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Investment in soil conservation in northern Ethiopia: the role of land tenure security and public programs

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Abstract

A double hurdle statistical analysis of 250 farms in the Tigray region of Ethiopia reveals different causal factors for soil conservation adoption versus intensity of use. Farmers' reasons for adopting soil conservation measures vary sharply between stone terraces and soil bunds. Long-term investments in stone terraces were associated with secure land tenure, labour availability, proximity to the farmstead and learning opportunities via the existence of local food-for-work (FFW) projects. By contrast, short-term investments in soil bunds were strongly linked to insecure land tenure and the absence of local food-for-work projects. Public conservation campaigns on private plots reduced adoption of both stone terraces and soil bunds.

Whereas capacity factors largely influenced the *adoption* decision, expected returns carried more influence for the *intensity* of stone terrace adoption (measured as metres of terrace per hectare). More stone terracing was built where fertile but erodible silty soils in higher rainfall areas offered valuable yield benefits. Intensity of terracing was also greater in remote villages where limited off-farm employment opportunities reduced construction costs.

These results highlight the importance of the right kind of public interventions. Direct public involvement in constructing soil conservation structures on private lands appears to undermine incentives for private conservation investments. When done on public lands, however, public conservation activities may encourage private soil conservation by example. Secure land tenure rights clearly reinforce private incentives to make long-term investments in soil conservation.

JEL classification: Q24; Q12

Keywords: Soil conservation; Soil erosion; Land tenure; Ethiopia; Double hurdle model

1. Introduction

Developing countries have been grappling with how to reconcile the three objectives of increasing agricultural production, reducing poverty and using natural resources sustainably. With the land frontier shrinking due to population pressure, future growth in agriculture will increasingly have to come from yield increases rather than from area expansion (Eicher, 1994). Production will have to increase in such a way that future production capacity of the natural resource is enhanced rather than diminished.

The major environmental problem of developing countries is land degradation in the forms of soil

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erosion and nutrient depletion, both of which undermine land productivity. Land degradation is especially serious in Ethiopia, where the agricultural sector accounts for more than 50% of gross domestic product and employs over 80% of the population. Hurni (1985) concludes that Ethiopia is the most environmentally troubled country in the Sahel belt.

Land degradation is most severe in the highlands (over 1500 m altitude) which account for more than 43% of the country, 95% of the cultivated area, 75% of the livestock and host about 88% of the population. The Ethiopian Highland Reclamation Study as quoted in Bojo and Cassels (1995) estimates that by the mid 1980s about 50% of the highlands (27 million hectares [ha]) was significantly eroded while more than one-fourth was seriously eroded. Hurni (1988) estimates that soil loss in cultivated areas averages 42 metric tons/ha per year (mt/ha per year), far exceeding the soil formation rate of 3–7 mt/ha per year. Stahl (1990) estimates that by the year 2010 the amount of total land incapable of supporting cultivation will reach 10 million ha.

Despite the magnitude of the problem, public intervention in soil conservation in Ethiopia is a recent phenomenon. Land degradation was largely neglected by policy makers until the 1970s. After the early 1970s national efforts to conserve land intensified. These interventions relied on mobilisation of farm households and food-for-work (FFW) projects to conserve degraded lands through the construction of soil bunds, stone terraces and afforestation. However, little prior research has guided national conservation programs. Perhaps as a result, Shiferaw and Holden (1999) note that peasants have occasionally dismantled conservation structures built on their farm lands. Appropriate public policies to promote soil conservation require understanding of the incentives and constraints that farm households face in their decision to conserve land.

This study examines the factors affecting farmers' decisions to invest in land conservation in the Tigray region of northern Ethiopia, focusing on land tenure and public programs. Land tenure insecurity has been a problem in Ethiopia due to frequent redistribution (Admassie, 2000). This study distinguishes between factors affecting short-term investments in soil bunds and long-term investments in stone terraces. Further, it makes a distinction between the determinants of the decision to invest in the first place, and the decision how much to invest in conservation given this initial decision. In the following, we review previous research on the determinants of soil conservation investment, develop a conceptual model with associated testable hypotheses, set forth a derived empirical econometric model and present results, focusing on how the determinants of conservation investment (adoption) differ from those of *degree* of investment (density of conservation structures).

2. Previous research on determinants of soil conservation investment

The role of property rights and social capital in providing incentives for the adoption of soil conservation in developing countries has only emerged since the late 1980s. Prior to that, land tenure institutions had been explored in the context of developed countries with well-defined property rights. McConnell (1983) shows that optimal private soil depletion decreases as the farmer's planning horizon increases in length from farm renter to family farm to corporate farm. Lee (1980) confirms that tenure security encourages soil conservation investment. But McConnell and Lee both assume that land tenure status is known with certainty. By contrast, in many developing countries, especially where private ownership of land is not allowed and only usufruct rights are permitted, the expectation of future land tenure may change over time (Besley, 1995). The interaction between land tenure expectations and willingness to invest in soil conservation has been investigated in relatively few cases. The hallmark study by Feder et al. (1988), shows that land titling in Thailand is associated with increased adoption of land improvements, including soil bunds and stump removal. Likewise, Besley (1995) finds evidence that in Ghana, more secure land tenure is linked to land improvements (although the improvements examined did not include soil conservation investments). Place and Hazell (1993) deny that their study of land rights as determinants of land improvement decisions in Ghana, Kenya and Rwanda implies that land rights play a significant role, but their results suggest that land rights do play a role in the choice to improve land, if not in the type of land improvement selected. In the Horn of Africa, the only published, quantitative study of conservation adoption to include land tenure is that of Shiferaw and Holden (1998) in Andit Tid, Ethiopia. They measure expected land tenure security at the extreme level of lifetime tenure or not; however, this is too rough a measure of time horizon to detect any influence on adoption behaviour.

Despite the dynamic nature of conservation investments, most studies fail to distinguish between short- and long-term investments. The chief exception to this generalisation is Hayes et al.'s (1997) study of land improvements in The Gambia, which finds that the probability of long-term investments (in fences and wells) is enhanced by the presence of complete (rather than preferential) land tenure rights. Most other studies employ either a single measure of land tenure status (Ervin and Ervin, 1982; Feder et al., 1988; Shiferaw and Holden, 1998) or a single measure of land improvement (Gavian and Fafchamps, 1996; Pender and Kerr, 1998; Shiferaw and Holden, 1998), making it impossible to link the degree of land tenure security with the durability of land improvement investment. Yet major differences exist in the time horizon and magnitude of net benefits associated with such practices as planting grassy strips, building soil bunds and constructing stone terraces. Besley (1995) analyses several types of land improvement in Ghana, but he interprets the results in light of the extent of land rights rather than their durability.

