CAUSAL IMPACT OF ADOPTION OF SOIL CONSERVATION MEASURES ON FARM PROFIT, REVENUE AND VARIABLE COST IN DARJEELING DISTRICT, INDIA

Chandan Singha,

Hindu College, University of Delhi, Delhi-110007, India

E-mail: chandan@econdse.org

Abstract

This study attempts to evaluate the effects of on-farm soil conservation practices on farm profits and its components, revenue and variable cost. Farmers self-select themselves to a particular type of conservation measure and therefore, there could be a problem of selection bias in evaluating their soil conservation practices. The selection bias is addressed by using binary propensity score matching. The comparison includes not merely adoption status, but also adoption intensity, to see if the adoption of multiple measures results in higher estimates of impact than the adoption of a single measure of conservation. Also, unlike the conventional literature, we use the spatial probit model to determine propensity scores. We use primary survey data of Darjeeling district of the Eastern Himalayan region of the year 2013.Our results from binary adoption case suggest that there is no difference in the profits in both winter and monsoon seasons, separately. Although revenues from adoption are higher, these appear to be associated with higher variable costs, thus resulting in no difference in profits. Furthermore, joint adoption of contour, afforestation, bamboo plantation or at least two of these measures can provide a significant gain in revenues but also increase costs. The causal impact of simultaneous adoption soil conservation measures such as contour buding, afforestation, bamboo plantation, on per acre total revenue varied between Rs 4560 to 5302 in the winter season and Rs 3469 to 5115 in the monsoon season. The causal impact of these soil conservation measures on per acre variable cost were between Rs 3209 to 5345 during winter season and Rs 2969 to Rs 3657. The lack of evidence on impact is not indicative of no impact, as these conservation measures may be interpreted to have helped restore soil fertility in regions and farms where there was considerable erosion.

Key Words: Soil Conservation, Adoption, Propensity Score Matching,

1 Context and Objectives

A great deal of farming in the world is in mountainous areas, which are ecologically fragile. The question of the availability of arable land is more serious there, and the problem of soil erosion is more acute, because the slopes are unstable and therefore do not allow the soil cover to evolve. High levels of rainfall on steep and, often, bare slopes gather energy and trigger the process of soil erosion further down (in a process known as splash erosion). Left unchecked, this transforms over time into the more familiar gully erosion (Desta et al., 2012). Due to these specific topographical features, cumulative soil erosion can cross the threshold beyond which erosion is irreversible much earlier in mountainous regions than in the plains, and may have serious implications in the long run for the productive capacity of land in general, and crop productivity in particular (Walker and Young, 1986).

The problem with soil erosion is multifaceted. First and foremost, there can be on-site negative impact of soil erosion on agricultural yield (Mbaga-Semgalawe and Folmer, 2000). However, soil erosion can be limited, and the resulting loss of top soil reduced, through proper soil and water conservation measures. Soil conservation measures can in principle be implemented by farmers on their own farms, if they perceive a present or future negative impact of soil erosion on crop production. Some farm-level measures common worldwide include terracing, contour bunding, revegetation, agro-forestry, crop mixture, fallow practices, land drainage system, crop residue management, etc. (Stocking and Murnaghan, 2001, p. 16). Although soil conservation measures have many regulating services (carbon sequestration, nutrient, hydrology, etc.) as well as conditioning services (food, wood, water, etc.), in this study we link soil conservation measures only with crop production, and ignore the downstream benefits of soil conservation. The adoption of soil conservation is likely to become sustainable if and only if it plays a role in improving farm profit, revenue and lowering variable costs.

The above discussion provides the context for this study, which attempts to address *if farm-level adoption of soil conservation measures have an impact on farm profit and its constituents, revenue and cost.* We attempt here to provide causal estimates of impact: in particular, the average impact of farm-level soil conservation measures on adopters, i.e., average treatment on the treated (ATT).[1] This study thus assesses the on-site impacts of soil conservation.

