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Abstract

This study measures the impact of *fanya juu* bunds (an important soil and water conservation technology and the most popular type of contour bund in east Africa) on the value of crop production in a high-rainfall area in the Ethiopian highlands using cross-sectional multiple plot observations. We applied switching regression, stochastic dominance analysis (SDA), and decomposition and propensity score matching methods to ensure robustness. The switching regression, SDA, and decomposition analyses relied on matched observations, which was important because regression and SDA often do not ensure that comparable plots with conservation technology (conserved) and plots without (unconserved) actually exist in the distribution of covariates.

All models told a consistent story that the value of crop production for plots with bunds was lower than for plots without bunds. In addition, the yield decomposition results showed that, although there was little difference in endowments between conserved and unconserved plots, the returns to endowments were substantially higher for unconserved plots. Based on these findings, it was hard to avoid the conclusion that these technologies might reduce soil erosion and associated off-site effects, but they did so at the expense of poor farmers in the Ethiopian highlands. We concluded that unless productivity was increased—for example by increasing fodder grass production on bunds—fanya juu bunds reduced on-farm production and therefore could not be characterized as a "win-win" measure to reduce soil erosion.

Key Words: Ethiopia, soil conservation, matched data, decomposition

JEL Classification Numbers: C21, C23, Q12, Q15, Q16

Contents

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Introduction

Land degradation, soil erosion, and nutrient depletion contribute significantly to low agricultural productivity—and thus food insecurity and poverty—in many hilly areas of the developing world (Pagiola 1999; Shiferaw, Okello, and Reddy 2007; Nakonya et al. 2006). In response, considerable public resources have been mobilized to develop soil and water conservation (SWC) technologies and promote them to farmers. Examples of technologies advanced throughout the developing world include structural methods, such as soil and stone bunds; agronomic practices, such as minimum tillage, grass strips, and agro-forestry techniques; and water harvesting options, such as tied ridges and check dams[1] (Shiferaw, Okello, and Reddy 2007).

The primary reasoning behind using these technologies in mountainous regions is to reduce movement of soils, water flow velocity, and the broader effects of erosion, such as siltation of rivers, lakes, and dams. SWC techniques also reduce soil loss from farmers' plots, preserving critical nutrients and increasing crop yields, and this is the chief selling point for farmers. Because SWC technologies serve not only the social good but also increase on-farm yields, they are considered "win-win."

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[1] Tied ridges (also called furrow dykes) help hold soil moisture. They are perpendicular ridges or earth dams placed at regular, often 1-meter intervals along the planting furrow. The crop is planted on top of the furrow and the depressions between the "ties" collect rain and and run-off water. Check dams, used to reduce erosion and slow water flow, are constructed of rock, gravel, sand bags, fiber rolls, logs, etc., across drainage channels or swales. They tend to hold water, like tiny ponds, which seeps slowly through the check dam.

Whether SWC technologies offer private benefits, social benefits, private and social benefits, or no benefits at all is important for a number of reasons. First, there are legitimate concerns about the off-site effects of soil erosion, particularly siltation, which can disrupt a variety of aquatic ecosystems and cause economic damage to reservoirs and waterways (Pagiola 1999; Scherr and Yadav 1997; European Environmental Agency 1995). In public and policy venues, catastrophic floods have also been linked to soil erosion in Ethiopia, which is the focus of this study. For example, flooding in eastern Ethiopia (Drie Dawa) in August, October, and December 2006 damaged buildings, killed hundreds of people, and displaced thousands (*Mail & Guardian Online*, 10 August 2006). The conventional policy wisdom, in fact, is that if SWC technologies can reduce these effects they should be promoted (Shiferaw, Okello, and Reddy 2007; World Food Programme 2005).

Regarding private benefits, there are real concerns about the incomes of the farmers to whom SWC technologies are promoted. Farmers in mountainous areas of developing countries typically rely almost wholly on agriculture for their incomes and have some of the lowest incomes and highest rates of poverty in the world (Jackson and Scherr 1995; Ehui and Pender 2005). This is also true in Ethiopia. As found by Bluffstone et al. (2007) and the Ministry of Finance and Economic Development (MOFED) of Ethiopia (2006; 2002), some 65–85 percent of incomes in rural Ethiopia, and particularly the highlands (which are home to over 85 percent of the 75 million Ethiopians), come from crop agriculture. Furthermore, incomes and consumption levels of these primarily subsistence farmers are extremely low. For example, MOFED (2002) found that in 1999–2000 the average rural adult income was only about US$ 95.00 per year and consumption was $136.28 per year, with about 42 percent of adults unable to obtain 2200 calories per day on average. A key reason for these minimal income and consumption levels is that agricultural productivity is very low by international standards (World Bank 2007), with an average yield of 1000 kilograms per hectare (Central Statistical Authority of Ethiopia 1995). Indeed, low agricultural productivity is a critical problem throughout Africa (Lufumpa 2005; Food and Agricultural Organization 2002). If SWC technologies do increase agricultural productivity, they could make a major contribution to reducing the astounding levels of poverty observed in rural Ethiopia and other hilly areas of Africa and offer a powerful rationale for their promotion.

Indeed, international and national initiatives have promoted SWC technologies in the name of both poverty alleviation and environmental conservation (Shiferaw, Okello, and Reddy 2007; Nakonya et al. 2006). The problem, however, is that often these outreach programs do not allow for the possibility that SWC benefits may at best only be social and could even reduce, rather than increase, farmers' incomes. This issue of the benefits to farms and farmers is crucial—not only so that SWC technologies can be promoted accurately, but also because farmers in hilly areas of developing countries can ill afford to make investments that reduce their incomes. Furthermore, there is evidence, both in Ethiopia and internationally, that poor farmers are extremely risk averse and after experiencing failures become more risk averse and avoid all changes in production technique (Yesuf and Bluffstone 2007). Conversely, success builds on success, even with wary farmers.

Another issue is the cost of construction and maintenance of these technologies, which can be very high. This paper analyzes returns from a typical type of soil bund, *fanya juu*,[2] which is a particularly important SWC technology. In a fanya juu bund, a ditch is dug along a contour around a plot, and the soil is thrown uphill to form a ridge to block soil movements. A natural terrace forms and increases in size over time, reducing erosion. This is a common bund promoted in east Africa, particularly in Kenya, Ethiopia, and Tanzania.

As discussed by Stocking and Abel (1989) and Shiferaw and Holden (1998), however, construction of bunds is arduous and labor intensive, requiring as much as 100 person days to construct a bund on a small quarter-hectare plot. Furthermore, opportunity costs can be very high, with bunds taking up 10–20 percent of cultivable area (Wubshet 2004; Krüger 1994), and even more on sloped plots. Bunds therefore actually *reduce* the area under cultivation by a significant percent. If farmers are to benefit from installing bunds, productivity must not only increase, but must increase by more than is lost by the reductions in cultivation area.

This paper attempts to shed light on incentives to farmers to adopt SWC by estimating the change in yield per hectare due to the use of contour bunds in the northwest highlands of Ethiopia. We also decomposed the sources of any differences, but did not attempt a full cost-benefit analysis because we found that gross benefits in all models were negative. In our study, farmers did not appear to gain yield increases from the technologies. Faced with this reality, the paper then looked deeper and evaluated whether crop type or age of bunds affected yield differences and whether there were ways to tweak the technology to increase productivity, and thereby reconcile private and social objectives.

In addition to its policy implications, this paper offers some key methodological improvements, compared with previous studies (e.g. Byiringiro and Reardon 1996; Shively

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[2] Literally, *fanya juu* means "throw soil uphill" in Kiswahili.

1998; Shively 2001; Kaliba and Rabele 2004; Kassie 2005). First, the use of matched observations for parametric regression, stochastic dominance analysis, and decomposition techniques to assess SWC impacts on yield are new to the literature. Second, the application of decomposition techniques to determine the sources and magnitudes of yield gaps between conserved plots (plots with conservation technology) and unconserved plots (plots without conservation measures) is also a methodological innovation. Finally, the use of cross-sectional multiple plots per household allowed us to control for unobservable household and observable plot characteristics that impact technology adoption and production decisions.