Because soil erosion also has off-site costs, neighbours and others have a stake in it. Yet with one exception, the influence of other people's opinions on farmer adoption of conservation practices has not been examined. In the sole study of which we are aware, Bultena and Hoiberg (1983) find the timing of conservation tillage adoption varies significantly with the perceived attitude of the local community towards farmers who fail to use conservation practices.

Another shortcoming in the conservation literature is the assumption that the factors affecting adoption of conservation practices are the same as those that determine the intensity of their use. Instead, most studies have focused on adoption alone, using logit, probit or linear probability models (e.g. Feder et al., 1988; Place and Hazell, 1993; Besley, 1995; Gavian and Fafchamps, 1996; Hayes et al., 1997; Shiferaw and Holden, 1998). In the instance of costly soil conservation practices such as terracing, there is reason to expect that adoption and degree of adoption are based on different criteria. Adoption may be a threshold-based decision depending upon awareness, planning horizon and capacity to invest. By contrast, the degree of adoption may depend on marginal profitability factors. The validity of this distinction between adoption factors and intensity of use factors is an empirical question. However, this hypothesis cannot be tested by tobit analyses that treat the decisions jointly, such as Pender and Kerr's (1998) model of soil conservation investment in India. In their Missouri, USA, study, Rikoon et al. (1996) find differences between the factors associated with adoption and continued use of banded application of herbicides. However, they fail to link their models econometrically. To date, no conservation adoption study of which we are aware has formally distinguished between adoption and intensity of use decisions as has been done in the consumption literature (Yen, 1993; Lin and Milon, 1993). The closest any has come to making this distinction is Place and Hazell's (1993, p. 16) observation that "multinomial logit analysis ... showed that land rights have less effect on choice of improvements than on the probability of undertaking an improvement."

These research gaps raise the following questions: (1) How do institutional, public program and social capital factors influence soil conservation investments? (2) How do the determinants of investment vary between short- and long-term soil conservation investments? (3) How do the determinants of investment vary between whether and how much farmers invest in land improvements?

Two alternative soil conservation investments—soil bunds and stone terraces—offer contrasts in length of investment and effectiveness of erosion abatement. Soil bunds are embankments made by ridging soil on the lower side of a ditch along a slope contour. They can be constructed by hand digging or plowing. Stone terraces are constructed walls that retain embankments of soil. Their construction involves the preparing a base for the wall, transporting construction rocks and carefully layering them. Stone terraces are more effective than soil bunds in preventing soil erosion on steep slopes prone to heavy runoff. Of course, building stone terraces requires considerably more time and inputs than does building soil bunds.

This study attempts to provide answers to the questions above regarding determinants of investment in soil bunds and stone terraces by 250 farm households in northern Ethiopia during 1992–1995. Investment in soil conservation practices is estimated using a double hurdle econometric model that examines separately the determinants of the decision on *whether* to invest and those of the decision on *how much* to invest, given investment.

3. Conceptual model

In order to highlight the institutional and organisational influences affecting conservation investments we present a model of soil conservation decisions in which both land tenure institutions and public image play roles. Farmer utility is assumed to be increasing in accumulated wealth (Ω) and public image (I), as indicated in Eq. (1):

$$\begin{aligned}
&\max_{\mathrm{CI}} U(E[\Omega_T], I)\\
&\text{subject to}\\
&E[\Omega_T] = \textstyle\sum_{t=1}^{T} \delta^t (p y_t a_t E[T_t] - w_{\mathrm{CI}}(K_h)\mathrm{CI}_t)\\
&y_t = y(s_t, z_t)\\
&s_t = s_0\left(1 - e\left(R, \textstyle\sum_{\tau=1}^{t}\mathrm{CI}_{\tau-1}, \sum_{\tau=1}^{t}\mathrm{PC}_{\tau-1}\right)\right)\\
&I_t = I(s_t).
\end{aligned} \qquad (1)$$

This equation defines the present value of accumulated wealth (Ω_T) at the end of the farmer's planning horizon (T) as accumulated annual crop revenues minus the unit cost (w_{CI}) of conservation investments (CI_t) discounted by the factor δ. It is assumed that the unit cost of conservation investments is decreasing in level of worker experience ($w_{\mathrm{CI}}'(K_h) < 0$). Price ($p$) variability is captured by distance from farm to nearest road or market. Expected crop revenues are the product of crop price (p), yield (y_t), land area (a_t), and the binary expectation of whether land tenure will be retained in period t ($E[T_t]$). Yield in season t, in turn, is concavely increasing in current soil depth ($y'(s_t) > 0$) and also depends upon other conditioning factors (z_t) such as weather, pest attacks and soil fertility.

Soil depth increases linearly with initial soil depth ($s'(s_0) > 0$) and decreases concavely with erosion ($s'(e) < 0$). The erosion function, in turn, is assumed to be bounded to the interval [0,1] and increasing in factors (R) that govern soil propensity to erode ($e'(R) > 0$) such as steepness and length of slope. Erosion is further assumed to be concavely decreasing in cumulative soil conservation investments, both private ($e'(\sum \mathrm{CI}_{\tau-1}) < 0$) and public campaigns that build soil conservation structures on the farmer's land ($e'(\sum \mathrm{PC}_{\tau-1}) < 0$). The cross partial derivatives of $e(\cdot)$ with respect to R and CI or PC are assumed negative. Note that because the erosion function is bounded to the [0,1] interval, the interaction effect of public and private conservation investment ($\partial^2 e/\partial\mathrm{CI}\partial\mathrm{PC}$) is indeterminate in sign. There is potential substitutability between private and public soil conservation investments, but there is also potential complementarity if farmers learn from experience with public projects and therefore opt to make private investments. Which effect dominates is an empirical question.

