Staff Paper

Poverty and the Deterioration of Natural Soil Capital in the Peruvian Altiplano

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ABSTRACT

The most severe challenges to sustainable development occur where many poor people struggle to eke out a living from marginal lands. In some cases, high human populations on fragile lands have led agricultural productivity to deteriorate (García-Barrios and García-Barrios, 1990, Mink, 1993, Zimmerer, 1993), but likewise intensification in some locales has led to sustainable productivity increases (Boserup, 1965, Tiffen, et al., 1994). These mixed results beg closer inquiry, in order to understand how contrary outcomes can come about. For the context of Peru's chilly high plain surrounding Lake Titicaca, this paper examines changes in the stock of natural capital in agricultural soils, how that came about, and what policy tools might contribute to sustaining this key natural capital stock and the agricultural productivity that it enables.

27 pages

POVERTY AND THE DETERIORATION OF NATURAL SOIL CAPITAL IN THE PERUVIAN ALTIPLANO

by[1]

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The most severe challenges to sustainable development occur where many poor people struggle to eke out a living from marginal lands. In some cases, high human populations on fragile lands have led agricultural productivity to deteriorate (García-Barrios and García-Barrios, 1990, Mink, 1993, Zimmerer, 1993), but likewise intensification in some locales has led to sustainable productivity increases (Boserup, 1965, Tiffen, et al., 1994). These mixed results beg closer inquiry, in order to understand how contrary outcomes can come about. For the context of Peru's chilly high plain surrounding Lake Titicaca, this paper examines changes in the stock of natural capital in agricultural soils, how that came about, and what policy tools might contribute to sustaining this key natural capital stock and the agricultural productivity that it enables.

Conceptual framework

Like other forms of capital, natural capital yields service flows overtime, depreciates, and can grow through investment. It is distinguished by the natural endowments available that allow humans to harvest service flows without prior investment. Natural capital can be transformed into forms of man-made capital, or its service flows can be consumed. Careful definitions of sustainable development recognize the fungibility of capital, and recognize that individual, household, or even social welfare can increased while natural capital is decreased, so long as the latter is converted into other forms of capital that will continue to yield income. Pearce and

Atkinson (Pearce and Atkinson, 1995) offer a simple behavioral model of sustainable development as the maximization of cumulative wealth (ω_T) (which changes from previous wealth through an income function, $\pi(\bullet)$), subject to keeping the capital stock from decreasing by choosing flow inputs (x_t) and depreciation rates (δ_{it}) for each type of capital i, subject to Pearce and Atkinson's (1995) weak condition for sustainable development that allows substitution between savings (S) and depreciation of three types of capital (K_i) : "man-made" (M), human (H) and natural (N).

$$\max_{x,\delta_i} \int_t \omega(t)dt$$

subject to:

$$\omega(t) = \omega_{t-1} + \pi(x_t, \delta_{it}, \omega_{t-1}, t)$$

$$S(t) - \delta_M K_M(t) - \delta_H K_H(t) - \delta_N K_N(t) \geq 0$$

What makes the second constraint a "weak condition" is precisely that it does allow the transformation of capital from one form to another. As a practical matter, measuring these disparate forms of capital is difficult, as is measuring transfers from one form to another. In response, Pearce and Atkinson (1995) offer the more restrictive "strong condition" for sustainable development, which simply states that the natural capital stock not depreciate ($\delta_N K_N(t) \leq 0$).

For convenience, we will adopt the strong condition and focus on changes in the natural capital stock. Hence, the three linked research questions are:

1. Is the stock of natural capital changing?
2. If so, what factors are responsible?

3. To the extent that human behavior is responsible, what policy changes could enhance the sustainability of the natural capital stock?

In the pages ahead, we present a two-step model for examining these research questions, an introduction to the research setting in the Peruvian Altiplano around Lake Titicaca, followed by empirical results for agricultural soil resources, and a discussion of policy implications.

Conceptual framework

The framework for understanding the evolution of the natural capital stock is based on the recursive model in Equation (1),

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

Equation (1) states that the status of natural capital of form 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 site-specific natural characteristics (z_{Nt}) and random effects (ε_{t+1}).