A few literature has evaluated the causal impact of soil conservation on crop production. Kassie et al. (2011) focused on the incentive of farmers in the Ethiopian hilly region to adopt soil and water conservation measures. They measured the incentive by the change in productivity per hectare because of soil and water conservation. Due to differences in pre-treatment parameters, the study used propensity score matching (PSM) techniques to measure the ATT. Faltermeier and Abdulai (2009) used the PSM methodology to estimate the impact of adoption and intensification of water conservation practices on farm output, demand for input and net returns in the northern region of Ghana.

We also use the PSM methodology to measure the impact of adoption of various conservation practices on farmer profit, revenue and variable cost. In identifying causal impact, the maintained assumption is that, the decision for farm-level adoption is based on observable household, farm-level, village characteristics. Once these covariates are accounted for, the assumption is that the adoption decision is independent of potential outcomes—in this case, farmer profit, revenue and cost. The PSM methodology matches adopters with non-adopters based on their propensity score. Propensity score is defined as the probability of adoption conditional on observed covariates (Hahn, 2010). We use the logit model to derive propensity scores. After matching, we compare the expected values of farm profit, revenue and cost

[1] The average impact of adoption of soil conservation measure on farmers who adopted is average treatment on treated (Heckman and Vytlacil, 2007).

between adopters and non-adopters to estimate the impact of adoption of plot-level soil conservation measures.

Kassie et al. (2011) and Faltermeier and Abdulai (2009) discussed above considered conservation a binary variable, i.e., adoption and non-adoption. However, neither study considered the possibility that more than one soil conservation technique could be adopted or that the effect of each of these on crop production could vary. We consider whether several (say, two or more) soil conservation measures adopted by the farmer have a greater impact than, say, the adoption of only two measures, and thus broaden the scope of adoption. Thus, following Imbens (2001) and Lecher (2001, 2002), the study incorporates a multiple adoption framework by defining k different and mutually exclusive soil conservation measures or adoptions.

We estimate causal impact on soil conservation measure on farm profits and its components by using our survey data from the Darjeeling district of the Teesta River Basin of Eastern Himalayan Region. In this study we have a situation with two types of intervention. The first type of intervention is the soil conservation measure adopted by the farmer at their own farm. This type of intervention is termed as on-farm adoption or simply *adoption*. The second type of intervention is the soil conservation measure in some of the sub-watersheds by the West Bengal Government (state government) with the help of Government of India, under the Teesta River Valley Programme. Soil conservation at the sub-watershed can complement or substitute adoption at farm indirectly (Feder and Slade, 1985). Therefore, we consider sub-watershed treatment as one of the observed covariate to estimate propensity score. Our findings suggest that some specific on-farm soil conservation measures do affect revenue and cost positively, but do not affect farm profit. Deeper analysis suggests that a positive, significant ATT is observed only in the case of simultaneous adoption of multiple soil conservation measures. Since the maintained assumption is that adoption is governed by observable characteristics, we perform sensitivity analysis to assess the potential for selection on unobservables. This suggests that our estimates are as sensitive to hidden bias, as in other studies of technology adoption in agriculture.

The rest of this study is organized as follows. In Section 2, we discuss the study area and soil conservation measures. In section 3, we describe primary data collection. In Section 4, we outline the conceptual framework for binary and multiple PSM. Section 5 discusses the method of estimation of binary and multiple PSM. Section 6 presents the results, and Section 7 presents the sensitivity analysis. Lastly, Section 8 concludes and discusses policy implications.

2 Study Area and Soil Conservation Measures

2.1 Description of Study Area

The study area is Darjeeling district in West Bengal state of India. Darjeeling district is located in the eastern part of the Himalayas, in the warm perhumid eco-region.[2] The altitude of the hills within the district varies between 300 feet and 10,000 feet. The soils in the steep hill slopes are shallow and excessively drained, and have severe erosion hazard. The soils of the foot hill slopes and valleys are moderately deep, well drained and loamy in texture and have moderate erosion hazard (West Bengal District Gazetteer Darjeeling, 2010). These translate into shallow soils that have little capacity for water storage. The average annual rainfall varies between 3,000 mm and 3,500 mm.[3] The Teesta is the major river of the district. Its catchment is affected by frequent landslides, slips and erosion of river banks. As a result, the Teesta and

[2] "National Bureau of Soil Survey and Land Use Planning (NBSS and LUP) of the ICAR has delineated 20 agro-ecological regions (AERs) in the country using the FAO 1978 concept of superimposition of growing periods and bio-climate maps on soil physiographic map." (TNAU Agritech Portal, http://agridr.in/tnauEAgri/eagri50/AGRO101/lec07.pdf, July 26 2015). The Darjeeling district perhumid ecosystem is one of these.