We assume a populous setting in which new lands of comparable quality are not available, so cropped land area (a_t) equals the initial land endowment (a_0) times the expectation of retaining land tenure in season t ($E[T_t]$). This expectation is assumed to be binary and non-switching, such that the farmer either expects ($E[T_t] = 1$) or does not expect ($E[T_t] = 0$) to retain tenure in season t; once tenure is expected to be lost ($E[T_t] = 0$), it cannot be regained in a later period. Finally, public image in any period (I_t) depends upon the degree of off-field soil erosion affecting other community residents, which is inversely connected to current soil depth (s_t) (hence, public image is increasing in field soil depth, $I'(s_t) > 0$). For simplicity, we ignore conservation maintenance activities.

Substituting the definitions in Eq. (1) into the utility function yields the unconstrained, undiscounted Hamiltonian:

$$H = U\left(E\left\{\sum_t \delta^t p y_t\left(s_0\left[1 - e\left(R, \sum_\tau \mathrm{CI}_{\tau-1}, \sum_\tau \mathrm{PC}_{\tau-1}\right)\right], z_t\right) a_0 E[T_t] - w_{\mathrm{CI}}\mathrm{CI}\right\}, I[s_t]\right). \qquad (2)$$

By differentiating Eq. (2) with respect to choice variable CI, we can identify the factors expected to influence the optimal rate of soil conservation investment under conditions of perfect factor markets:

$$\frac{\partial H}{\partial \mathrm{CI}} = \frac{\partial U}{\partial \Omega}\frac{\partial \Omega}{\partial y}\frac{\partial y}{\partial s}\frac{\partial s}{\partial e}\frac{\partial e}{\partial \mathrm{CI}}(a_0 E[T_t]) + \frac{\partial U}{\partial I}\frac{\partial I}{\partial s}\frac{\partial s}{\partial \mathrm{CI}} - \sum_{t=1}^{T}\delta^t w_{\mathrm{CI}} = 0. \qquad (3)$$

These conditions specify that optimal soil conservation investment takes place where the marginal utility of the cumulative added yield equals the marginal cumulative discounted cost of the conservation investment required to achieve the added yield. In this model, apart from the familiar wealth argument, marginal utility also accrues via the improved public image of the farmer who is not creating economic externalities in the form of gullies and muddied water that irritate neighbours. The signs of both marginal utility terms are positive; hence, farmers who care about their image in the community as well as garnering wealth will find it optimal to invest in more soil conservation than those farmers who care about wealth alone.

This optimality condition also highlights the importance of the subjective expectation of enjoying land tenure in time period t ($E[T_t]$). Because this term appears multiplicatively in the wealth term, the expectation of land tenure dictates the length of the planning horizon, thereby largely determining whether soil conservation appears desirable at all and, if so, the type of conservation practice chosen. To illustrate, a capital budgeting analysis of conservation investments in northern Ethiopia (Gebremedhin et al., 1999) suggests that the higher initial cost of stone terracing takes longer to pay off in crop yield gains than do soil bunds. However, the larger cumulative, discounted net revenue from stone terraces after 5 or more years makes it the more beneficial choice for longer planning horizons (Fig. 1).

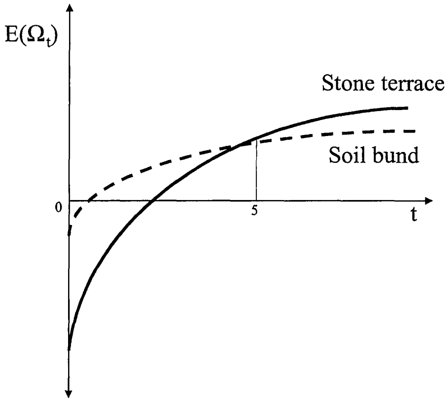

Fig. 1. Hypothetical expected cumulative net returns from two alternative soil conservation practices.

4. Hypotheses

From the conceptual model above, several hypotheses can be derived that merit empirical examination. These hypotheses can be divided between factors that affect adoption and those that affect the degree of soil conservation investment. The two sets of explanatory factors differ primarily in length of planning horizon, based on the expected duration of land tenure.

4.1. Adoption hypotheses

Based on the physics of soil erosion, physical factors should affect adoption patterns:

HA$_1$. Where productive soils are more prone to erode (R is large), farmers will be more likely to adopt soil conservation. This follows given $e'(R) > 0$, $e'(\mathrm{CI}) < 0$, $e'(R) < 0$, and $\partial^2 e/\partial \mathrm{CI}\partial R < 0$.

But land tenure status affects the likely returns from conservation investments, generating twin hypotheses based on the type of conservation investment:

HA$_{2\mathrm{L}}$. Where land tenure is expected over the long-term ($E[T_t] = 1$ for $t > 5$ years), farmers will adopt durable soil conservation measures (such as stone terraces). This follows from (a) the temporal growth paths of cumulative net returns for stone terraces versus soil bunds as illustrated in Fig. 1, and (b) the need to maintain the inequality in Eq. (3) which militates for making larger investments in order to obtain more than compensating discounted returns.

HA$_{2\mathrm{S}}$. Where land tenure is expected only for the short term ($E[T_t] = 1$ for $t \leq 5$ years), farmers will either adopt cheaper, less durable soil conservation measures (such as soil bunds), or else they will refrain altogether from investing in soil conservation (for the reasons in the previous hypothesis).

Given that public and private investments in long-term structures can substitute for one another:

HA$_3$. Where farmers have already benefited from publicly constructed soil conservation structures on their own land, they will be less likely to invest in private ones ($\partial \text{CI}/\partial \text{PC} < 0$). This direct substitution effect is expected to be dominant in the instance of stone terraces, where public and private constructions are identical on public and private lands.

However, when public soil conservation campaigns have provided learning opportunities without building conservation structures on the farmer's own land, they may encourage adoption by reducing the perceived cost of conservation investments:

HA$_4$. Where public soil conservation activities (PC) take place in the same community but not on the household's own land, farmers will be more likely to adopt soil conservation. This result follows from (a) the experience effect reducing real conservation investment costs ($w'_{\text{CI}}(\text{CI}) < 0$, and (b) awareness of the effectiveness of conservation, leading to more accurate assessment that $y'(s)s'(e)e'(\text{CI}) > 0$.

Finally, the hypothesised role of social capital suggests that:

HA$_5$. Where farmers feel community pressure to conserve soil ($U\{I[s]\}$), they will be more likely to adopt soil conservation measures. This follows from the second term in Eq. (3), making the community pressure effect on derived demand for the CI input even stronger and amplifying willingness to pay for conservation.