The next section reviews the relevant literature on SWC technologies and the substantial controversy over their use. Section 3 presents the data, as well as some key descriptive statistics. Section 4 discusses challenges associated with the empirical estimation and presents the methods chosen to address those problems. Section 5 presents our results, and the final section concludes and discusses possible mechanisms for improving the economic performance of fanya juu bunds

2. Literature on Soil and Water Conservation Technologies

Land degradation is a serious problem in eastern Africa: easily 14 percent of its total area suffers from severe to very severe degradation (Food and Agricultural Organization Statistical Database 2005). This is especially true in Ethiopia, where as early as 1986, the Food and Agricultural Organization (1986) estimated that 50 percent of its highlands had significant erosion, 25 percent was seriously eroded, and 4 percent was beyond reclamation. Since then, the problem has only become worse, with an erosion-induced productivity decline estimated at 2.2 percent per year. The average annual rate of erosion on croplands is estimated to be 42 tons per hectare per year (Hurni 1993), far exceeding the soil formation rate of 3–7 tons (Gebremedhin and Swinton 2003). In a country with a fast-growing population that is vulnerable to frequent famines, loss of any food-production potential is a concern for both present and future generations.

It is beyond doubt that soil conservation measures reduce erosion. For instance, soil loss estimates from Soil Conservation Research Project experiments in the northwestern and northeastern highlands of Ethiopia indicated that fanya juu bunds, on average, could reduce soil loss by 65 percent, or 25–72 tons per hectare per year (Grunder and Herweg 1991a; 1991b). In spite of what may be important ecological benefits and substantial efforts to promote bunds, the reality is that SWC technologies have not been widely adopted by smallholders in Ethiopia or many other countries (Okoba et al. 2007; Barrett et al. 2002; Pender and Kerr 1998; Fujisaka

1994; Herweg 1993). In Ethiopia, it has been noted that pilot demonstration projects often cannot be replicated on smallholder farms (Amede 2001; Shiferaw and Holden 1998), and there is even evidence that conservation structures after some time are partially or fully removed (Shiferaw and Holden 1998; Tadesse and Belay 2004). These findings raise real questions about the appropriateness of the technologies and, indeed, why they were adopted in the first place. The policy literature sheds some light on the adoption rationale because usually either government extension agents and/or non-governmental organizations promote the bunds. These institutions often offer incentives, such as food-for-work or cash-for-work, if farmers build bunds on their farms (Bewket and Sterk 2002; Gebremedhin and Swinton 2003; Shiferaw, Okello, and Reddy 2007).

The policy literature is starting to take note of such events. For example, the World Food Programme (2005) recently noted that:

> There is a growing agreement in the area of land rehabilitation and soil conservation that profitability and cost effectiveness has in the past been largely neglected…For many years technical soundness and environmental factors have provided the only guiding principles for government and donors…The limited success of soil conservation programmes in Ethiopia in the past was largely a result of the "top down" approach to design and implementation. Many farmers were compelled to participate in the food-for-work conservation programmes implemented in the 1980s and consequently failed to maintain the physical structures adequately.

The literature also identified several factors that determine the adoption and performance of SWC technologies, but most involved farm-level tradeoffs between key resources, such as land and labor, for SWC or production (Okoba et al. 2007; Shiferaw, Okello, and Reddy 2007; Pender and Kerr 1998; Holden, Shiferaw, and Pender 2001). Indeed, in many sloping areas, the emphasis has been on arresting soil erosion and reducing run-off without regard to cost (Shiferaw, Okello, and Reddy 2007). From the private perspective, however, farmers should defer SWC investments until risk-adjusted marginal benefits and costs are equal (Kerr and Sanghi 1992). It has also been noted in the literature that whether SWC technologies generate private as well as societal benefits may depend on interactions between agro-ecological conditions and SWC technologies. Kassie et al. (2007) and Sutcliffe (1993) found that bunds offered much higher returns in low-rainfall areas, but did poorly in zones with higher rainfall. Sutcliffe (1993) also noted that, in areas with less water stress, conservation may be profitable if bunds produce fodder grass or trees.

3. Data

Data for our analysis was collected in 2001 from a random sample of 148 farm households, cultivating 1290 plots. The study village, Anjeni, is located in the northwestern Ethiopian highlands. The area is characterized by relatively high rainfall (1690 mm or 66 inches per year), altitudes of 2,100–2,500 meters, and medium to deep soils (68–143 cm). Household and plot variables were collected for the 2000 production year. Plot size, slope, and area occupied by conservation structures were also measured.

The sample households primarily utilized a subsistence production system of mixed crops and livestock that is characteristic of Ethiopia and many low-income countries. The average landholding was about 1.56 hectares, with average plot size of 0.25 hectares; the average adult-equivalent household size was 4.69 members; and livestock holding (transportation and land use) was 3.57 units (tropical livestock units). All sampled households except one used some chemical fertilizer, but only 49 percent of sample plots were fertilized. Improved seeds were used on 10.5 percent of the sample plots. Farm households typically retained seeds from the previous harvest for the next year's sowing. (Seed use, therefore, was a pre-determined variable.) Labor markets were very thin in the study area and the households depended on family resources for agricultural labor. Consequently, we viewed labor as fixed in the short run.

Fanya juu-soil conservation bunds were introduced by the Soil Conservation Research Project (SCRP), which started in 1984 and ended in 1996, with the goal of identifying and promoting suitable conservation technologies as potential improvements on traditional furrows, which were used by some farmers in the area. Project experts and government agricultural extension officers mobilized community labor for the construction of 78 percent of the bunds. To gain community support, the SCRP also built a health clinic for the village. At the time of our survey in 2001, about 32.7 percent of plots had conservation structures, and 61 percent of these structures were more than 15 years old. The frequency of plowing was higher on plots without conservation, which had an average plowing frequency of 18 person-days per hectare, compared to 16 days for conserved plots. Farmers said this difference was because turning an ox-drawn plough at the end of a furrow was more difficult due to the narrow spacing between bunds. Chemical fertilizer was used on 8 percent of conserved plots, compared with 30 percent on unconserved plots.

Bunds also produce grass, which is fed to oxen during the rainy season when grazing is difficult. Estimated grass production was as high as180 kilograms of dry matter per plot, or about 1995 kilograms per hectare—which is about one-third of native common pasture productivity

(Mengistu 1987). Farmers reported that grass from bunds supplied an average of 9.5 percent of total feed requirements. Grass is thus a potentially important output of these technologies, but there was no market for grass or hay in the study area. We noted that grass on bunds has no alternative use and there is no good substitute for this grass. To value grass produced on bunds, we therefore used an average value of one ox (from our data) at US$ 97 (ETB 800[3]), divided by the average dry grass consumption by one ox of 1825 kilograms per year (Sutcliffe 1993), as our estimate of the value of the average product of grass grown on bunds. This yielded an average grass value of $0.05 (ETB 0.45) per kilogram.

We found that the mean value of crop production per hectare was US$ 102 (ETB 840) on unconserved plots, compared with $84 (ETB 697) on conserved plots after matching. The unconditional mean value of crop production was higher on plots without bunds. We also found that yields were higher on plots with newer bunds than those with older ones. We emphasize, however, that this output difference may not be the result of soil bunds, but instead may be due to other factors, such as crop-land quality, input use, or other features. Careful multivariate analysis was called for, but as discussed in the next section, a number of econometric challenges had to be overcome first.

4. Estimation Challenges and Techniques Used

There are a number of econometric challenges to be addressed when trying to assess the productivity gains from soil conservation and the cost of ignoring these issues can be biased estimates of SWC effects. We first present these important empirical issues and then discuss the literature on potential solutions, as well as our chosen methods. The first important issue was that counterfactual outcomes were rarely observed. In other words, results with conservation, had plots not been conserved or vice versa, were not observed. Second, farmers are not randomly assigned to groups which adopt conservation technology (adopters) and to groups which do not (non-adopters), but make adoption choices themselves. Worse yet for getting consistent estimates is that the farmers might be selected by development agencies to try certain conservation technology based on their propensities to participate and benefit from adoption. Third, often plots are likely to be selected for conservation technology investment based on unobservable quality attributes (non-random). Therefore, plots receiving and not receiving

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[3] In 2001, the exchange rate between the Ethiopian birr (ETB) and the US dollar was ETB 8.25/$US 1.

treatment may be systematically different from each other, resulting in differences in farm performance that could be mistakenly attributed to adoption behavior.