[3] Annual Admin Report, http://darjeeling.gov.in/admin_rpt/Annual_Admin_Report201112.pdf, December 14, 2014

its tributaries wash out an enormous amount of top soil every year (National Land Use and Soil Conservation Board, 1992).

Farmers grow a multiplicity of crops including maize, squash, ginger, cardamom, chilly, peas, tomato, spinach, beans and fruits like orange, pineapple etc. Land degradation due to water-induced soil erosion, along with other on-site and off-site impacts, poses a major threat to agricultural activity in this region. The role of the agricultural sector is also important in terms of the absorption of the work force, given the gradual decline of the tea industry in the post-independence period. At the same time, in the past 50 years or so, the district has experienced a falling land-man ratio due to population growth, ever-increasing demand of land for housing, road construction, agriculture, grazing and deforestation. All these human interventions have produced large quantities of sediments in water bodies. Therefore, soil erosion in this region could be attributed to both geological and man-made causes (Tirkey and Nepal, 2010).

2.2 Soil Conservation Measures in the Study Area

Soil conservation measures, as noted earlier, may be categorised as on-site measures and off-site measures. The farm-level (on-site) soil conservation measures adopted by farmers are: contour bunding, plantation of woody perennials, i.e., afforestation, bamboo plantation, orchard plantation, terracing, tree belt (plantation of trees on the farm boundary), broom plantation; and grass stripping.[4] The list is exhaustive but not mutually exclusive. Among these measures, contour bunding and terracing are measures that reduce the velocity of rain water flow on the agricultural farm, thereby reducing top soil loss. The rest of the measures help maintain a permanent vegetative cover on the farm to protect top soil from erosion. However, these measures vary with respect to their effectiveness in soil conservation.

---

[4] "A strip planted with grass across the slope. It slows down water flowing down the slope and catches sediment that has been eroded uphill", Food and Agriculture Organisation of the United Nation http://www.fao.org/ag/ca/africa trainingmanualcd/pdf%20files/08WATER.PDF, October 23, 2015

The off-site measures are undertaken mainly by the Teesta River Valley Programme for Soil Conservation. The Government of West Bengal (state government) started implementing the Teesta River Valley Programme to control soil erosion from 1977 onwards, with the help of Government of India (central government). The unit of treatment was the sub-watershed (National Land Use and Soil Conservation Board, 1992). The Teesta River Valley Programme was implemented by the State Forest Department. The department implemented several off-site measures, including: afforestation, broom/fodder cultivation, orchard plantation, belly benching and stream bank control, to avoid landslides (reducing the force of water through engineering construction and vegetation to minimize removal of soil particles of the site); construction of catch water drains (which divert the water flow and reduce soil erosion), [5] slip control/stabilization (technical measures to mitigate landslide) (National Land Use and Soil Conservation Board, 1992; Kurseong Soil Conservation Division, 2011; Kalimpong Soil Conservation Division, 2010).