The research questions begin the basic one of what kinds of changes are occurring in the natural capital stock. Descriptive statistics on first differences from Equation (1), ΔNR_i, characterize changes in natural resource i since the previous period. As discussed in greater detail below, the data available use a 20-year time step based on the recollections of farmer interviewees.

What determines observed natural capital changes is examined in the second stage. Based on first differences, evolution of the natural capital stock is modeled as a function of the change processes in Equation (2),

(2)

$$\Delta K_{Ni} = f(x_t, z_N) + e_i$$

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 are largely unchanging, but they play an important role in conditioning the effects of the farming practice variables (x) that are chosen by human decision makers.

From a policy design standpoint, what matters are the anthropogenic effects on the natural capital base. So the third stage of analysis is to focus in on those agricultural practices that induce changes in the natural capital stock and to examine what determines those choices. Based on a household model of utility maximization subject to budget and economic resource constraints (Swinton and Quiroz, 2000), we can obtain a simplified, 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).

(3)

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

The optimal input demand function for x_{ji} in Equation (3) depends on a vector of output and input prices (p), the levels of other agricultural practices $x_{(j)}$ apart from x_j, farm capital (k), and conditioning factors (z) related to economic infrastructure, natural characteristics, and the household's management knowledge and information. Most of these variables are potentially amenable to policy manipulation.

Data and the research setting

The setting for this research is the high plain or Altiplano surrounding Lake Titicaca on the Peru-Bolivia border. The Altiplano can be thought of as a bowl perched atop the Andes mountain range. The flat bottom of the bowl contains Lake Titicaca, which at 3800 meters above sea-level, is the world's largest high-mountain lake.

Although it has been intensively farmed for nearly a thousand years, the Altiplano is a marginal agricultural region for reasons of both biophysical potential and economic infrastructure. Potential agricultural productivity is limited by drought, flooding and cold. Its remote location in the central Andes and the absence of paved roads to the Peruvian coast make access very costly for major agricultural markets other than the Bolivian capital of La Paz. Perhaps as a result, poverty levels in the area are high, and net outmigration toward the coastal cities and the Amazonian rainforest frontier has been occurring for over two decades (Caballero, 1992, Collins, 1988, Wiegers, et al., 1999).

The Altiplano can be divided into three distinct agro-ecological zones based on altitude and distance from the lake. Surrounding the lake is a flat lakeside zone of productive alluvial soils where annual crops such as potato, quinoa, barley, oats, and alfalfa are raised yearly with no break for fallow. Although the lakeside zone is subject to flooding from the lake, its position makes it less subject to drought and frosts that afflict farming at the higher altitudes. Moving up and away from the lake, the Suni zone is one of transition from farming. Based on rainfall effects due to the aspect of the slopes (toward or away from the lake), this zone can be subdivided between the Suni-A zone, where crop farming prevails, and the Suni B zone, where extensive livestock grazing is the norm. As shown in Table 1, annual rainfall and the number of frost-free months are both lower in the Suni zones than in the lakeside zone, resulting in less intensive crop production and a shift from fed livestock by the lake to grazed livestock in the Suni zone. Moving above 4500 meters altitude, the dry Puna zone offers less than three months without overnight frosts and less than 600 mm of rainfall on the southwest side of the Lake (Tapia, 1996). Farming activity in the dry Puna is confined almost exclusively to extensive grazing of alpacas, sheep, llamas and cattle (Swinton, et al., 1999).

The analysis reported here focuses on the soil resource, specifically both the stock of soil and the stock of nutrients in available soil. 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 having at least one Unmet Basic Need (INEI, 1994).

The survey employed a hierarchical, stratified and clustered sampling design. Recognizing that natural capital would be affected strongly in this region by biophysical constraints on farming, the four basic strata represent the four agro-ecological zones described above, Lakeside, Suni A, Suni B, and Dry Puna (Swinton, et al., 1999, Tapia, 1996). Within each stratum, two to three villages were selected to represent relatively high and low levels of poverty. Finally, within each village, an attempt was made to stratify households by apparent wealth level in consultation with village leaders. The sampling stratification scheme was designed to insure a broad range of asset levels across all four agro-ecological zones in order to evaluate natural capital sustainability across a range of agricultural conditions. The analysis presented here uses data from the three arable zones, excluding the Dry Puna.