The upshot of all these problems is that getting consistent estimates of the returns to conservation was a challenge if one relied on observational data. In terms of method, Heckman's two-step approach (1979) and the matching approach of Heckman and Robb (1985) are possible solutions to the selection problem. The Heckman two-step approach assumes selection on unobservables and achieves comparability by imposing distributional and functional form assumptions (usually linear) and extrapolating over regions of no common support. However, the evidence from Heckman et al. (1998), Dehejia and Wahba (1999; 2002), and Smith and Todd (2005) suggests that avoiding functional form assumptions and imposing a common support condition can be important for reducing selection bias.

A second critical estimation issue was that, even if there was no selection problem or one could account for selection, using a pooled sample of adopters and non-adopters with a binary indicator to assess the effect of soil conservation on productivity might be inappropriate. Pooled estimation assumed the set of covariates had the same impact on adopters and non-adopters (i.e., common slope coefficients). This implied that SWC only affected intercept terms and that the shift was always the same, irrespective of the values taken by other covariates that determined yield.

These were strong assumptions commonly made in the literature (e.g., Byiringiro and Reardon 1996; Shively 1998; Kaliba and Rabele 2004), but using Chow tests, we rejected equality of non-intercept coefficients at better than the 1-percent significance level in all our models. This suggested that we needed to use empirical approaches that differentiated coefficients of adopters and non-adopters.

Furthermore, previous studies that used conventional regression and stochastic dominance (SDA) methods did not in general use fully comparable conserved and unconserved plot observations in terms of the distribution of covariates (i.e., they lacked common support). Recent results in the literature, however, indicated that failure to compare matched samples of participants (conserved plots) and non-participants (unconserved plots) was a major source of bias in impact assessment (see Heckman et al. 1998). To address this problem, our regression and SDA analyses were based on propensity score matched samples of conserved and unconserved plots. In contrast to Heckman (1979), this approach assumed selection on observables using matching to create randomness in program assignment. This was based on the assumption that if untreated plots had the same probability of participation as treated plots, given their characteristics, then average crop production from unconserved plots would approximate what conserved plots would have yielded had they not been conserved. Comparisons, therefore, were made between conserved and unconserved plots that were similar in those characteristics relevant to technology and production choices. This reduced the potential for bias in comparing plots that were observably different, although there still might be selection bias caused by differences in unobservables.

In terms of econometric methods, we used both parametric and non-parametric techniques and adapted the Oaxaca-Blinder (1973) decomposition technique to investigate sources of any unconserved/conserved plot yield differences. Decomposition was important, because if farmers adopted SWC on a degraded plot and yield was low, this might suggest that SWC was not profitable when the cause of the low yield was really the initial status of the plot.

The decomposition required two steps. The first step was to estimate separate regression equations for conserved and unconserved plots. The second was to use those regression results to decompose the difference in mean value of crop production per hectare. The decomposition is given in (1):

$$y_{hp1} - y_{hp0} = \underbrace{\bar{X}_{hp0}\left(\hat{\beta}_{hp1} - \hat{\beta}_{hp0}\right)}_{coefficie\mathrm{int}\,s} + \underbrace{\left(\bar{X}_{hp1} - X_{hp0}\right)\hat{\beta}_{hp0}}_{endowments} \ , \qquad (1)$$

where y_{hp} is the value of crop production per hectare obtained by household h on plot p when plots are conserved and unconserved, and $\bar{X}_{hp}$ is a vector of average endowment values, and the β s are parameters to be estimated. The first term on the right hand side of (1) measures the yield differential that is due to the difference in returns to endowments, and the second measures the yield gap from inter-group differences in average plot endowments of conserved and unconserved plots.

The intuition behind the existence of $\bar{X}_{hp0}\left(\hat{\beta}_{hp1} - \beta_{hp0}\right)$ is that conservation may affect the productivity of inputs, such as fertilizers, seeds, and labor. It also might affect returns to natural endowments, such as rainfall and plot quality. For example, conservation structures may affect moisture retention, increasing or decreasing returns to plot quality depending on how the structures leverage water and soil quality attributes. There are at least two possibilities. First, plots without conservation may be more degraded than plots with conservation due to erosion risk. As a result, returns to endowments may be lower on plots without conservation than on those with conservation. Alternatively, farmers might invest in degraded plots so that returns to endowments due to conservation may be lower on those plots, compared to those without conservation. As we did not find previous studies applying this method to agriculture, we believe the use of such a decomposition is a methodological innovation.

$$\begin{cases} y_{hp1} = x_{hp1}\beta_1 + u_{h1} + e_{hp1} \text{ if } C_{\text{hp}} = 1 \\ y_{hp0} = x_{hp0}\beta_0 + u_{h0} + e_{hp0} \text{ if } C_{\text{hp}} = 0 \end{cases} \tag{2}$$

In terms of parametric method, we used the switching regression model defined in (2), where y_{hp} is value of crop production per hectare obtained by household h on plot p, depending on the plot's conservation status (c_{hp}); u_h are unobserved household characteristics that affect crop production, such as farm management and average land fertility that affects productivity; e_{hp} is a random variable that captures unobservable effects of plot characteristics, such as plot-specific production factors like temperature, soil structure, rainfall, frost, weed propensity and diseases; x_{hp} includes our observed explanatory variables; and β is a vector of parameters to be estimated.

To obtain consistent estimates of the effects of conservation, we needed to control for unobserved fixed effects (u_h) that might be correlated with observed explanatory variables. One way to address this issue was to exploit the panel nature of our data (i.e., repeated plot observations) and use household-specific fixed effects. Unfortunately, a number of our sample households had only one plot, which meant we could not use fixed effects, but fortunately Mundlak (1978) suggested an alternative way to handle this problem using either random effects or pooled OLS. Wooldridge (1995; 2002) later proposed practical applications of Mundlak's approach.

$$u_h = \bar{x}_{(h)p}\gamma + \eta_h, \ \eta_h \sim \text{iid}(0, \sigma_\eta^2). \tag{3}$$

Following Mundlak (1978), we parameterized the fixed effects, as in (3), which is a linear projection on the within-individual means of plot varying regressors, where $\bar{x}$ is the mean of plot-varying explanatory variables (cluster mean), γ is the vector of coefficients, and η is a random error assumed to be unrelated to the $\bar{x}'s$. It was especially important to include average plot characteristics, such as average plot fertility, soil depth, slope, and agricultural input use, which we believed had important effects on production and technology adoption decisions. The vector γ equals zero if explanatory variables are uncorrelated with the random effects.

$$E(y_{hp1} \mid x_{hp}, u_h, C_{hp} = 1) - E(y_{hp0} \mid x_{hp}, u_h, C_{hp} = 1) = x_{hp}(\beta_1 - \beta_0) + \bar{x}(\gamma_1 - \gamma_0). \tag{4}$$

Incorporating equation (3) into (2), the expected yield difference between adoption and non-adoption is given in (4), where the second term on the left-hand side of (4) is the expected value of y, if the plot had not adopted conservation technology (i.e., counterfactual outcome), which will be approximated by unconserved plot observations after taking into account the selection process. Estimating β_1, β_0, γ_1, and γ_0 in order to estimate the left-hand side of (4) was the primary objective of the parametric switching regression analysis.

The selection process in a parametric switching regression model is typically addressed by using the inverse Mills ratio derived from a probit criterion function. However, all coefficients of the probit model turned out not to be significantly different from zero. This was perhaps not surprising as we used nearest-neighbor matched samples. This implied there should be no systematic difference in the distribution of covariates across groups. As a result, we did not include the inverse Mills ratio in the switching models and assume exogenous switching.