In an impoverished, rural setting where capital and labour markets are imperfect, farm level endowments of these factors affect capacity to invest (Clay et al., 1998; Pender and Kerr, 1998). Hence, endowments of labour and capital may affect the likelihood of farmer adoption of conservation practices, implying:

HA$_6$. Where capacity to invest per unit of land is greater, farmers will be more likely to adopt conservation practices.

4.2. Degree (intensity) of adoption hypotheses

If the factors affecting adoption differ from those that affect degree of adoption, then we expect the degree of investment to depend more on marginal factors related to costs and returns from the degree of investment. Two hypotheses emerge:

HD$_1$. Land tenure status is relevant to the decision on *whether* to make soil conservation investments, but it is not relevant to *how much* investment is made, given the decision to invest. This hypothesis emerges from the assumed relation between the investment return time paths illustrated in Fig. 1, such that the wealth-maximising return depends entirely on the time horizon.

HD$_2$. Where expected return on investment per unit of land is greater, farmers will invest more in soil conservation.

5. Empirical methods and data

These hypotheses were tested using data from a survey of villages, farms and fields in the Tigray region of Ethiopia during 1995–1996. Agriculture in the region is characterised by mixed subsistence farming, where oxen are the only sources of draft power. Soil erosion and deforestation are very severe. Intense tropical rainstorms, steep slopes and inappropriate land use have resulted in heavy soil loss. Extensive efforts to conserve soil have been made in the region since 1991. These efforts take three approaches: (1) private investments in terraces and bunds by farmers assisted by the agricultural extension service, (2) public conservation investments via mandatory community labour, and (3) public conservation investments via food-for-work projects. FFW payment is used for conservation works, mostly for micro-dam construction, area closures and afforestation. In some cases, FFW also is used to construct stone terraces on hillsides.

6. Data

The survey covered 250 farm households in 30 villages spread among six districts in the Tigray region (Gebremedhin, 1998). It focused on farmers' adoption of soil conservation practices, including stone terraces, soil bunds and vegetative plantings. A variety of background information was also collected in order to associate adoption with the major classes of explanatory variables in the literature.

For sampling purposes, the area was classified into four topographic zones: steep, moderately steep, hilly and plain. Representative villages were purposely selected in each topographical class. The number of villages selected was proportional to the land area covered by each class. A sampling frame of household heads in each village was then prepared and a random sample of 250 households drawn. The number of households sampled from each village was proportional to the number of households in the village (Gebremedhin, 1998).

Data were collected at village, household and plot levels. Most village level data came from observation and interviews with village leaders. Data on household characteristics and agricultural activities were collected via interviews with household heads. Physical characteristics of farm fields were observed and measured during site visits. Farm field observations included area, slope, shape of slope, position on slope, soil texture and the lengths of any stone terraces and soil bunds that were present.

The explanatory variables included in the empirical models were selected following the literature on farm level investment theory (Feder et al., 1992; Clay et al., 1998). Following this literature, farm investment can be modelled as a function of:

1. market access factors (as a proxy for return on investment factors);
2. physical incentives to invest;
3. capacity to invest;
4. land tenure security (as a proxy for riskiness of investment);
5. socio-institutional factors; and
6. household demographic characteristics.

The roles of market access and physical incentives are captured in the conceptual model above, as are land tenure and other socio-institutional factors. For simplicity, the conceptual model omitted the relevant capacity constraint on investible funds. As an individual farmer's behavioural model, it omitted the household demographic characteristics that become relevant conditioning factors in a cross-sectional data set.

The dependent variables used in the study were classified as adoption (use or non-use) and intensity of use of soil conservation practices. Intensity of use was measured as the number of metres per hectare (m/ha) of terraces or bunds constructed. An average estimated length of 700 m/ha of stone terraces or soil bunds is required to conserve a hectare of land to reduce soil erosion effectively on typical slopes in the area.

7. Econometric specification: double hurdle versus tobit models

Our research objectives are to understand both the factors affecting the probability of adoption and the factors affecting the intensity of practices adopted. As such, it was necessary to go beyond the typical binary dependent variable methods applied to cross-sectional surveys on technology adoption (Feder et al., 1992).

The decisions on whether to adopt and how much to adopt can be made jointly or separately. When the decisions are joint, the tobit model is appropriate for analysing the factors affecting the joint decision (Greene, 1993). This assumption has been the norm in previous research into the determinants of the intensity of soil conservation investments (Sureshwaran et al., 1996; Pender and Kerr, 1998). However, adoption and intensity of use decisions are not necessarily made jointly. The decision to adopt may precede the decision on the intensity of use, and the factors affecting each decision may be different, as assumed in the present case. In this case, it is more suitable to apply a 'double hurdle' model in which a probit regression on adoption (using all observations) is followed by a truncated regression on the non-zero observations (Cragg, 1971).

The double hurdle model is designed to analyse instances of an event which may or may not take place and if it takes place, takes on continuous positive values. In the case of farmer adoption of soil conservation practices (e.g. building terraces or bunds), a decision on adopting the practice is made first, and then decision on the intensity of use (how many metres per hectare of terracing or bunds) follows. Following Cragg (1971), the decision on adoption can be modelled as a probit regression:

$$f(y = 1|X_1, X_2) = C(X_1'\beta), \tag{4}$$

where $C(\cdot)$ is the normal cumulative distribution function, and X_1 and X_2 are vectors of independent variables, not necessarily distinct. The decision on the intensity of use can be modelled as a regression truncated at zero:

$$f(y|X_1, X_2) = (2\pi)^{-1/2}\sigma^{-1} \exp\left\{\frac{-(y - X_2'\gamma)^2}{2\sigma^2}\right\} \times \frac{C(X_1'\beta)}{C(X_2'\gamma/\sigma)} \quad \text{for } y > 0. \tag{5}$$

Whether a tobit or a double hurdle model is more appropriate can be determined by separately running the tobit and the double hurdle models and then conducting a likelihood ratio test that compares the tobit with the sum of the log likelihood functions of the probit and truncated regression models (Greene, 1993).

7.1. Regression specification

Based on the general model of soil conservation investment presented above, the regression models were specified for investments in both stone terraces and soil bunds to mitigate soil erosion. All regression equations used the explanatory variables in Table 1, which correspond to the six categories identified in the general model.