Empirical statistical analysis

The first research question, “Is the stock of natural capital changing?” is addressed with descriptive statistics from the three primarily crop producing areas of the study zone. The cross-sectional nature of the study required that changes in soil quantity and quality be measured by relying on farmer recall. In all cases, the period of reference was the past 20 years. Soil quality changes were measured in simple binary fashion. Farmers were asked if they had experienced productivity losses over the past 20 years. Soil erosion was measured in two ways. First, farmers were asked to compare soil depth today with soil depth 20 years ago, applying a Likert scale that increases from 1 = major gain in soil depth to 5 = major loss of soil. Second, farmers were asked to estimate the proportion of yield lost under typical growing conditions over the past 20 years.

The second research question, “If the natural capital stock is changing, what factors are responsible?” was addressed using limited dependent variable regression models. Soil nutrient loss was modeled as a probit based on the conceptual model in Equation (2). 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 (means of 71 and 4 percent, respectively), 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.

Soil loss was modeled as an ordered probit, using the same explanatory variables as in the soil nutrient loss probit, along with several environmental variables that related specifically to the 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 yield loss model was estimated using tobit regression, as the data were truncated to included only the 89 percent of respondents who reported yield declines. Explanatory variables were the same as for the soil loss ordered probit.

The third research question was, “To the extent that human behavior is responsible, what policy changes could enhance the sustainability of the natural capital stock?” As it turned out, at least one agricultural practice turned out to be significantly associated with each of the changes in natural capital. Hence, the policy change question was informed by generalized least squares (GLS) and probit analyses to identify the determinants of why farmers chose management practices that were linked to change in the agricultural natural capital stock. The agricultural practice regressions used random-effects models to accommodate the clustered sampling design.

All models used the same set of explanatory variables, based on the input demand function in Equation (3). 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.

Results

1.Farmers report that both soil quality and depth are in decline

Descriptive statistics reveal that farmer respondents in the study zone are experiencing declining productivity, much of it linked to depletion of the natural soil capital stock. Virtually all respondents (91.4 percent) had experienced productivity declines over the past twenty years. Farmers were invited to specify up to three causes related to crop and to livestock productivity, respectively. Reasons cited for crop yield declines were led by “lack of nutrients” or “tired land” (69.5 percent), far more than any other response (Table 2). Poor or overgrazed pastures were the highest ranked livestock-related cause (31.5 percent). Soil erosion, though named by only 8.6 percent, could well be related to the insufficient soil nutrient problem, as could poor pastures.

In order to assess whether soil depth had changed, farmers were asked if they perceived any change in soil depth in their fields over the past 20 years. The Likert scale for their responses ranged from “major increase” (1) to “major decrease” (5). The mean response was 3.8, with 6% reporting an increase and 78% reporting a decrease in soil depth. No respondents reported a “major increase” in soil depth.

Crop yields had declined for 89 percent of respondents. Potato yields suffered more than any other crop on all respondent farms but one. Asked to compare crop yields in a normal year 20 years ago with yields in a normal year today, farmers reported a mean yield decline of 35 percent (s.d. 17%) from levels of 20 years past.

2. Agricultural practices are key determinants of natural capital status

In order to understand the determinants of these significant declines in soil nutrients, soil depth and associated crop yields, a series of regression analyses were run. Results of the soil nutrient loss and erosion models highlight the importance of fallows and tillage practices (Table 3).

The probability of a farmer reporting soil nutrient loss over the past 20 years depended upon village, soil depth loss, soil texture, and farming practices. As hypothesized above, perceived loss of soil depth contributed significantly to the probability of perceiving 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 perceived soil nutrient loss. Both of these results are somewhat unexpected, as neither directly affects soil fertility, although both affect crop yield.