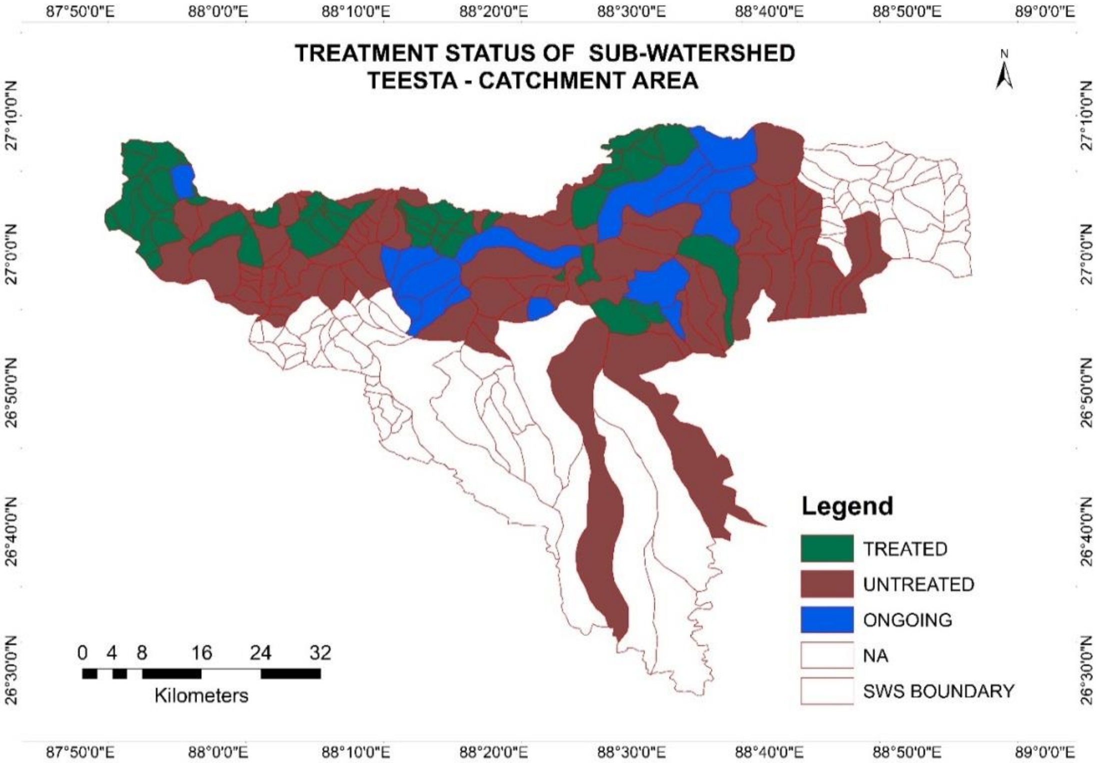
3 Primary Data Collection

To study the causal impact of on-farm soil conservation measures on agricultural outcomes, we first looked at a census to select sub-watersheds. The sample in this analysis includes 19 treated sub-watersheds and 16 untreated sub-watersheds.[6] Map 1 presents the sub-watershed of the Teesta River Valley region, delineated using the satellite image of the Landsat Operational Land Imager.

[5] Unabridged Dictionary, http://www.merriam-webster.com/dictionary/catchwater, October 23, 2015

[6] For the detailed discussion of sub-watershed selection see Singha C, 2016

Map 1: Delineated Sub-Watershed Boundary in Darjeeling



Source: Teesta Sub-Catchment Boundary, *Kurseong Soil Conservation Division and GIS and* Satellite Image Landsat, OLI

Having identified the treated and untreated watersheds, the next step was to select households from these areas. However, since the sub-watershed is a geophysical unit and not an administrative one, we super-imposed a map of village boundaries onto the sub-watershed boundaries using GIS, the ArcView software.[7] The total number of selected villages in the sample was 37. Of these 37 villages, 18 villages were revenue villages and 19 villages were forest villages.[8]

Next, we selected a uniform number of households from each village. Our budget could support approximately 450 sample households. We reallocated 450 in equal proportion to all the

[7] *ibid*

[8] "Forest villages were set up in remote and inaccessible forest area with a view to provide uninterrupted manpower for forestry operations." (Maharashtra Forest Department, http://mahaforest.gov.in/fckimagefile/Handbook-13.pdf, December 17, 2014).

37 villages. The total number of observations we surveyed from each village is, thus, 12. Moreover, some villages are divided into several hamlets. As there are no formal listings of the households, our enumerators first compiled a list of household heads and the location of the household, by approaching one or more village or hamlet elders. On average, a village consists of 150 households. Once this list was compiled, we selected 12 households by random sampling without replacement from the prepared list. Among these, about 75 percent of households had adopted at least one soil conservation measure (in addition to terracing).