The *market access factors* affect the relative profitability of investment in conservation practices. Ideally such factors would include crop prices, cost of labour and materials used for conservation and the yield effect of conservation practices. However, information on the effect of conservation on yield was not available. Moreover, the large number of infra-subsistence farmers meant that crop sale prices were unavailable. Instead, relative prices were proxied by distance from marketplace. Labour input is a major cost component in conservation investment in the study area. Distance from an all-weather road was used to proxy for differences in the opportunity cost of labour. The expected effects of these on conservation investment were ambiguous, as distance reduces both crop income and off-farm work opportunities during the dry season.

Physical incentives to invest in conservation practices include the village level ecological factors and physical characteristics of plots. We expect that the greater the land degradation in a village, the more likely resident farmers would be to invest in conservation practices. Villages in hilly areas tend to suffer more soil erosion and thus should benefit more from soil conservation. Highland zones have higher rainfall than the intermediate highland zones and so should experience greater soil erosion, giving more incentive for conservation practices to reduce runoff.

The field level physical factors associated with soil erosion (and hence likely benefits from soil conservation) include slope steepness, concave or convex (rather than rectilinear) slope, and non-clay soils. Due to the expected low return of investment on very steep slopes, a squared degree-of-slope term was included to capture this effect. Larger fields cultivated for longer periods were also expected to favour soil conservation investment. By contrast, distance of plot from homestead, and plot fragmentation were expected to detract from investment due to increased transaction costs.

The factors expected to affect the *capacity to invest* include cash income, wealth, land area and family labour. Of these, the cash income and wealth data were unusable due to under-reporting. Usable data included land area, measured as hectares of cultivated land, and family labour, measured as number of household members aged 15–64 years. The effect of land area is ambiguous. On the one hand, more land indicates greater wealth and capacity and should encourage investment; on the other, more land may reduce the need to conserve land. Own labour availability should encourage investment either due to availability of labour to do the work or due to the need to feed more people.

Three different measures were used to capture the degree of land tenure security, an institutional factor in *investment risk*. In the immediate period, risk was measured in terms of whether or not the land was owned or leased. For the medium-term, tenure security was measured by whether farmers believed that they would cultivate the same plots 5 years from the time of the survey. Long-term tenure security was gauged by whether farmers believed they would bequeath the plot to their children. At the village level, time elapsed since the last land distribution was used

Table 1
Definition and measurement of explanatory variables, 250 rural households, Tigray region, Ethiopia, 1995–96

Variable	Definition	Mean	Standard deviation
Dependent variables			
Terraces	Stone terrace construction (m/ha)	71.2	198.2
Bunds	Soil bunds constructed (m/ha)	13.2	82.2
(1) Market access factors			
Market distance	Distance from village to nearest market (walking hours)	1.62	0.77
Road distance	Distance from village to nearest all weather road (walking hours)	1.49	1.17
(2) Physical factors			
Firewood distance	Village roundtrip distance to fetch fuelwood (walking hours)	6.30	3.30
Highland	Village lies above 2500 m altitude (0/1)	0.10	–
Hilly village	Predominant topography of village (0/1)	0.655	–
Plots cultivated	Number of plots cultivated by household	3.52	1.98
Slope	Slope of plot (°)	6.44	6.68
Soil sandy[a]	Predominant soil type of plot is sandy (0/1)	0.213	–
Soil silty	Predominant soil type of plot is silty (0/1)	0.019	–
Soil loamy	Predominant soil type of plot is loamy (0/1)	0.280	–
Slope convex[b]	Plot slope has convex shape (0/1)	0.041	–
Slope concave	Plot slope has concave shape (0/1)	0.066	–
Slope mixed	Plot slope has mixed shape (0/1)	0.086	–
Plot on upper slope[c]	Plot located on upper slope (0/1)	0.135	–
Plot on mid slope	Plot located on middle slope (0/1)	0.121	–
Plot on lower slope	Plot located on lower slope (0/1)	0.265	–
Plot area	Plot area (ha)	0.445	0.323
Plot distance	Distance of plot from home (walking hours)	0.476	0.477
Plot age	Duration that plot operated by owner (years)	7.57	6.06
(3) Capacity factors			
Workers	Number of working-age (15–64 years) household members	2.95	1.32
Farm size	Area of cultivated land (ha)	1.19	0.50
(4) Land tenure security factors			
Own plot now	Plot is owned (not rented or borrowed) (0/1)	0.808	–
Own in 5 years	Owner feels certain to cultivate the same fields after 5 years (0/1)	0.604	–
Own on bequest	Owner feels certain to leave plots to children (0/1)	0.422	–
Time since land redistributed	Years since last land distribution in village	6.56	2.41
(5) Socio-institutional factors			
Community pressure	Household head feels pressure from community to conserve soil (0/1)	0.594	–
Extension contact	Household had contact with extension conservation service (0/1)	0.574	–
FFW available	Food-for-work was available in village (0/1)	0.448	–
Public conservation	Household had conservation work done on its plots by public campaigns (0/1)	0.695	–
(6) Household demographic characteristics			
Dependency ratio	Ratio of total household members to working-age household members	1.80	0.547
Age of head	Age of household head (years)	46.5	14.4
Male head	Male head of household (0/1)	0.829	–
Literate head	Literate household head (0/1)	0.229	–

[a] Clay soil was the base of comparison for all soil texture dummies.

[b] Rectilinear shape of plot was the base of comparison for all slope dummies.

[c] Plain or plateau was the base of comparison for all plot location dummies.

as measure of the stability of land tenure. Given evidence elsewhere that land improvements may be made to enhance tenure security (Otsuka et al., 1997), the medium and long-term land tenure security variables were checked for endogeneity.

Several *socio-institutional variables* were expected to encourage farmers toward investing in soil conservation. These include community pressure, contact with the agricultural extension service and availability of FFW projects. Due to the substitution effect, public soil conservation campaign beneficiaries were expected to invest less in private soil conservation.

Household *demographic variables* include age, sex, dependency ratio and literacy of household head. We expected older, male and literate household heads with fewer dependents to be more likely to invest due to experience and the influence of extension posters about soil conservation.

The models were initially specified as household level random effects models, in order to accommodate correlation in management among fields within the same household (Deaton, 1997).

8. Regression results

A likelihood ratio test rejected the tobit model in favour of the double hurdle model (Gebremedhin, 1998, p. 187). The test confirmed that the adoption and intensity of use decisions are in fact separate for this data set. Hence the results reported here are for the double hurdle model only. Results for all variables are reported in both the probit and truncated regression models, despite the fact that they confirm hypothesis HD_1 (that land tenure status is relevant only for the probit model).