Soil depth loss over the previous 20 years became the dependent variable in an ordered probit model of erosion determinants (Table 3). Perceived soil loss was much more likely in the hilly Suni A and Suni B zones than in the flat Lakeside zone. 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. Indeed, farmers recollect that fallow periods 20 years ago were some two years longer (Figure 2). Curiously, the proportion of fields with vertical furrows was associated with reduced yield loss[1]. Subsequent analysis (not shown) reveals that the effect is significant only in the Suni B zone where erosion-prone Irish potatoes cannot be grown. 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).

3. Social and human capital are clearly linked to sustainable soil management

The third stage analyses sought to determine what factors influence the choice of those human behaviors linked to natural resource degradation (or sustainability). Of particular interest was the effect of kinds of capital other than natural capital on choice of agricultural practices. The two practices analyzed were fallowing cropland and vertical furrows. These analyses were modeled using a single set of explanatory variables derived from the categories in input demand Equation (4).

The results are as surprising for the relationships that are absent as the ones that are present. As shown in Table 4, prices and economic infrastructure have no significant effect on the choice of these agricultural practices. Fixed capital variables have mixed effects that are not readily interpreted. The proportion of fields in fallow increases with

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[1] The unanticipated association of vertical furrows with reduced nutrient and yield loss raised the question of whether vertical furrows might be a management response to these conditions rather than a causal factor. Hausman tests for endogeneity of both the vertical furrows and fallow variables proved insignificant in the soil loss and yield loss models, with one exception. The exception was for vertical furrows in the soil loss ordered probit model, in which the use of predicted values for the vertical furrows had no effect on coefficient signs but did result in a loss of 49 degrees of freedom. The data were ill-conditioned to conduct the Hausman test for the soil nutrient loss probit. The unadjusted models were retained in all cases.

well equipment units and decreases with non-farm income. The proportion of fields with vertical furrows decreases with Unmet Basic Needs.

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. 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 cited by farmers for loss of soil fertility was that they had given up their *aynoca* fields; 16% of respondents (including 35% of those in one village) blamed crop productivity loss on the abandonment of *aynocas*. Association memberships are also associated with more land in fallow.

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.

Discussion and policy recommendations

In Peru's Altiplano, the soil capital stock appears to be in decline, and with it crop yields. Some of the decline is due to natural factors, but agricultural management factors play a clear role. The link between use of fallows and natural resource sustainability is clear. In the impoverished setting of the Peruvian Altiplano, soil loss and associated yield losses were diminished by the use of fallow. Vertical furrows appear related to reduced nutrient loss, although the logical connection remains obscure. These agricultural practices that are linked to sustaining the natural capital stock require either land (for fields in fallow rotation) or labor (for tillage). Neither one requires much investment capital, because poverty was pervasive among the farm households surveyed. Seventy-three percent had “unmet basic needs” according to the government’s definition. Two-thirds earned less than Peru’s monthly minimum wage of $100 per month. Nearly everyone interviewed suffered “welfare poverty,” not to mention “investment poverty” (Reardon and Vosti, 1995). The very limited cash investments in purchased crop inputs were limited to modest fertilizer and pesticide use on potatoes, the highest value crop in intensively farmed the Lakeside zone.

But the fact that little investment capital was used in a setting where prevalent poverty makes it is very scarce does not mean that investment capital is unneeded. The stocks of soil nutrients and soil itself are clearly in decline, a decline hastened by shortening fallows in reponse to population pressure, especially in the Lakeside agro-ecological zone (but extending to the Suni zones as well). Investment capital could play a valuable role in replacing natural capital with human-made (physical) capital with human capital (knowledge). Three distinct policy directions can address the challenge of sustaining the agricultural natural capital stock of the region. The three are partially exclusive paths that would focus on 1) capital-led intensification, 2) research-informed and labor-led intensification, or 3) disintensification and emigration.