Next, in our survey,[9] virtually all the households owned, in addition to a homestead, a single plot of land that they cultivate. Rental markets for land are relatively rare in this area; evidence of leased-out land is negligible. Where farmers had more than one plot (though negligible in number), we asked questions related to the largest plot. The survey was carried out in the calendar year 2013. We collected data on the post-monsoon crop (May to July) and the winter crop (September to December). In the second phase of our survey, i.e., for the winter crop, although we tried to revisit all the households of the first phase, we could not locate approximately 5 percent of households. In these cases, we visited the adjacent household. The interview was conducted in Nepali, as this is the native language of the study area. Enumerators interviewed an adult in the household. Approximately 65 percent of our respondents were male; the rest were female. Even though we visited 444 households the final data analysis we drop 52 households in the post monsoon season and 12 households during winter season due to the issue of unreliability.

4 Conceptual Framework

The fundamental problem in the causal inference is that it is impossible to observe the outcome and its counterfactuals on the same farmer (Holland, 1986). A solution can be to use a randomized control

[9] We conducted pilot visits of two rounds to finalize the interview schedule. The final questionnaire consisted of several modules (See Singha C, 2016 for details)

trial, in which soil conservation measures are assigned randomly but this can rarely be implemented in practical settings. For this reason, we rely on quasi-experimental techniques, such as the PSM methodology, to deal with the problem of the missing counterfactual. This section discusses the selection bias problem in studying the causal impact of soil conservation measures, and how PSM can be used to overcome it.

The different types of soil conservation measures used by farmers as mentioned in section 2. [10] We specify adopters as those who have adopted at least two measures from contour bunding, afforestation and bamboo plantation.

$D_i = 1$ if the farmer i is an adopter of soil conservation measure

$D_i = 0$ if the farmer i is a non-adopter of soil conservation measure

To estimate ATT, we need to determine the outcome of the counterfactual state, i.e., we need to observe the counterfactual outcome of the adopter of soil conservation measure in non-adoption state. Thus,

$$ATT = E[\pi(1)|D = 1] - E[\pi(0)|D = 1] \tag{1}$$

Where π is the outcome variable, i.e., farm profit and its components namely, revenue and variable cost. The outcome for the adopter in non-adoption state, that is, $E[\pi(0)|D = 1]$ cannot be observed.

What is possible to estimate, of course, is the difference:

$$E[\pi(1)|D = 1] - E[\pi(0)|D = 0] \tag{2}$$

that is, the difference between the expected farm outcomes between adopters and non-adopters. However, this is a biased estimate of the impact of adoption, since it is more than likely that the outcomes of adopters and non-adopters may have been different in the absence of any soil

[10] During the pilot survey, we also asked the respondents to rank each soil conservation measure by its effectiveness in tackling soil erosion on a scale of 1 to 10. By calculating the average, we worked out that the soil conservation practices considered most effective are stone terracing, stone/contour bunding, plantation of woody perennial, bamboo plantation and terracing. Only a few used stone terracing; therefore, we exclude this soil conservation practice. Moreover, 90 percent of the farmer reported to adopt terracing as soil conservation measure. We consider terracing as ‘”no conservation measure”.

conservation measure (Duflo et al., 2007). For instance, determinants of soil conservation measures and outcome variables share many factors (socioeconomic characteristics, input-output market access, farm characteristics).[11] In general, outcomes on farms that did not adopt soil conservation measures do not represent the outcomes if the farms were randomly selected for adoption (Godtland et al. 2004; Caliendo and Kopeinig, 2008).

The matching approach is one possible way to overcome selection bias. It assumes that the adoption decision is based on observables and that once these are accounted for, it possible to construct, for each adopter of soil conservation measures, a comparable group of non-adopters who have similar observable characteristics. The matching techniques impose two assumptions. The first is the assumption of unconfoundedness, or conditional independence, i.e., given a set of observable Z, the farm outcomes are independent of the adoption of soil conservation measures. Z consists of different observables related to socioeconomic, farm, sub-watershed and village characteristics; and market access variables. We assume that these covariates are all exogenous.