If the unobserved plot component (e_{hp}) is correlated with the decision to adopt bunds and other observed regressors, parameter estimates from equation (2) will be inconsistent and we would not be finding the true effect of conservation. Fortunately, our data set offered a particularly rich characterization of plot characteristics, and so we were able to include slope, plot size, soil fertility, soil depth, distance from plot to residence, input use by plot, and areas of other plots. Including these variables addressed the issue because selection due to idiosyncratic errors, such as plot heterogeneity, could be addressed using observed plot characteristics and inputs if—as was likely—observable plot characteristics were positively correlated with unobservable ones (Fafchamps 1993; Levinsohn and Petrin 2003; Assunção and Braido 2004). Including input use also helped control for plot heterogeneity because farmers typically responded to shocks by changing input use.

Furthermore, much of the unobserved variation in plot quality that was not described perfectly by observed plot quality indicators was removed as a result of our estimation approach. This was because our matching variables captured differences in plot fertility across plots for a given household, but not differences in average plot fertility across all households, which were captured by the Mundlak method (1978) we employed.

Although conventional inputs (e.g., fertilizer, labor, and seed use) might potentially be endogenous, we did not believe this was a problem because variables that explained input use as well as output were included in our switching model. Furthermore, input use did not affect our matching estimates. The propensity score matching procedure required that only those variables affecting both adoption and the outcome variable (agricultural productivity) be included

(Heckman et al. 1998). As we did not expect short-run input use to influence long-term investments, conventional inputs were not included in our matching model.

We utilized a number of non-parametric methods, but present here the details of our stochastic dominance analysis, which also relied on matched observations derived from nearest neighbor matching.[4] Our main goal in using propensity score matching was to identify the average treatment effect on the treated plots (ATT). This was achieved using a two-step procedure. In the first step, we estimated the propensity score, which was defined as the conditional probability that plot p receives conservation treatment, given the covariates, using a probit model. In the second stage, we used nearest-neighbor matching, based on propensity scores estimates as an input to obtain the ATT. The nearest-neighbor matching method allowed us to specify a dummy variable, indicating matched observations, which would be used as inputs for parametric regressions and SDA, which was not true for other matching estimators.

Matching on every covariate is difficult to implement when the set of covariates is large. To overcome this problem of dimensionality, Rosenbaum and Rubin (1983) showed that if matching on x_{hp} is valid, so is matching on the propensity score. This allows matching on a single index rather than on the x_{hp} vector. Matching methods assume that selection is based only on observable characteristics. To adjust for unobservables, we included the means of plot varying covariates following the panel data sample selection estimation approach of Wooldridge (1995).

SDA is used to compare and rank distributions of risky outcomes according to levels and dispersion (Shively 1999; Mas-Colell, Whinston, and Green 1995). The comparison and ranking is based on cumulative density functions. Like propensity score matching, SDA makes no assumption about relationships between regressors and outcome variables and does not require distributional assumptions. Unlike matching and linear regression models, however, the entire density of yields is examined in SDA instead of focusing only on means.

5. Results

In this section, our various estimates of the impact of fanya juu-bund adoption on crop production are presented. These results are presented using the entire sample and three sub-samples. First, plots with bunds were divided into those with old and new conservation

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[4] For complete details of our non-parametric methods, see Kassie (2005).

structures, where "old" was defined as structures standing 15 years or more. This allowed us to consider the effects of changing productivity over time.

We also allowed for the possibility that growing different crops might yield different returns to conservation. Barley is the major crop grown in the study area and is planted on the most plots. The χ^2 tests, that the distribution of crops was independent across conserved and unconserved plots, were rejected for the full sample as well as old and new conservation plot sub-samples. We therefore used plots that grew barley to examine the effects of crop choice on any productivity differentials between conserved and unconserved plots. Tables 1 and 2[5] provide the descriptive statistics for the entire sample before and after matching and for conserved and unconserved plots after matching.

The average treatment effect was estimated using propensity score matching and the results are reported in table 3. Table 4 provides nearest-neighbor matching estimates for the outcome variable, value of crop production per hectare. The matching estimates showed a significant negative impact of bunds on mean value of crop production. We found, for example, that over the entire sample the use of bunds reduced the mean value of output by US$ 19.00 (ETB 155). Age of bund did not appear to be an important factor because older bunds were correlated with a decline in average crop value of $19.00 (ETB 160), and new bunds yielded a $21.00 (ETB 171) decline. The negative relationship between bunds and yields was smaller, however, for barley plots. Barley plot bunds had $14.00 (ETB 117) lower yields per hectare than those without bunds.[6]

To people in developed countries, this may not seem like a lot of money. In the context of highland Ethiopia, however, these are significant sums. The gross domestic product per capita in 2001 was only about US$ 120 per capita and the average yield per hectare in our sample was $100 (ETB 826), indicating that the yield "loss" was in the 15–17 percent range.

The SDA estimates also utilized matched observations to control for impacts of other factors on production apart from the existence of bunds. SDA, therefore, determined the

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[5] All tables are located at the end of the paper.

[6] This result was consistent with results using alternative matching methods, including kernel (ETB 125, 140, 97, and 45 for entire sample, old and new conservation, and barley plots, respectively) and stratification (ETB 109, 133, 79, and 41 for entire sample, old and new conservation, and barley plots, respectively). Similarly, the same conclusion was reached by estimating the propensity score without Mundlak's approach, although the mean yield difference was higher for the entire sample (ETB 166) and old conservation (ETB 190) plots, and it was lower for new conservation plots (ETB 160).

difference in the yield distribution between the two states that was due only to technology effects. Results from tests of first order stochastic dominance revealed that cumulative density functions for the value of crop production without conservation unambiguously dominated crop production distributions with conservation for all production levels and each sample type. These results are presented in figures 1–4.[7] The implication of these findings was that the chance of getting higher yields was everywhere greater for plots without conservation than for plots with conservation, given a matched sample of conserved and unconserved plots. These results are fully consistent with but extend the nearest-neighbor propensity-score matching results to consider full cumulative density functions (CDFs).

Tables 5 and 6 present the results of the switching regression models. The dependent variable is the natural logarithm of value of crop production per hectare. Random effects models were used for the analysis. We found that conventional inputs were associated with increases in crop production at statistically significant levels. We also found that some of the coefficients of the mean of plot varying regressors were statistically significant, and the null that all coefficients of the mean values (the vector γ) equal zero was rejected for four of eight models. This suggested possible correlation between explanatory variables and unobservable effects.[8]

To determine the effects of conservation adoption on mean output, we compared the predicted mean value of crop production from plots with and without conservation. As shown in table 7, consistent with our other results, we controlled for input use and plot characteristics and found that mean predicted value of crop production on plots with conservation was substantially and significantly lower than on plots without conservation. We estimated (for example) that, for the overall sample, use of bunds decreased yield by an estimated US$ 14.00 (ETB 118), and considering sub-samples defined by age of conservation structures and crop type did not change these results. This finding was consistent with other studies of the Ethiopian highlands (Herweg 1993; Benin 2006).

The decomposition results are presented in table 8, and we found that there was little difference in plot characteristics between conserved and unconserved plots, but the returns to characteristics were higher for unconserved plots. For example, soil fertility and depth endowments between plots with and without conservation differed little, but returns to these

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[7] All figures are located at the end of the paper.

[8] In the interest of brevity, detailed results are not reported. All results are, of course, available from the authors.

endowments were higher for plots without conservation. The return to plowing is also higher for plots without fanya juu bunds.

These findings suggest that fanya juu bunds neither increased yields nor complemented other inputs. It is therefore hard to argue that they represent a "win-win" solution to the problem of soil erosion. Furthermore, farmers have voiced serious objections to bunds. For example, farmers have been concerned about waterlogging and have also complained about loss of planting area because the bunds reduced cultivable area by 8–20 percent. There were also difficulties in turning ox-drawn plows due to narrow terrace spacing.

Is there any way to improve the performance of what seems like a highly inappropriate technology? Perhaps the key problem of bunds is that they take up a lot of crop area. While we included the value of grass produced on bunds in our analysis, we also tested whether increasing grass output changed our results by conducting sensitivity analysis using matching methods and SDA. We increased grass production to 5,986 kilograms per hectare, which is a three-fold increase from current levels and is at the top end of the estimated native pasture productivity from Ethiopian communal grazing lands (Mengistu 1987).