The random effects models were found to yield insignificant coefficients of within-household and within-village correlation of disturbance terms, so household effects were dropped from the models. Likewise, the Hausman tests for endogeneity of the land tenure-related explanatory variables yielded no evidence of simultaneity. The probit models of stone terrace and soil bund adoption were tested for independence of these decisions against a bivariate probit alternative; the likelihood ratio test could not reject the hypothesis of independence.

8.1. Determinants of adoption

The regression results (Table 2) show that household investment in both stone terraces and soil bunds is influenced by a wide range of factors. Physical incentives to invest, household capacity to invest, land tenure security and socio-institutional factors were important in explaining household adoption of stone terraces, and market access was also important for adoption of soil bunds. Overall, the likelihood of adoption of stone terraces was modest; an average farmer had 18% predicted probability of adopting the practices. By contrast, the predicted probability of adopting soil bunds was far lower, just over one percent during the 1992–1995 study period. Interestingly, many of the determinants of adopting soil bunds had effects contrary to those on stone terraces.

The physical factors influencing soil conservation are the ones that relate most closely to hypothesis HA_1: "Where productive soils are more prone to erode, farmers will be more likely to adopt soil conservation."

Degree of slope increased the use of both stone terraces and soil bunds, up to a maximum steepness. Plot location influenced both kinds of structures. Farmers prefer to use soil bunds on toe slopes, as indicated by the negative signs on middle and upper slope locations. By contrast, they are more prone to build stone terraces on middle and lower slopes where they can curb erosion. The fact that hilly topography of villages was an important determinant of the adoption of stone terraces but did not matter for soil bunds suggests that Tigrayan farmers believe that stone terraces are more effective when soil erosion is more severe. Compared with the base case of clay soils, farmers preferred to construct soil bunds on sandy soil textures that are both more prone to erode and easier to work than clays. All these factors are consistent with the null hypothesis that physical propensity toward erosion enhances the likelihood of soil conservation adoption. Farmers are more likely to build both soil bunds and stone terraces on plots that they cultivated longer, suggesting the importance of stable tenure for soil conservation. Results appear mixed on the influence of slope shape, since concave shape favours the adoption of terraces while mixed shape detracts from the adoption of bunds. The negative effect of rainy upper highland villages ran counter to initial expectations, but may be explained by a tendency toward waterlogging of vertisol soils

Table 2
Probit regression results for adoption of stone terraces and soil bunds

Variable	Adoption of stone terraces		Adoption of soil bunds	
	Coefficient (robust standard error)	Marginal effect	Coefficient (robust standard error)	Marginal effect
(1) Market access factors				
Market distance	0.028 (0.160)	0.0076	−0.343 (0.184)*	−0.013
Road distance	−0.112 (0.106)	−0.030	−0.075 (0.645)	−0.002
(2) Physical factors				
Highland	−0.987 (0.316)***	−0.172	−0.316 (0.469)	−0.009
Firewood distance	−0.023 (0.039)	0.006	0.092 (0.076)	0.003
Hilly village	0.724 (0.246)***	0.139	0.389 (437)	0.007
Plots cultivated	0.006 (0.086)	0.0016	0.250 (0.112)**	0.009
Plot age	0.047 (0.025)*	0.012	0.046 (0.018)**	0.001
Soil sandy	−0.186 (0.227)	−0.047	0.808 (0.367)**	0.049
Soil silty	0.435 (0.718)	0.136	0.637 (0.622)	0.050
Soil loamy	−0.276 (0.205)	−0.089	0.803 (0.359)**	0.046
Slope	0.118 (0.052)**	0.031	0.176 (0.077)**	0.006
Slope squared	−0.0039 (0.0017)**	−0.001	−0.004 (0.002)*	−0.0001
Slope convex	0.306 (0.272)	0.090	0.721 (0.355)	0.071
Slope concave	0.485 (0.236)**	0.138	0.038 (0.414)	0.009
Slope mixed	0.305 (0.242)	0.089	−0.773 (0.437)*	−0.011
Plot distance	−1.101 (0.291)***	−0.293	0.091 (0.332)	0.003
Plot area	0.600 (0.307)**	0.159	0.568 (0.444)	0.022
Plot on upper slope	0.015 (0.112)	0.004	−0.869 (0.366)**	−0.015
Plot on middle slope	0.539 (0.264)**	0.167	−0.713 (0.328)**	−0.017
Plot on lower slope	0.454 (0.258)*	0.133	−0.490 (0.497)	−0.014
(3) Capacity to invest factors				
Workers	0.597 (0.218)***	0.230	0.0312 (0.181)	0.001
Farm size	−0.220 (0.140)	−0.036	−0.219 (0.209)	−0.008
(4) Land tenure security factors				
Own plot now	0.375 (0.233)	0.034	0.862 (0.311)***	0.020
Own in 5 years	−0.480 (0.491)	−0.186	0.318 (0.378)	0.011
Own on bequest	0.416 (0.211)**	0.286	−0.957 (0.291)***	−0.038
Time since land redistributed	0.104 (0.052)**	0.007	−0.136 (0.079)*	−0.005
(5) Socio-institutional factors				
Community pressure	0.284 (0.227)	0.076	−0.382 (0.244)	−0.035
Extension contact	−0.190 (0.235)	−0.049	−0.323 (0.326)	−0.014
FFW available	0.744 (0.382)**	0.248	−0.548 (0.272)**	−0.016
Public conservation	−0.545 (0.177)***	−0.145	−0.426 (0.263)**	−0.013
(6) Household demographic characteristics				
Dependency ratio	−0.101 (191)	−0.026	0.440 (0.299)	0.017
Age of head	−0.0038 (0.0104)	−0.001	−0.015 (0.014)**	−0.000
Male head	0.414 (0.359)	−0.093	−0.433 (0.517)	0.025
Literate head	0.083 (0.254)	0.021	−0.423 (0.320)	−0.013
Constant	−2.004 (0.940)**	–	−1.400 (1.041)	–
Regression diagnostics				
Chi-square	118.52	–	101.22	–
Probability > Chi-square	0.0000	–	0.0000	–
Pseudo R-square	0.2783	–	0.2762	–
Predicted probability at mean	0.184		0.015	
Sample size (n)	638	–	638	–

* Significance at the 10% level.