Alternative one, the capital-led intensification route, is to make available targeted credit and extension information to support fertilizer, while investing in roads to improve market access. This approach would aim to substitute imported soil nutrients for those exported by crop harvest and diminished fallows. Such an approach might be informed by the experiences of the Sasagawa-Global 2000 experiences in Africa. Clearly, a crucial step is to transform such a policy from project-supported direct delivery of inputs into a system that is privately self-sustaining with public involvement limited to support of the transport infrastructure and selected financial incentives. Successful investment in roads and market access could, by triggering increased profitability, induce new investments in terraces to reduce soil erosion (Gonzales de Olarte and Trivelli, 1999).

Alternative two, the research-informed and labor-led intensification route, is to support agricultural research into commercially viable cropping systems that are more efficient at cycling nutrients. This approach would accept the capital constraint and attempt to offer appropriate cropping systems practices for a limited investment capital environment. Recognizing that labor-led intensification is not necessarily sustainable (Reardon and Vosti, 1995), it would require a research base to make it so. Renewed investment in cropping systems research could make important improvements in nutrient cycling via crop rotations, so long as it conforms with the market and resource constraints within which farmers operate (e.g., Snapp et al., 2001).

Alternative three, the disintensification route, is to invest in education to enable the Altiplano's youth to find productive employment by emigrating toward the cities and Amazonian frontier. This approach would address the problem of natural capital deterioration by reducing the current population pressure on the land (and perhaps generating a strengthened flow of remittances that can contribute to investment in the stock of agricultural natural capital). If the people of the Altiplano are trapped at the bottom of the intensification U-curve – with too many people for traditional systems to be sustainable but too few people (or too little market access) for land values to rise enough to induce capital-led intensification (Templeton and Scherr, 1999) – then this approach would address the problem by relieving population pressure rather than intensifying land productivity through complementary investments in the natural soil capital stock.

Within the limitations of a cross-sectional study in a relatively homogeneously impoverished region, this study demonstrates that modest improvements can be made in maintaining the natural capital stock – even among the very poor. In areas where the social fabric is strong and human-made capital is scarce, natural resource policies can follow Alternative #2 and focus on developing and diffusing knowledge about natural resource stewardship using affordable practices. Traditional social institutions like the *aynoca* continue to play a valuable role in a setting where fallow rotations remain the primary means of restoring soil fertility and preventing erosion. These institutions should be understood and built upon if the objective is to encourage marginal changes to effect better stewardship using traditional practices.

Greater leaps to tackle the deteriorating stock of natural soil capital will require much larger public investments in facilitating market access, targeted credit, as well as agricultural research and extension. This Alternative #1 approach would require a serious commitment at the national level. Failing that, the current drift toward deterioration of the natural capital base will continue accompanied by slow emigration from the Altiplano, but without the virtuous cycle of reinvestment that could be triggered by exporting well-educated workers who will return significant remittance flows (Alternative #3).

Table 1: Agro-ecological zones in the Lake Titicaca basin of the Peruvian Altiplano.

Agro-ecological zone	Altitude (m)	Precipitation (mm/year)	Frost-free period (days/year)
Lakeside	3800-3900	700-750	150-180
Suni	3850-4000	600-850	90-145
Dry Puna	4000-4800	440-600	30-60

Source: Tapia, 1996, p. 69 (Cuadro 37).

Table 2: Causes cited for declines in crop and livestock productivity over past 20 years, 197 farms, Puno, Peru 1999.

Cause for declining productivity	Linked to soil capital	Percent
Crops		
Soil nutrients lacking	*	69.5%
Drought		41.1%
Crop pests		33.5%
Frost or hail		19.3%
No aynoka		16.2%
Agrochemical damage		10.2%
Land lacking		10.2%
Erosion	*	8.6%
Livestock		
Pastures poor or overgrazed	*	31.5%
Pastures lacking		26.9%
Sun or heat excessive		7.6%
Pasture pests		2.5%

Table 3: 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 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	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	Propn. of fields	-0.004	-0.06	0.265	1.82 *
Slope	Propn. of fields	-0.082	-1.13	0.102	0.61
Sandy soil	Propn. 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. 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 (***) level.
#During 1998-99, exchange rate of Peru's nuevo sol was approximately US$1 = S/. 3.20.