We found, as shown in figures 5–8, that the gap between the CDFs of conserved and unconserved plots decreased for the full, old conservation structure and barley plot samples and, indeed, first order stochastic dominance was no longer observed. Results did not change for new conservation structures, however, probably because grass production area was smaller than for old bunds (0.01 versus 0.02 hectares, on average). The matching estimates (table 9) showed that the difference in mean production between conserved and unconserved plots reduced considerably (except for new conservation) and was no longer statistically significant. We found, for example, that for the entire sample the estimated difference in yield per hectare was now US$ 10.00 (ETB 86); for old structures, $8.00 (ETB 69); and a mere $3.00 (ETB 26) for barley plots. These results were again consistent with other matching methods.

These results suggested there could be possible ways to make conserved plots as productive as unconserved ones. The question, of course, is why farmers—many of whom had more than 15 years experience with bunds—had not already taken the step of planting high value fodder on their bunds. Common sense suggests that some variable is missing from our model; it may be that costs are understated or benefits overstated.

We believe, however, that additional analysis is justified, if only to try to mitigate what seems an unfortunate soil conservation initiative in the past. There is also the possibility, of course, that additional steps may reconcile private and public interests. For example, because extension work has been much more focused on crops than livestock, perhaps additional extension effort could be invested to promote production of high-value fodder grass on bunds.

6. Conclusions

This paper measured the impacts of fanya juu bunds on crop production in a high-rainfall area of the Ethiopian highlands and found rather conclusively that these bunds were counter-productive. All models, in fact, showed negative yield effects, and the yield decomposition indicated that while there was little difference in endowments between conserved and unconserved plots, the returns to endowments were higher for unconserved plots. While the sensitivity analysis weakly suggested that there may be possibilities for conserved plots to approach the productivity of unconserved ones, it was hard to avoid the conclusion that fanya juu, and possibly other soil bunds, reduced off-site erosion at the expense of poor farmers who can ill afford any additional costs.

Although we do not know the details of what exactly is wrong with bunds, from farmer responses it seems likely that agro-ecological conditions play a role. As found by Kassie et al. (2007), drier areas offer higher returns to bunds than wetter ones. The combination of wet conditions, complications associated with small plots where bunds occupy significant portions of cultivable area, and difficulties in plowing appear to drive these results.

Efforts to reduce off-site erosion effects and improve on-farm yields are laudable and should be encouraged. However, it is clear from our results that to truly achieve such “win-win” outcomes, much more attention to the interactions between SWC technologies and production factors, such as land, labor, and weather endowments, is needed. Furthermore, as has often been shown in the past, technologies must be promoted carefully with specific attention given to the fragile circumstances under which farming households in developing countries exist.

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Tables

Table 1 Descriptive Statistics for Entire Sample and Old Conservation Sub-sample Plots

	Entire sample plots				**Old conservation sub-sample plots**			
Independent variables	**Mean 1**	**Mean 2**	**Mean 3**	**Mean 4**	**Mean 1**	**Mean 2**	**Mean 3**	**Mean 4**
Crop production (value per hectare)	825.789 (698.193)	756.408 (651.265)	696.865 (577.344)	840.445 (736.049)	842.326 (711.922)	767.103 (656.718)	685.876 (572.096)	870.043 (739.115)
Good fertile plots (dummy)	0.192	0.178	0.171	0.187	0.201	0.197	0.195	0.198
Medium fertile plots (dummy)	0.504	0.480	0.479	0.482	0.507	0.478	0.477	0.480
Deep soil plots (dummy)	0.427	0.413	0.393	0.441	0.430	0.395	0.383	0.411
Medium-deep soil plots (dummy)	0.322	0.302	0.315	0.284	0.335	0.352	0.367	0.332
Plot slope (degree)	17.380 (9.198)	16.976 (8.314)	17.063 (6.633)	16.854 (10.238)	17.347 (9.368)	17.275 (8.187)	16.711 (5.585)	17.989 (10.579)
Plot distance to residence (minutes)	16.714 (27.708)	13.781 (22.535)	13.431 (16.174)	14.274 (29.274)	16.866 (28.705)	11.480 (13.430)	11.969 (13.234)	10.861 (13.683)
Rented-in plots (dummy)	0.147	0.100	0.088	0.117	0.152	0.085	0.074	0.099
Plot size (hectares)	0.248 (0.139)	0.254 (0.142)	0.260 (0.140)	0.245 (0.144)	0.246 (0.141)	0.253 (0.146)	0.261 (0.149)	0.242 (0.143)
Other plots area (total farm size minus plot size)	1.402 (0.570)	1.455 (0.563)	1.459 (0.532)	1.448 (0.606)	1.400 (0.578)	1.494 (0.559)	1.488 (0.543)	1.502 (0.580)
Plowing labor (man-days / hectare)	17.245 (22.755)	16.782 (26.240)	15.682 (19.782)	18.334 (33.265)	17.570 (23.738)	16.865 (19.530)	16.098 (22.660)	17.838 (14.630)
Weeding labor (man-days / hectare)	18.912 (31.216)	16.902 (29.519)	14.816 (22.551)	19.848 (37.040)	19.169 (31.930)	15.783 (24.715)	13.291 (20.005)	18.940 (29.381)
Fertilizer use (value per hectare)	128.873 (218.674)	136.201 (193.710)	153.386 (206.685)	111.947 (171.178)	122.978 (197.635)	132.049 (220.664)	143.398 (210.207)	117.667 (179.937)
Seed use (value per hectare)	123.987 (136.196)	116.724 (122.355)	106.812 (104.781)	130.714 (142.566)	126.070 (140.036)	123.140 (135.792)	104.822 (104.212)	146.354 (164.857)
N	1290	721	422	299	1124	458	256	202

Notes: We did not report standard errors for dummy variables.

Mean 1 = Refers to mean and standard deviations (sd) of variables from total sample before matching

Mean 2 = Refers to mean and standard errors (se) of variables from total matched sample

Mean 3 = Refers to mean and standard errors (se) of variables of matched sample with conservation

Mean 4 = Refers to mean and standard errors (se) of variables of matched sample without conservation

Table 2 Descriptive Statistics for New Conservation and Barley Sub-sample Plots*

	New conservation sub-sample plots				Barley sub-sample plots			
Independent variables	**Mean 1**	**Mean 2**	**Mean 3**	**Mean 4**	**Mean 1**	**Mean 2**	**Mean 3**	**Mean 4**
Crop production (value per hectare)	860.428 (722.104)	778.409 (677.340)	713.810 (586.679)	858.433 (769.901)	583.108 (391.850)	571.271 (415.361)	520.941 (331.497)	644.912 (507.037)
Good fertile plots (dummy)	0.191	0.133	0.133	0.134	0.211	0.226	0.216	0.242
Medium fertile plots (dummy)	0.511	0.480	0.482	0.478	0.517	0.483	0.475	0.495
Deep soil plots (dummy)	0.438	0.393	0.410	0.373	0.450	0.440	0.417	0.474
Medium soil plots (dummy)	0.311	0.247	0.235	0.261	0.331	0.295	0.317	0.263
Plot slope (degree)	17.546 (9.886)	17.417 (7.861)	17.607 (7.972)	17.181 (7.746)	18.189 (11.389)	16.379 (7.376)	16.636 (7.407)	16.003 (7.353)
Plot distance to residence (minutes)	17.889 (30.130)	16.177 (22.128)	15.687 (19.707)	16.784 (24.866)	13.634 (17.586)	14.833 (18.821)	13.755 (15.614)	16.411 (22.714)
Rented-in plots (dummy)	0.164	0.130	0.108	0.157	0.119	0.090	0.115	0.053
Plot size (hectares)	0.244 (0.136)	0.250 (0.132)	0.258 (0.124)	0.241 (0.142)	0.271 (0.135)	0.283 (0.141)	0.286 (0.134)	0.278 (0.151)
Other plots area (total farm size minus plot size)	1.380 (0.575)	1.412 (0.516)	1.415 (0.514)	1.408 (0.520)	1.380 (0.560)	1.427 (0.562)	1.397 (0.511)	1.473 (0.629)
Plowing labor (man-days / hectare)	17.529 (22.781)	17.041 (18.118)	15.042 (14.292)	19.517 (21.757)	11.610 (8.533)	10.709 (6.700)	10.414 (6.519)	11.140 (6.969)
Weeding labor (man-days / hectare)	20.303 (33.277)	19.351 (29.761)	17.167 (25.884)	22.057 (33.864)	1.127 (3.872)	1.147 (3.988)	0.732 (2.944)	1.754 (5.105)
Fertilizer use (value per hectare)	125.277 (220.671)	157.155 (291.415)	168.789 (200.787)	142.743 (374.864)	59.729 (116.994)	68.792 (115.187)	86.987 (118.048)	42.169 (105.943)
Seed use (value per hectare)	128.732 (142.660)	113.966 (122.524)	109.882 (105.894)	119.024 (140.681)	141.636 (88.531)	142.068 (97.089)	138.767 (77.179)	146.897 (120.751)
N	1034	300	166	134	402	234	139	95

Notes: We did not report standard errors for dummy variables.

