.02 **
Association memberships	Units	0.100	0.61
Aynoca area	hectares	-0.007	-2.61 ***
Families using communal pastures		0.002	0.24
Natural & conditioning factors			
Suni A zone	Binary	3.074	6.22 ***
Suni B zone	Binary	0.283	0.39
Dry Puna zone	Binary		
Natural Resource project	Binary		
Constant		1.526	0.96
Regression diagnostics:			
	Nbr. of observations	197	
	Nbr. of groupings	10	
	Chi-square	58.88	
	P-value	0.0001	
	Rho	0.000	0

Note: SEVU=sheep-equivalent value unit.

Note: Asterisks denote coefficient significance at 0.10 (*), 0.05 (**), and 0.01 (***) levels.

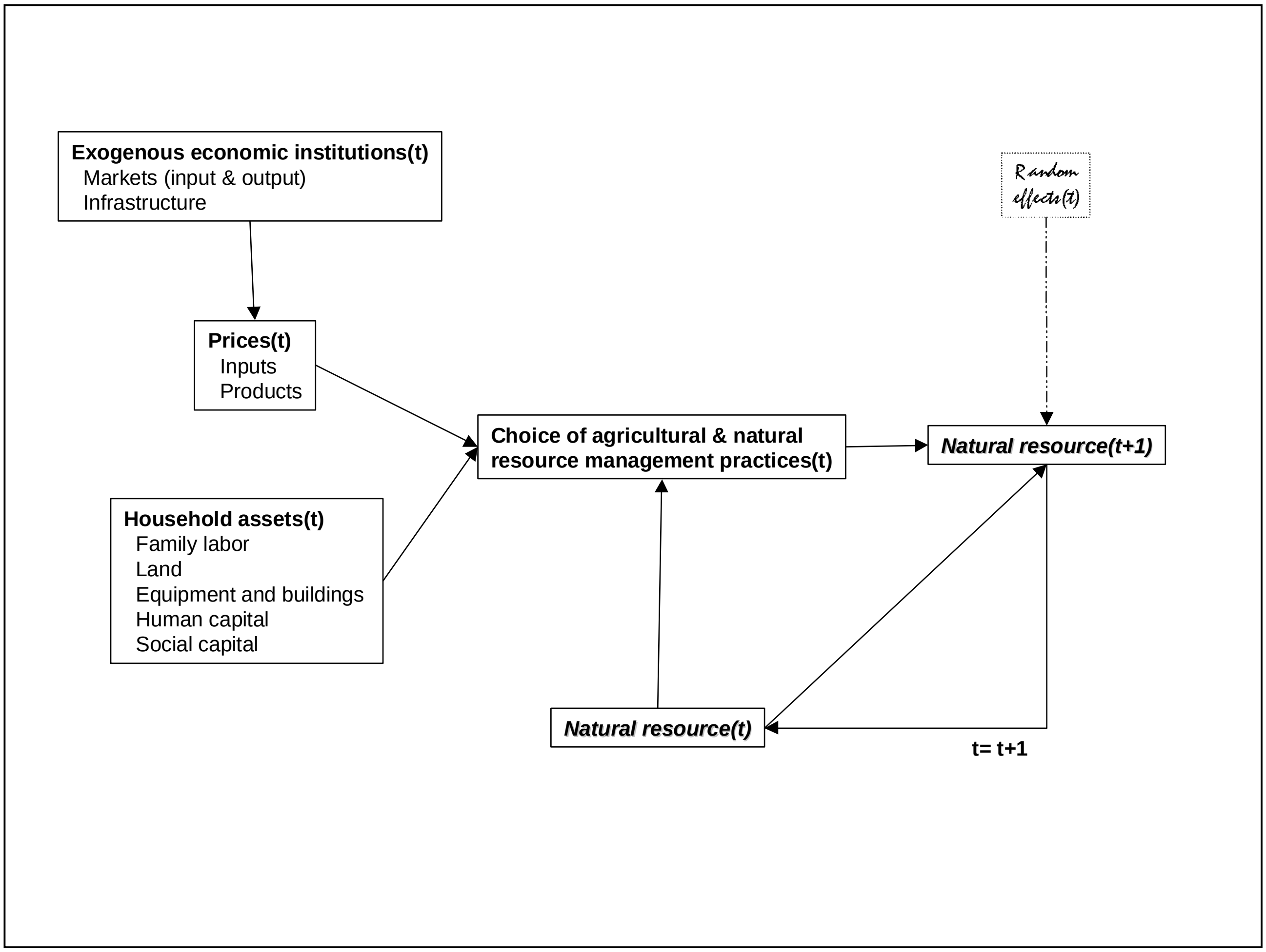

Figure 1: Flow chart of links between household assets, farming practices, and natural resource outcomes.