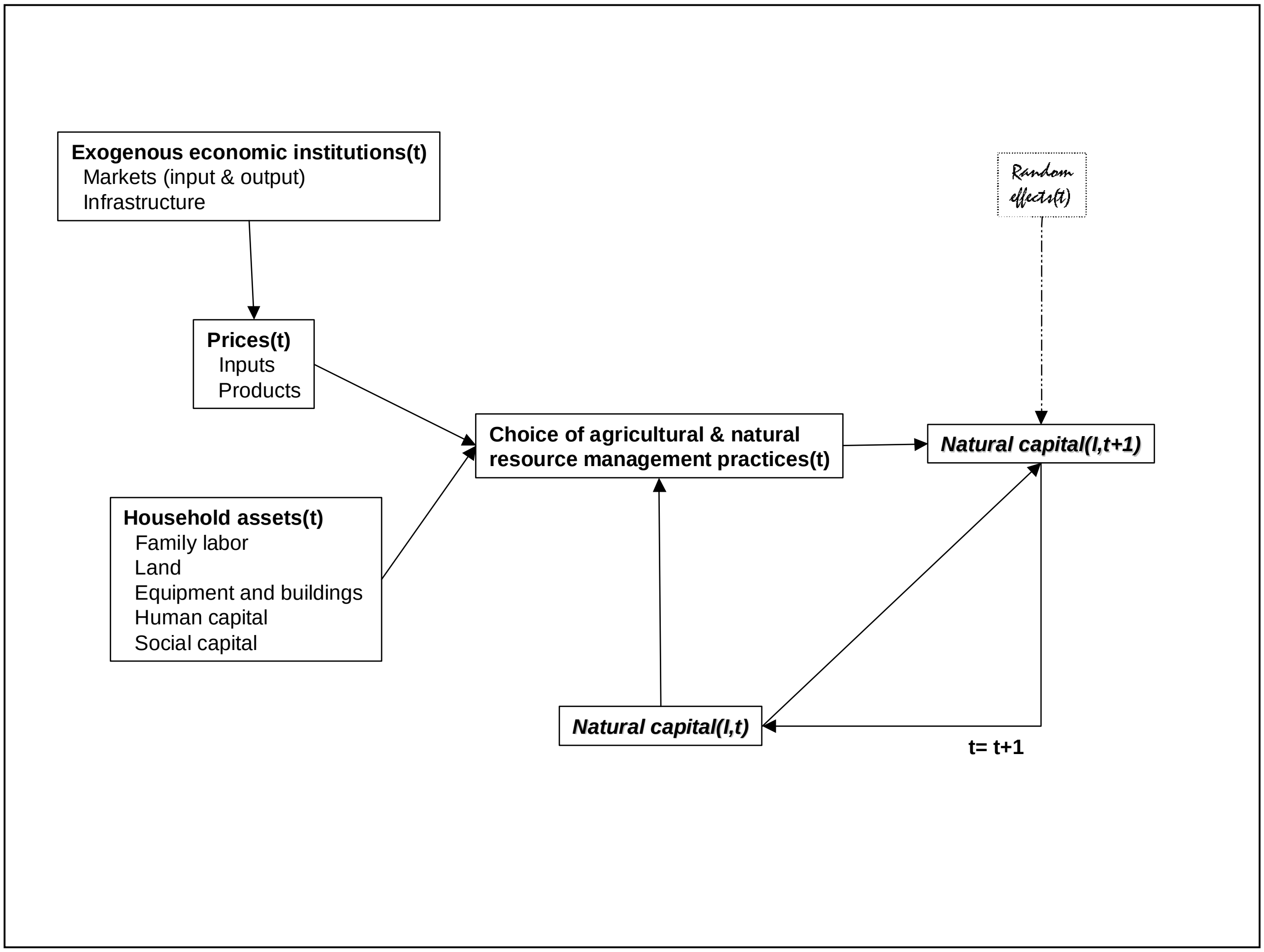

Figure 1: Flow chart of links between household assets, farming practices, and natural capital evolution.

Figure 2: Duration of crop rotations in 1998-99 and 20 years earlier.

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