Mean 1 = Refers to mean and standard deviations (sd) of variables from total sample before matching

Mean 2 = Refers to mean and standard errors (se) of variables from total matched sample

Mean 3 = Refers to mean and standard errors (se) of variables of matched sample with conservation

Mean 4 = Refers to mean and standard errors (se) of variables of matched sample without conservation

Table 3 Propensity Score Estimates of Fanya Juu Bunds Adoption

Independent variables	Entire sample	Old conservation plots	New conservation plots	Barley plots
Good fertile plots	-0.404*** (0.152)	-0.401** (0.172)	-0.260 (0.211)	0.002 (0.208)
Medium fertile plots	-0.222* (0.114)	-0.203 (0.128)	-0.164 (0.157)	-0.135 (0.172)
Deep soil plots	-0.042 (0.136)	0.039 (0.156)	-0.280 (0.185)	-0.252 (0.193)
Medium-deep soil plots	-0.090 (0.132)	0.066 (0.150)	-0.429** (0.180)	-0.197 (0.195)
Plot slope (degree)	-0.002 (0.005)	-0.006 (0.006)	0.004 (0.006)	-0.001 (0.019)
Plot slope square				-0.000 (0.000)
Plot distance to residence	-0.004* (0.002)	-0.005* (0.003)	-0.002 (0.003)	0.001 (0.004)
Rented-in plots	-0.245* (0.136)	-0.332** (0.166)	-0.177 (0.175)	0.041 (0.211)
Plot size	0.316 (0.482)	1.230* (0.678)	1.565** (0.577)	0.354*** (0.125)
Ln (other plots area)	-0.944* (0.489)	-2.223*** (0.735)	-0.273 (0.540)	0.124 (0.147)
Joint chi2 test for significance of mean of plot varying regressors	30.11*** (p=0.0004)	28.33*** (p=0.0008)	43.09*** (p=0.0000)	
Constant	0.301 (0.286)	-0.438 (0.329)	0.361 (0.383)	0.416 (0.352)
Model chi2	76.170***	69.357***	72.644***	18.135*
R-squared	0.0467	0.0575	0.0797	0.0350
N	1290	1124	1034	402

Notes: p<0.10, ** p<0.05, *** p<0.01
Standard errors adjusted for clustering in parentheses.

Table 4 Propensity Score Matching Estimates of Crop Production Gains from Fanya Juu Bunds Adoption*

Samples	Predicted mean value of crop production with conservation	Predicted mean value of crop production without conservation	Predicted mean yield difference (std. error)
A	B	C	D =B-C
Entire sample plots	6.283	6.482	-0.199(0.033)***
Old conservation sub-sample plots	6.271	6.500	-0.229(0.044)***
New conservation sub-sample plots	6.302	6.481	-0.179(0.055)***
Barley crop sub-sample plots	6.085	6.236	-0.151(0.057)***

Table 7 Predicted Mean Value of Crop Production Results from Parametric Switching Regression

Sample plots	Treated plots	Controlled plots	ATT	Standard error	t
Entire sample plots	422	299	-155.215	58.765	-2.641
Old conservation plots	256	202	-159.590	64.029	-2.492
New conservation plots	166	134	-171.791	101.757	-1.688
Barley plots	139	95	-116.503	57.701	-2.019

Note: Treated and controlled plots refer to conserved and non-conserved plots respectively.

* Bootstrapped standard errors used to take into account the estimated propensity score used in the second stage (nearest neighbor matching estimator).

Table 9 Propensity Score Matching Estimates of Crop Production Gains Assuming Increased Grass Production on Bunds*

Sample plots	Treated plots	Controlled plots	ATT	Standard error	t
Entire sample plots	422	299	-86.473	58.237	-1.485
Old conservation sub-sample plots	256	202	-69.219	63.709	-1.086
New conservation sub-sample plots	166	134	-136.406	101.909	-1.339
Barley sub-sample plots	139	86	-25.841	75.501	-0.342

* Bootstrapped standard errors used to take into account the estimated propensity score used in the second stage (nearest neighbor matching estimator).

Table 5 Descriptive Statistics for Entire Sample and Old Conservation Sub-sample Plots

	Entire sample plots		**Barley sub-sample plots**	
Independent variables	**With bunds**	**Without bunds**	**With bunds**	**Without bunds**
Good fertile plots	0.204 (0.125)	0.339** (0.146)	0.111 (0.180)	0.705* (0.394)
Medium fertile plots	0.004 (0.088	0.251*** (0.103)	-0.138 (0.132)	0.652*** (0.216)
Deep soil plots	0.055 (0.109	-0.002 (0.095)	0.143 (0.172)	0.131 (0.254)
Medium-deep soil plots	-0.060 (0.109)	-0.079 (0.108)	0.121 (0.168)	-0.449 (0.282)
Plot slope (degree)	0.008 (0.005)	0.001 (0.004)	0.025 (0.021)	0.028 (0.029)
Plot distance to residence	-0.002 (0.002)	-0.000 (0.001)	-0.000 (0.001)	0.000 (0.001)
Rented-in plots	0.164 (0.111)	0.367*** (0.106)	0.005 (0.004)	-0.001 (0.005)
Ln (other plots area)	0.625** (0.306)	0.729** (0.362)	1.663*** (0.555)	0.070 (1.060)
Ln (plowing labor	0.012 (0.085)	0.278*** (0.078)	-0.173* (0.094)	0.143 (0.136)
Ln (weeding labor)	0.137*** (0.034)	0.123*** (0.030)	0.190* (0.109)	0.003 (0.096)
Ln (fertilizer use)	0.042** (0.017)	0.029* (0.017)	0.056** (0.024)	0.116*** (0.038)
Ln (seed use)	0.181*** (0.045)	0.187*** (0.044)	0.382*** (0.122)	0.362** (0.183)
Joint chi2 test for significance of mean of plot varying regressors	11.73 (p=0.4680)	26.07** (p=0.0105)	21.19* (p=0.0693)	23.58** (p=0.0352)
Constant	4.632*** (0.360)	5.166*** (0.516)	5.046*** (0.913)	6.125*** (1.542)
Model chi2	214.59***	195.58***	86.911***	259.993***
R-squared	0.2894	0.4470	0.3239	0.4993
N	422	299	139	95

Notes: * p<0.10, ** p<0.05, *** p<0.01

Standard errors in parentheses are adjusted for clustering.