Specifically, the conditional independence can be written as below.

Assumption 1. Conditional independence: $\pi(0), \pi(1) \coprod D \mid Z$ (Caliendo and Kopeinig, 2008).

The second assumption is common support.

Assumption 2. Common support: $0 < P(D = 1|Z) < 1$ (Caliendo and Kopeinig, 2008).

In other words, the probability of adoption lies between 0 and 1 for both adopters and non-adopters. The common support assumption ensures that the farmer with the same observable covariates can be both adopter and non-adopter with a positive probability.

One implication of these assumptions is that no unobservable factors influence adoption and farm profit (and its components) simultaneously (Caliendo and Kopeinig, 2008). Another implication is of "stable unit treatment value assumption" (SUTVA) (Aakvik, 2001)—which implies that a farmer's adoption of soil conservation measures does not depend on another farmer's adoption.

[11] See Teklewood et al., 2015 for details.

If these assumptions are met, the matching technique can be used to match adopters and non-adopters and create counterfactuals. The ATT is given by:

$$ATT = E[\pi(1)|D = 1, Z] - E[\pi(0)|D = 0, Z] \quad (3)$$

Nevertheless, since the set of observed covariates is large, matching on covariates can be problematic. The literature terms this problem as "the curse of dimensionality". It can be resolved if we can control "for a scalar valued function of the observable covariates, namely, propensity score" (Hahn, 2010).

The PSM estimator for ATT is given by:

$$ATT(PSM) = E[\prod(1)|D = 1, P(Z)] - E[\prod(0)|D = 0, P(Z)] \quad (4)$$

Where P(Z)=P(D=1 | Z) is the propensity score, i.e., the conditional probability for a farmer to adopt soil conservation measures given his observed covariates Z. The PSM methodology resolves the curse of dimensionality by using the propensity score, generated from all the covariates in vector Z, to create the counterfactual. Therefore, ATT (PSM) is the mean difference of farm outcomes (profit, revenue and variable cost) over common support between adopters and non-adopters.

Thus far, adoption has been defined as in, a farmer is considered an adopter if he adopts at least two of the following measures: contour bunding, afforestation and bamboo plantation. Since there are multiple soil conservation techniques, (contour bunding, afforestation, bamboo plantation, terracing.), and a farm household may adopt more than one conservation measure, the impact of adoption on farm profit and its components may vary depending on the number of measures adopted. We define different adoption groups by the number of soil conservation measures a farmer adopts.[12] The number of soil conservation measures does not follow any natural order, and it is not

[12] If a farmer adopts any one of the soil conservation measures mentioned above, it belongs to adoption category 1. If a farmer adopts two of these, it belongs to adoption category 2, and so on.

feasible to ascribe any increase in intensity or effectiveness in reducing soil loss, as a function of the particular subset of conservation measures adopted.

Following Imbens (2001) and Lechner (2001), we incorporate a multiple adoption framework by generalizing four different and mutually exclusive categories of soil conservation measure. By construction, each farmer chooses to participate in exactly one soil conservation category from {D=0,1,2,3}. The potential outcomes are denoted by the vector $\{\pi^0, \dots \dots .., \pi^3\}$. For every adoption group d, a realization of one outcome is possible. The remaining three outcomes are counterfactuals.

In the multiple adoption states, the ATT is defined as the pair-wise comparison between any adoption groups r and s, where r, s $\in$ D and r $\neq$ s for the participation

$$ATT^{rs} = E[\pi(r)|D = r] - E[\pi(s)|D = r] \quad (5)$$

As before, the counterfactual mean of soil conservation measure $E[\pi(s)|D = r]$ cannot be observed. In this case as well, following a parallel treatment to that outlined above, imposing assumptions like unconfoundedness and overlap of common support, as in the binary adoption case, we can identify ATT as follows:

$$ATT^{rs}(PSM) = E\left[\pi(r)\middle|D = r, P^{r|rs}(Z)\right] - E\left[\pi(s)\middle|D = s, P^{r|rs}(Z)\right] \quad (6)$$

where $P^{r|rs}(Z)$ is the conditional choice probability (Imbens, 2001).

