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Assessing the costs and benefits of improved land management practices in three watershed areas in Ethiopia

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ABSTRACT

Unsustainable land use management and the resulting soil erosion are among the most pervasive problems in rural Ethiopia, where most of the country's people live, jeopardizing food security. Despite various efforts to introduce soil conservation measures and assess their costs and benefits, it is unclear how efficient these measures are from an economic point of view in securing food production. This paper examines the costs and benefits of three soil conservation measures applied in the country in three different rural districts facing different degrees of soil erosion problems using survey data collected from 750 farm households. A production function is estimated to quantify the costs and benefits of more sustainable land use management practices. We show that the soil conservation measures significantly increase productivity and hence food security. Comparing the costs and benefits, the results indicate that implementing soil conservation measures would benefit farm communities in the case study areas through increased grain productivity and food security.

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1. Introduction

Soil erosion and the resulting agricultural land degradation are the most severe environmental problem in the Ethiopian highlands (Amsalu & de Graaff, 2007; Pender, Gebremehedhin, Benin, & Ehui, 2001; Shiferaw & Holden, 1999; Tefera & Sterk, 2010), jeopardizing the sustainability of agricultural production and

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ultimately national food security (Kassie, Holden, Kohlin, & Bluffstone, 2008; Sonneveld & Keyzer, 2002). The on-site effects are a major source of concern since they threaten the livelihoods of a majority of the country's population. The highlands of Ethiopia cover 40 percent of the country's land mass and are home to almost 88 percent of its human population and 70 percent of the total livestock population (Ayele, 1999). The causes underlying land degradation are a combination of climate conditions and extreme weather events, such as heavy rainfall and droughts, population pressure, unsustainable agricultural land use practices such as overgrazing, cultivation of steep slopes, and no or limited fallow periods (Geist & Lambin, 2004), and lack of institutions to enact regulations or laws that enhance sustainable land management practices (FAO, 2011).

The problem is transboundary in nature particularly in the upper Blue Nile basin where soil and excessive runoff that leave the boundary of individual farms cause off-site or off-farm impacts to reservoirs, irrigation schemes and waterways downstream across political borders. An example is the sedimentation of the Gezira irrigation scheme in Sudan due to massive erosion from the Upper Blue Nile river basin. Ahmed (2003) reported that the sediment load of the Blue Nile at the border at El Diem (120 km upstream of the El-Roseires Dam) is 140 million tons per year, causing management difficulties of irrigation canal networks in the Gezira scheme and consuming more than 60 percent of the total costs of the operation and maintenance in sediment clearance.

In the Ethiopian highlands, topsoil loss due to soil erosion is estimated to be 1.5 billion tons per year (Taddese, 2001), and average annual soil loss from cultivated land is 42 t/ha (Hurni, 1993). This is very high compared to other countries worldwide (Pimentel, 2006). Total estimated soil erosion in the US, for example, a country 9 times the size of Ethiopia is 3 billion t/year (Carnell, 2001 cited in Pimentel, 2006). The estimated soil formation rate in Ethiopia is less than 2 t/ha/year, which is very low compared to the estimated soil erosion rates (Hurni, 1983). Worldwide soil erosion rates are highest in Asia, Africa and South America, averaging 30–40 t/ha/year, and lowest in the United States and Europe, averaging about 17 t/ha/year (Barrow, 1991). Studies conducted in the Amhara region confirm that soil loss due to erosion has a significant impact on the decline of crop yield and loss of agricultural land (e.g. Ludi, 2002; Shiferaw & Holden, 1999; Sonneveld, 2002). In order to mitigate the problem of soil erosion, the regional government and non-governmental organizations have supported various efforts to introduce soil conservation measures.