** Significance at the 5% level.

*** Significance at the 1% level.

that occurs in some of the upper highland areas. Soil type was omitted from the model, but waterlogging concerns would discourage farmers from practices that would retain water on vertisol fields. On the whole, the evidence strongly supports the importance of physical factors behind adoption of soil conservation measures.

The coefficient estimates for land tenure security in Table 2 provide the primary basis for testing hypotheses HA_{2L} and HA_{2S}. Farmers with secure land tenure who (1) expect to bequeath their fields to their children and (2) live in villages with no recent land redistribution are both more likely to build stone terraces and less likely to build soil bunds. By contrast, field owners who currently operate a field are associated with soil bund use, either because tenure insecurity causes them to limit investment, or because unimproved fields are more likely to be rented out (and hence benefit only from short-term bund conservation). Overall, the evidence gives resounding support for the linked hypotheses that tenure security favours long-term soil conservation investments such as stone terraces, whereas insecurity favours short-term investments, such as soil bunds.

Socio-institutional factors are the key to testing the three remaining adoption hypotheses. Hypothesis HA_3, that farmers benefiting from publicly constructed conservation structures substitute for private investment, can be tested by examining the coefficient estimates on the 'Public conservation' variable. Evidently, households that had benefited from public conservation campaigns were less prone to adopt either soil bunds or stone terraces, as expected.

The hypothesis that nearby public soil conservation activities that take place off the farmer's own land may encourage private soil conservation investment (HA_4) can be tested via coefficient estimates on the 'FFW available' variable. The availability of FFW increased adoption of stone terraces but decreased that of soil bunds. This is consistent with the fact that FFW projects emphasised the rehabilitation of hillsides, focusing in part on stone terraces but not on soil bunds.

The effect of community influence (social capital) in inducing adoption of soil conservation (HA_5) is tested via the 'Community pressure' variable. This had no significant effect on adoption of either terraces or bunds. Although the signs of the coefficient estimates are consistent with our expectations, there is no compelling statistical support for this hypothesis.

The capacity to invest and convenience of doing soil conservation were the basis for testing hypothesis HA_6 and played roles that are consistent with the maintained hypothesis of wealth in the utility function. The presence of more working-age household members favoured adoption of labour-demanding stone terraces, as did ownership of large plots that would yield greater rewards to the costs of construction. By contrast, households having many plots were more inclined to build soil bunds which demand less labour. Distance of plots from the homestead detracted strongly from the propensity to build stone terraces, with each added hour of walking reducing the probability of building terraces by 29%. Village distance from markets had mild negative effect on adoption of soil bunds.

8.2. Determinants of level of soil conservation investment

The second stage of the double hurdle model measures extent of adoption among adopters of the soil conservation practices. The truncated regression of stone terraces showed that the factors that influence adoption and intensity of use of stone terraces are different (Table 3). This result was robust whether the intensity of use model was specified with actual non-zero values or predicted non-zero values from the first-stage probit analysis. As expected under hypothesis HD_1, the land tenure status variables that were key to the decision on *whether* to invest in soil conservation (the probit model) were insignificant in the decision on *how much* to invest (the truncated regression model). Likewise, the capacity to invest and socio-institutional factors that were important in determining adoption, had no influence on intensity of use. The one exception was plot area, which detracted from terrace density. Given that the dependent variable measures metres of stone terracing per hectare, larger fields have fewer metres of terracing per hectare because of terrace indivisibility and diminishing marginal returns to terrace construction within a field. The truncated regression for soil bunds was insignificant and is not reported.

On the other hand, there is clear evidence that farmers invested more in stone terraces where expected returns were higher (HD_2). In villages that were more distant from markets and roads, terrace density was significantly higher. In such remote villages, off-farm

Table 3
Probit and truncated regression results for adoption and intensity of use of stone terraces

Variable	Adoption of terraces [probit] (robust standard error)	Density of terraces [truncated regression]	
		Actual non-zero values (asymmetric standard error)	Predicted non-zero values from probit (asymmetric standard error)
(1) Market access factors			
Market distance	0.028 (0.160)	216.80 (120.3)**	187.13 (61.01)***
Road distance	−0.112 (0.106)	137.25 (57.07)**	162.57 (76.42)**
(2) Physical factors			
Highland	−0.987 (0.316)***	659.47 (296.2)**	721.03 (314.71)**
Firewood distance	−0.023 (0.039)	−16.74 (32.29)	21.07 (24.12)
Hilly village	0.724 (0.246)***	174.54 (245.6)	161.36 (212.07)
Plots cultivated	0.006 (0.086)	−68.13 (57.81)	−61.23 (45.69)
Plot age	0.047 (0.025)*	23.14 (11.59)**	31.25 (10.25)***
Soil sandy	−0.186 (0.227)	207.04 (161.7)	−189.67 (158.08)
Soil silty	0.435 (0.718)	1383.3 (387.4)***	1407.00 (421.05)***
Soil loamy	−0.276 (0.205)	102.33 (214.8)	116.68 (176.89)
Slope	0.118 (0.052)**	63.76 (44.21)	81. 79 (45.89)*
Slope squared	−0.0039 (0.0017)**	−2.46 (1.87)	−6.03 (3.52)*
Slope convex	0.306 (0.272)	200.86 (227.8)	201.72 (187.96)
Slope concave	0.485 (0.236)**	76.41 (218.6)	56.45 (178.31)
Slope mixed	0.305 (0.242)	145.72 (183.5)	153.12 (171.01)
Plot distance	−1.101 (0.291)***	−287.67 (243.4)	−321.73 (252.02)
Plot area	0.600 (0.307)**	−810.30 (261.8)***	−756.03 (251.14)***
Plot on upper slope	0.015 (0.112)	248.92 (232.4)	213.34 (211.23)
Plot on middle slope	0.539 (0.264)**	194.65 (239.8)	201.87 (223.46)
Plot on lower slope	0.454 (0.258)*	61.71 (184.2)	87.69 (201.45)
(3) Capacity to invest factors			
Workers	0.597 (0.218)***	32.28 (66.18)	65.21 (58.45)
Farm size	−0.220 (0.140)	8.15 (77.71)	−6.78 (81.34)
(4) Land tenure security factors			
Own plot now	0.375 (0.233)	−204.59 (199.4)	−198.87 (201.34)
Own in 5 years	−0.480 (0.491)	163.87 (196.7)	134.07 (154.89)
Own on bequest	0.416 (0.211)**	−113.88 (165.8)	−78.96 (147.65)
Time since land redistributed	0.104 (0.052)**	−43.74 (31.02)	−38.21 (43.38)
(5) Socio-institutional factors			
Community pressure	0.284 (0.227)	−106.16 (118.3)	−112.38 (107.63)
Extension contact	−0.190 (0.235)	−187.69 (157.6)	−89.35 (143.21)
FFW available	0.744 (0.382)**	198.98 (167.9)	201.23 (154.37)
Public conservation	−0.545 (0.177)***	−101.76 (197.5)	−76.48 (187.23)
(6) Household demographic characteristics			
Dependency ratio	−0.101 (191)	131.58 (91.3)	102.36 (76.89)
Age of head	−0.0038 (0.0104)	−1.69 (5.76)	2.46 (6.06)
Male head	0.414 (0.359)	−162.64 (226.3)	−189.67 (231.06)
Literate head	0.083 (0.254)	−157.27 (151.8)	−167.42 (150.30)
Constant	−2.004 (0.940)**	–	–
Regression diagnostics			
Chi-square	118.52	–	–
Probability > Chi-square	0.0000	–	–
Pseudo R-square	0.2783	–	–
Sample size (n)	638	139	123