We make the following sets of comparisons in terms of impact on the three outcome variables (profits, revenues and costs):

- Farmers who adopt two measures compared to those who adopt none.
- Farmers who adopt three measures compared to those who adopt none
- Farmers who adopt two measures compared to those who adopt one
- Farmers who adopt three measures compared to those who adopt one
- Farmers who adopt three measures compared to those who adopt two

5 Estimation Method

For the binary adoption case, the study estimates the probability of adoption in relation to non-adoption by using the logit model. We estimate the propensity score by using the variables mentioned in Appendix Table 1 and 2. We neither know the actual propensity score nor do we know the correct functional form of the probability of adoption. We conducted two sample t-tests between the adopters and non-adopters on covariates (see Table 1). All these covariates are important determinants of adoption.[13] Village and sub-watershed specific variables dummy for forest village and dummy for village belonging to very high soil erosion prone sub-watershed.[14] Since the government also undertook technical and vegetative measures (treatment) to tackle the problem of soil erosion on some sub-watersheds in the study area, and this can influence both outcome and adoption, we use the sub-watershed treatment dummy as one of the variables to estimate the propensity score. We followed the rule of thumb suggested by Roenbaum (2002) to choose covariates for the probability of adoption. We selected only those covariates if group difference i.e. mean difference between adopters and non-adopters meet the threshold t –value 1.5 (Guo and Fraser, 2009, pp; 138-140). Here the objective is not to predict adoption rather the objective is to get better matches between adopters and non-adopters. By implementing the rule of thumb, we drop the covariates like: age of the household head, household size, proportion of household members studied at least 10 years and soil texture.

For the multiple adoption case, we use Multinomial Logit Model to get p^0,………., p^3 and compute $p^{r\,|\,rs} = \frac{p^r}{p^r+p^s}$, the conditional probabilities of adoption of a particular type of soil conservation measure by using the same set of covariates as in the binary case (Lechner, 2002). The present study uses the Epanechnikov Kernel matching, as it uses information from all observations, thus providing for lower variance (Caliendo and Kopeinig, 2008).

[13] See Teklewood et al., 2014, Wossen et al. 2015 Mbaga-Semgalawa and Folmer 2000 and Sidibe 2004 for details.
[14] *ibid*

6 Econometric Results

Table 1: Summary Statistics & Two Sample t-test with Survey Data

1	2	3	4	5
Variable	**Full Sample**	**Adopters**	**Non-adopters**	**Mean Difference = Adopters - Non-adopters**
Number of observations	432	211	221	
Proportion in sample (%)	100	49	51	
Number of observations in treated sub-watershed	220	90	130	
Number of observations in un-treated sub-watershed	212	121	91	
Number of observations in forest village	120	47	73	
Number of observations in Revenue village	312	164	148	
Number of observations in very high$^{\$\ \$}$ soil erosion prone sub-watershed	120	75	45	
Number of observations in high$^{\$}$ and medium$^{\$\$\$}$ soil erosion prone sub-watershed	312	136	166	
Socio Economic Variables				
Age of the Household Head (Years)	53 (.70)	54 (1.03)	52 (.96)	1.15 (1.41)
Years of Education of Household Head (Years)	4 (.19)	4 (.29)	3 (.25)	1*(.4)
Household Member between age 14-65 (%)	3.81 (.080)	3.88 (.11)	3.73 (.15)	0.15 (.16)
Household size	5 (.08)	5 (.1)	5 (.1)	0.23 (.16)
Proportion of household members studied at least 10 years	0.21 (.01)	0.22 (.016)	0.20 (.015)	0.025 (.022)
Experience of household head in agriculture (Years)	27 (.62)	28 (.9)	26 (.87)	2* (1.25)
Market Access Variables				
Distance to Nearest Local Market From farm (In Meters)	11323 (502)	8835 (618)	13743 (753)	-4908*** (977)
Distance to all-weather Road (In Meters)	2950 (185)	2377 (199)	3507 (306)	-1129*** (368)
Farm Characteristics				
Farm Area in Acres	1.25 (.052)	1.52 (0.08)	1 (.05)	0.52*** (.10)
Altitude of the farm in Meters	1281 (24)	1193 (31)	1366 (37)	-173** (49)
Soil Texture	2.17 (0.04)	2.17 (0.06)	2.16 (0.05)	0.01
Soil Colour	2.89 (0.05)	3.03 (0.06)	2.75 (0.06)	0.28***
Soil Stoniness	2.22 (0.04)	2.15 (0.05)	2.29 (0.05)	-0.14**