A number of studies exist that investigated the costs and benefits of soil conservation measures in east Africa in general and Ethiopia in particular. However, the empirical evidence base is ambiguous. There does not seem to be a straightforward answer to the question whether soil conservation measures are economically efficient, that is, whether the benefits of using soil conservation measures outweigh the cost of these measures. Tenge, De graaff, and Hella (2005) for example, found that in Tanzania the costs of establishing bench terraces, grass strips and *fanya juu* bunds exceed the returns in the initial two years. However in the long term, the three soil and water conservation measures are profitable to farmers on gentle to moderate slopes and with low to medium opportunity costs of labour. It was also found that soil and water conservation measures are not financially attractive to most farmers with off-farm activities and other sources of income. In Kenya Kauffman et al. (2014) estimated the effect of 11 soil conservation measures on soil erosion and three ecosystem services that is food production, water availability and energy production acting as provisioning services. Modelling indicated that the three ecosystem services could be improved, as compared with the base level, by up to 20 percent by introducing appropriate conservation measures with benefit/cost relations of around 7. However, farmers were unable to make the necessary investments and much effort and many institutional studies were needed to achieve progress towards implementation. Whereas in Ethiopia studies by Gebremedhin, Swinton, and Tilahun (1999), Shiferaw and Holden (2001), Ludi (2002) and Kassie et al. (2008) report that combined soil and water conservation measures benefit farmers only in low rainfall areas as these measures primarily serve the purpose of water harvesting in such areas. The research carried out by Bekele (2005) and Kassie et al. (2008) on the other hand find that in high rainfall areas soil conservation measures only become profitable if the land lost because of the construction of these measures on the land such as bunds is compensated through the planting of grass for livestock fodder and trees for fuel and fruits on these bunds. These studies employed a variety of different approaches, such as ANOVA, stochastic dominance analysis, matching methods, and damage cost functions to estimate the costs and benefits of soil conservation measures. In the case of ANOVA, group means are compared based on estimated crop yields on plots with and without soil conservation measures and tested for their statistical significance. Stochastic dominance analysis compares and ranks the expected net returns from crop production with and without soil and water conservation measures to assess the most likely profitable plot treatment. Matching is a statistical technique which is used to evaluate the effect of a treatment by comparing the treated and the non-treated units in an observational study or quasi-experiment (i.e. when the treatment is not randomly assigned). The goal of matching is, for every treated unit, to find one (or more) non-treated unit(s) with similar observable characteristics against whom the effect of the treatment can be assessed. By matching treated units to similar non-treated units, matching enables a comparison of outcomes among treated and non-treated units to estimate the effect of the treatment without reduced bias due to confounding. Hence, matching methods examine how crop yields and productivity indicators on plots with and without soil conservation measures differ based on a search procedure to match comparable plots focusing on key plot and climate characteristics such as soil conditions and precipitation. Damage cost functions estimate the monetary value of the loss of crop yield based on soil erosion rates on plots without soil conservation measures. Unlike the different methods reviewed above, one methodological similarity to our research was a study by Kato, Ringler, Yesuf, and Bryan (2011) who applied the Just and Pope framework using a Cobb– Douglas production function to explore the effect of soil and water conservation technologies on crop yields in different regions and rainfall zones in Ethiopia. Their result indicates that soil and water conservation investments perform differently in different rainfall areas and regions of the country.

The main objective of this study is to inform land use policy in Ethiopia based on the estimation of a Cobb–Douglas production function using a stratified rural household survey and farmers' self-reported costs and benefits of soil conservation measures. The functional relationships embodied in the estimated production function help us to identify the direct contribution of the soil conservation measures to agricultural productivity by isolating their effect from other factors. Moreover, while some work has already been done in estimating the costs and benefits of soil conservation measures at farm household level, there has been no attempt to address the costs and benefits of these measures at the wider watershed level. Hence, this study tries to fill this information gap by estimating the costs and benefits of soil conservation measures in the whole Gedeb watershed in Ethiopia.

2. Study area

The Blue Nile basin is the second largest basin in Ethiopia comprising 17 percent of the surface area (176,000 km^2) (Conway,