* Significance at the 10% levels.

** Significance at the 5% levels.

*** Significance at the 1% levels.

employment opportunities are limited and lower wages prevail (Gebremedhin, 1998, p. 196), reducing the cost of hired labour as well as the opportunity cost of family labour. On the revenue side, stone terracing was significantly denser where slopes were steeper (up to a maximum) and in highland settings, where rainfall is higher and the expected benefits from erosion abatement are highest. Similarly, plots operated by current owner longer received more terracing, presumably because the evidence of erosion was greater and perhaps also because land tenure security was greater. Likewise, silty soils, which tend to be very fertile, also received more terracing.

8.3. Discussion of results

The importance of physical determinants of soil erosion in influencing the adoption of conservation practices by Tigrayan farmers reinforces similar findings elsewhere (Ervin and Ervin, 1982; Pender and Kerr, 1998; Shiferaw and Holden, 1998; Sureshwaran et al., 1996). The specific results are consistent with the region's hilly and rugged terrain. The significant negative quadratic term indicates that farmers are disinclined to invest in conservation practices when slopes become very steep.

The cost of conservation works is especially important. It includes not only cash costs, but also the transaction costs of travel to plots distant from the homestead or highly fragmented and small. Such plots are more likely to be developed with soil bunds than with stone terraces. Clay et al. (1998), in their Rwanda study, likewise found that distance of plots from homestead discouraged investment in stone terraces.

Where labour markets function poorly, the availability of family labour encourages adoption of labour-demanding conservation technologies (Pender and Kerr, 1998). The labour market in Tigray is likely to be imperfect due to information asymmetry or transaction costs. Hence it makes sense that in this case too, the availability of family labour encouraged adoption of stone terraces.

Neoclassical economic theory suggests that, ceteris paribus, reduced risk and longer planning horizons should enhance expected returns and encourage investment. Land tenure security and stability embody both of these attributes. Our results from Tigray confirm that farmers who have long-term land tenure security are more likely to invest in costly but durable stone terraces, while farmers who have only short-term land tenure security are more likely to invest in cheaper, less durable soil bunds. The greater specificity of the tenure status variables used here allows more insights to be gleaned than from Shiferaw and Holden's (1998) single variable for lifetime tenure security. Our results echo those from the United States that tenure security encourages land improvements, notably the use of conservation practices (Lee, 1980; Ervin and Ervin, 1982; Feder et al., 1988; Besley, 1995; Gavian and Fafchamps, 1996; Hayes et al., 1997).

The determinants of conservation adoption and intensity of use have been considered to be the same in most of the conservation literature. A notable exception is the work by Ervin and Ervin (1982), which modelled conservation effort separately from adoption. Our results demonstrate that the factors affecting adoption and intensity of use of stone terraces in Tigray are, in fact, different. Intensity of use of stone terraces is affected by the opportunity cost of labour and the expected return from investment. While development of off-farm employment opportunities may detract from intensified use of conservation practices due to competition for labour, market and infrastructure development is likely to encourage intensity by enhancing the return to conservation investments. Policy makers will find that the relevant tools for encouraging conservation investments depend on whether or not farmers are already convinced of the need to adopt soil conservation. Awareness of conservation practices, plus secure, stable land tenure are important for adoption of long-term soil conservation. But for farmers who have already decided to invest in conservation practices, expected net benefits and resource constraints are the key factors influencing degree of investment in conservation practices.

9. Conclusions

This research explores the contrasts between the determinants of whether to invest and how much to invest, as well as how those decisions are affected by land tenure security. In general the results confirmed the hypothesised outcomes. The key findings and their implications are as follows. Investment in stone terraces was positively influenced by factors associated with long-term investment perspective such as capacity to invest and land tenure security. By contrast, investment in soil bunds was associated with a short-term, low-budget investment perspective. The factors affecting level of investment were different from those that affect the decision of whether to invest. The opportunity costs of labour and foregone land productivity were strong determinants of level of investment, despite making no significant contribution to the choice of whether to invest. This suggests that activities that use labour in the dry season when bunds and terraces are constructed and maintained (such as migration, local off-farm activity and food-for-work programs) may compete with soil conservation.

Recent research on soil conservation in Ethiopia (Shiferaw and Holden, 1999; Gebremedhin et al., 1999) has highlighted the need for public policy interventions to supplement private incentives to make soil conservation investments in erosion-prone mountain areas. The social benefits of soil conservation often justify public intervention, especially when private returns are marginal at typical discount rates.

But the evidence presented here reveals that not all public interventions are helpful. Direct public involvement in constructing soil conservation structures on private lands appears to compete with private conservation investments, undermining incentives for the latter. But public conservation campaigns need not be counterproductive. When carried out on public lands, public conservation activities may be exemplary, serving an educational role that reduces the learning cost of privately building soil conservation structures.

The right kind of policy interventions can strongly enhance private incentives to invest in soil conservation. Secure and stable rights to land tenure assure the long-term perspective that favours costly, durable investment in soil conservation such as construction of stone terraces. Land titling and legal enforcement of title are fundamental for the widespread adoption and sustained use of conservation practices. The drive in the region towards land registration seems to be a step towards this goal.

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