Table 6 Crop Production Value Determinants for Old and New Conservation Sub-sample Plots*

	Old conservation plots		New conservation plots	
Independent variables	**With bunds**	**Without bunds**	**With bunds**	**Without bunds**
Good fertile plots	0.157 (0.129)	-0.047 (0.149)	0.037 (0.295)	0.273 (0.233)
Medium fertile plots	0.073 0.110)	0.057 (0.121)	-0.417** (0.189)	-0.051 (0.129)
Deep soil plots	-0.012 (0.131)	0.107 (0.141)	0.373 (0.234)	0.074 (0.147)
Medium-deep soil plots	-0.154 (0.136)	-0.019 (0.144)	0.244 (0.258)	0.032 (0.150)
Plot slope (degree)	0.008 (0.007)	0.007 (0.004)	0.010 (0.007)	0.004 (0.009)
Plot distance to residence	-0.003 (0.004	0.003 (0.003)	0.000 (0.003)	-0.007** (0.003)
Rented-in plots	0.253 (0.182)	0.249** (0.113)	0.031 (0.176)	0.284 (0.182)
Ln (other plots area)	0.741* (0.406)	0.755** (0.353)	0.487 (0.393)	0.641** (0.281)
Ln (plowing labor	0.008 (0.109)	0.366*** (0.078)	0.028 (0.114)	0.094 (0.105)
Ln (weeding labor)	0.121*** (0.041)	0.148*** (0.033)	0.184*** (0.050)	0.167*** (0.049)
Ln (fertilizer use)	0.050** (0.021)	0.024 (0.020)	0.016 (0.028)	0.010 (0.023)
Ln (seed use)	0.186*** (0.042)	0.176*** (0.040)	0.176* (0.091)	0.226*** (0.062)
Joint chi2 test for significance of mean of plot varying regressors	17.73 (p=0.1240)	18.57* (p= 0.0994)	8.18 (p=0.1707)	19.76* (p=0.0728)
Constant	4.879*** (0.501)	5.021*** (0.520)	3.874*** (0.536)	3.699*** (0.852)
Model chi2	179.16***	335.75***	119.86***	163.349***
R-squared	0.3180	0.4864	0.3224	0.4945
N	256	202	166	134

Notes: * p<0.10, ** p<0.05, *** p<0.01

Standard errors adjusted for clustering are in parentheses.

Table 8 Decomposition Results

Endowments	**Decompositions results for variables (as percentages)**							
	Entire sample plots		**Old conservation**		**New conservation**		**Barley plots**	
	Endowments	***Coefficients***	***Endowments***	***Coefficients***	***Endowments***	***Coefficients***	***Endowments***	***Coefficients***
Good fertile plots	-0.3	-2.2	-0.1	4.9	-0.0	-4.1	-0.5	-1.2
Medium fertile plots	-0.0	-12.4	-0.0	0.5	-0.1	-14.4	0.2	-23.3
Deep soil plots	-0.1	-0.5	0.2	-4.7	1.4	6.8	0.1	-16.3
Medium-deep soil plots	-0.1	0.8	-0.4	-2.4	-0.6	3.4	-0.1	4.0
Plot slope (degree)	0.2	8.9	-0.7	-7.8	0.5	8.9	0.1	26.2
Plot distance to residence	0.2	-3.0	-0.3	-5.3	-0.0	4.4	-1.3	6.2
Rented-in plots	-0.4	-1.5	-0.2	-0.5	-0.5	-2.4	0.7	0.2
Ln (other plots area)	0.1	6.9	0.0	-1.3	-0.2	-6.6	-1.3	13.3
***Ln* (plowing labor)**	**-1.0**	**-57.7**	**-1.9**	**-78.1**	**-1.5**	**-25.1**	**-0.1**	**-30.5**
Ln (weeding labor)	-4.4	2.5	-4.3	-6.9	-6.3	2.2	-2.6	3.7
Ln (fertilizer use)	2.9	2.9	2.2	8.2	1.3	-1.7	7.8	-0.4
Ln (seed use)	-3.0	-1.8	-5.8	9.6	0.1	-13.6	3.6	20.1
Subtotal	**-6.0**	**-57.1**	**-11.3**	**-83.9**	**-6.2**	**-28.9**	**7.0**	**-45.6**
Production gap	**Summary of decomposition results (as percentages)**							
-Due to endowments	-6.0		-11.3		-6.2		7.0	
-Due to coefficients	-57.1		-83.9		-28.9		-45.6	

Note: (A) positive and negative number indicates advantage to plots with and without conservation, respectively.

Figures

Figure 1. Fanya Juu Bunds Impact on Crop Production (Entire Sample Plots without Grass Production)

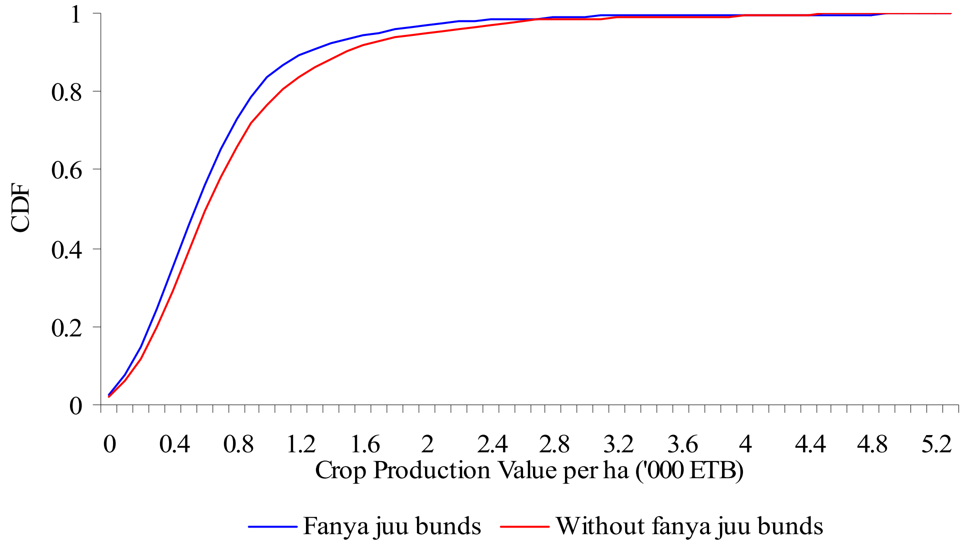

Figure 2. Old Fanya Juu Bunds Impact on Crop Production (without Grass Production on Bunds)

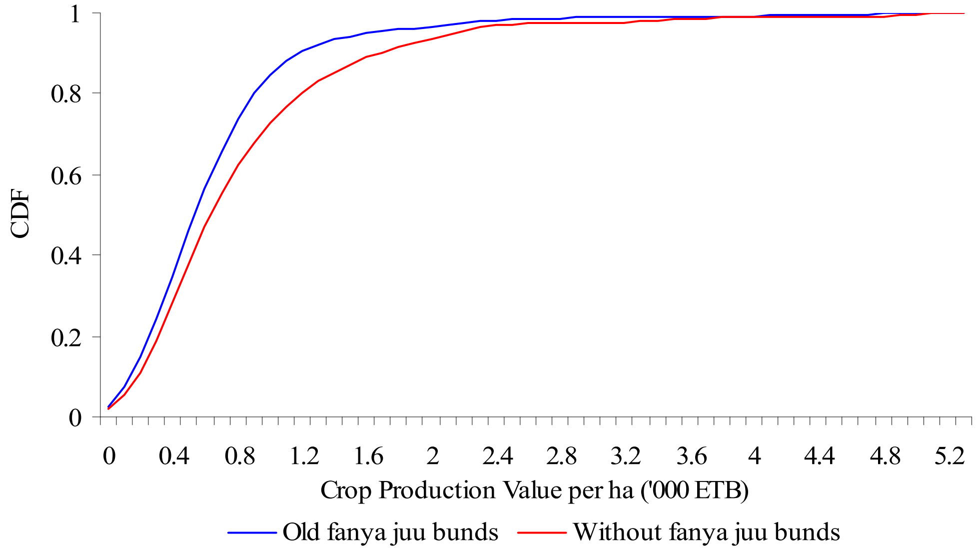

Figure 3. New Fanya Juu Bunds Impact on Crop Production (without Grass Production on Bunds)

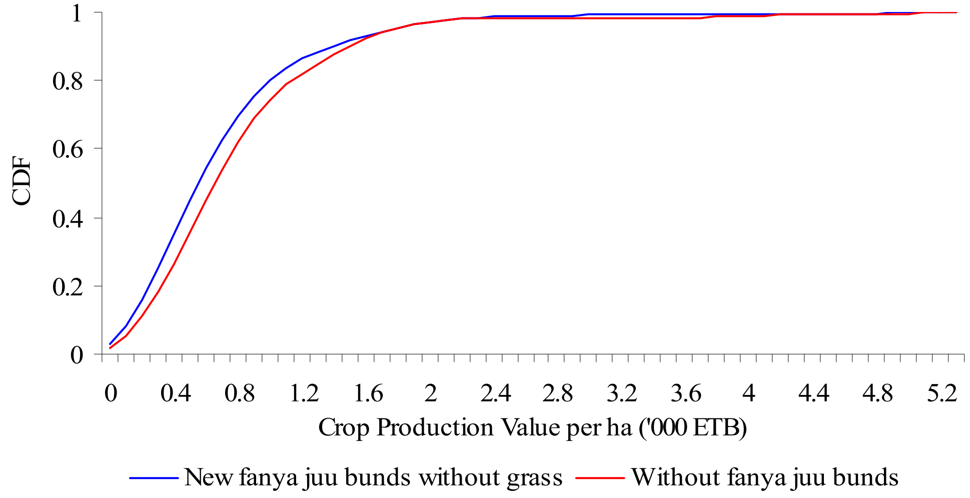

Figure 4. Fanya Juu Bunds Impact on Crop Poduction for Barely Sub-sample plots (without Grass Production on Bunds)

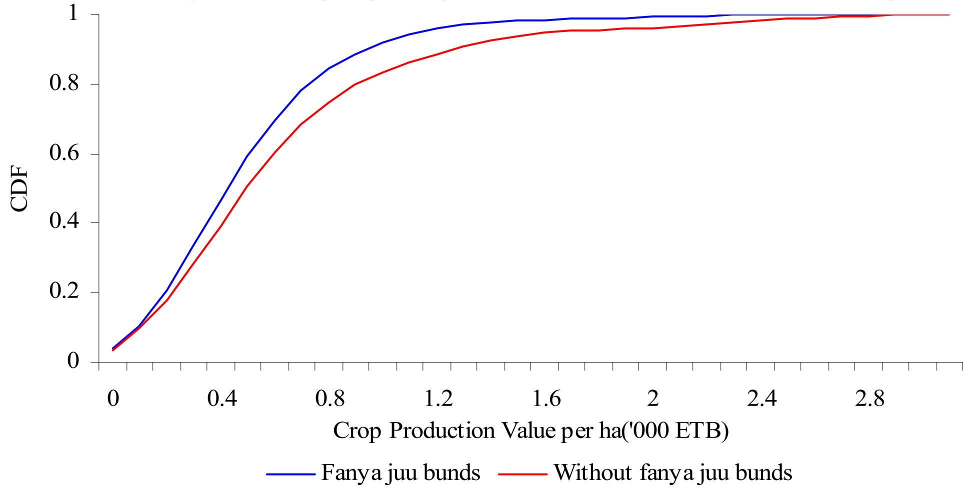

Figure 5. Fanya Juu Bunds Impact on Crop Production (Entire Sample plots without Grass production on Bunds)

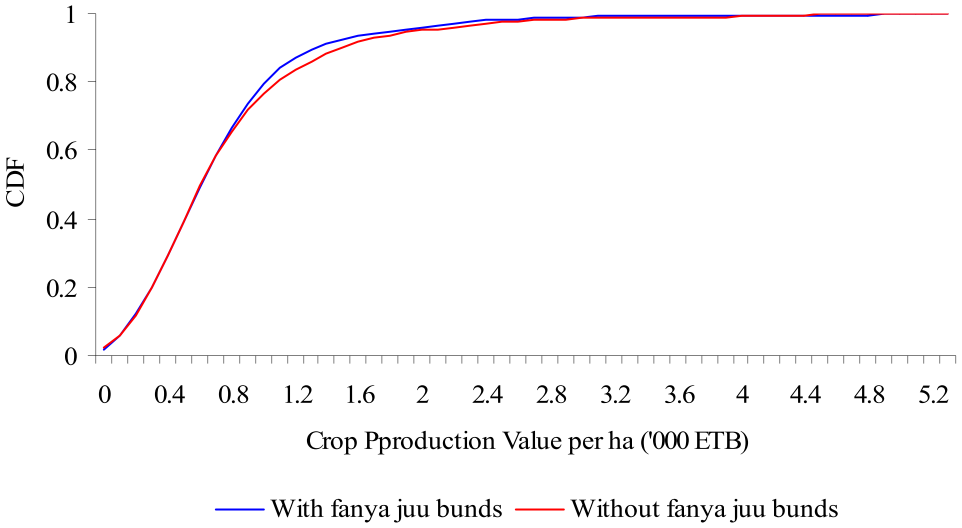

Figure 6. Old Fanya juu Bunds Impact on Crop Production (with Grass Production)

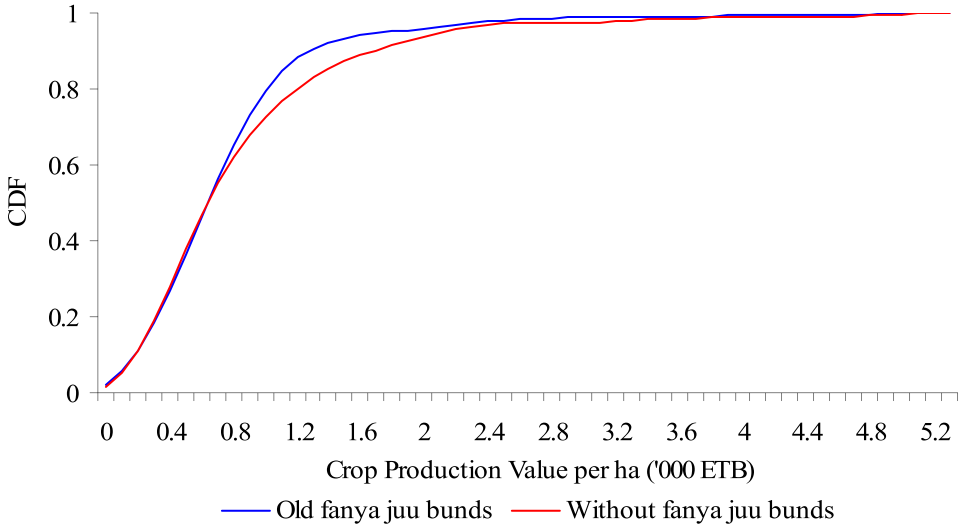

Figure 7. New Fanya Juu Bunds Imapct on Crop Production (with Grass Production on Bunds)

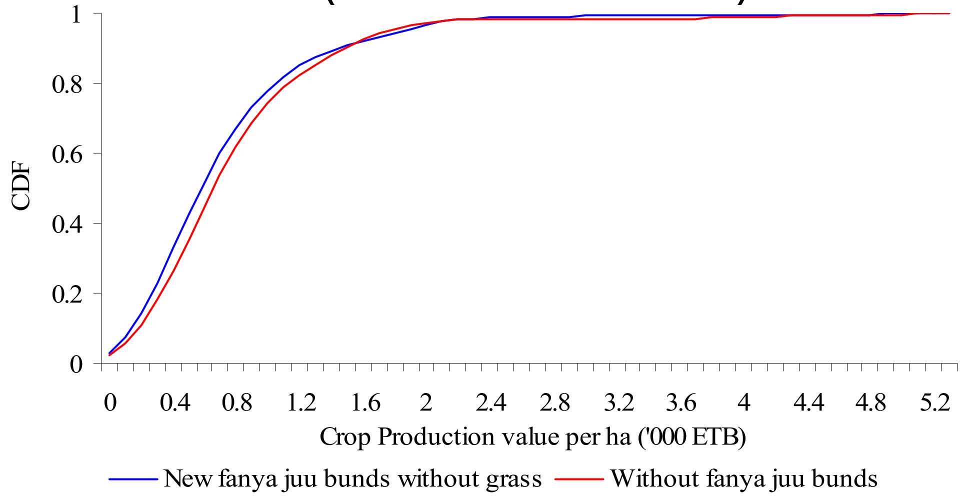

Figure 8. Fanya Juu Bunds Impact on Crop Production for Barley Sub-sample plots (with grass production on bunds)