Sources: 1) Primary survey carried out in Darjeeling District, West Bengal, India carried out in the year 2013, 2*)* Kalimpong Soil Conservation Division (2010), Kurseong Soil Conservation Division, (2011)

Notes: 1) Standard deviation in parentheses, 2) ***, ** and * indicate significance at 1, 5 and 10 percent respectively, 3) Adopter => farmers who adopted at least two soil conservation practices from stone bunding, afforestation and bamboo plantation, Non-adopter => farmers who adopted at most one soil conservation practice 4) In Treated sub-watersheds state forest department of West Bengal has taken soil conservation measures. In untreated sub-watersheds no government initiative for soil conservation, 5) Soil Texture, Soil Colour and Soil Stoniness have been reported by the respondent according to a hedonic scale. Scale of soil Texture: Sandy /Coarse--- 1, Loamy/Medium coarse—2, Clay- 3, Silt-4, Scale of oil Colour: Gray- 1, Reddish- 2, Brown- 3, Black- 4, Scale of Soil Stoniness: High Stoniness- 1, Medium Stoniness- 2, Low Stoniness-Scale 3, Non stony- 4

As shown in Table 1, there are significant differences between adopters and non-adopters in several covariates (years of education of household head, experience of household head in agriculture, distance to market from farm, farm area, soil colour and soil stoniness). We are not going into detailed discussion here, except to note that these differences provide support for the use of matching techniques to assess the causal impact of on-farm soil conservation measures.

Table 2: Summary statistics for full sample, adopters and non-adopters

Crop Season	Variable	Full sample	Adopters	Non-adopters	Mean Difference (Adopter-Non-Adopter)
Winter	Number of Observations	432	211	221	
	Per Acre Profit (Rs.)	8230 (360)	8060 (651)	8394 (329)	-334
	Per Acre Total Revenue (Rs.)	19855 (435)	20478 (693)	19256 (531)	1221
	Per Acre Variable Cost (Rs.)	11624 (361)	12418 (605)	10862 (401)	1556**
Monsoon	Number of Observations	392	230	162	NA
	Per Acre Profit (Rs.)	7037 (424)	7617 (578)	6214 (7334)	1403*
	Per Acre Total Revenue (Rs.)	20570 (594)	21699 (794)	18967 (879)	2732**
	Per Acre Variable Cost (Rs.)	13532 (404)	14081 (497)	12752 (676)	1328*

Source: 1) Based on primary survey carried out in Darjeeling District, West Bengal, India carried out in the year 2013.

Notes: 1) Standard error in parentheses, 2) ***, ** and * indicate significance at 1, 5 and 10 percent respectively, 3) Adopter => observations who adopted at least two soil conservation practices from stone bunding, afforestation and bamboo plantation, Non-adopter => observations who adopted at most one soil conservation practice, 4) NA => Not Applicable, 5) Rs. => Indian National Rupees

Table 2 compares differences by season in the three outcome variables (profit, revenue and variable cost per acre).[15] In the winter season also, adopters bear a significantly higher cost than non-adopters. However, we are unable to see any significant difference in other outcome variables for the winter crop. In the monsoon season, the mean difference is positively significant in farm profit per acre (10 percent level of significance), total revenue per acre (10

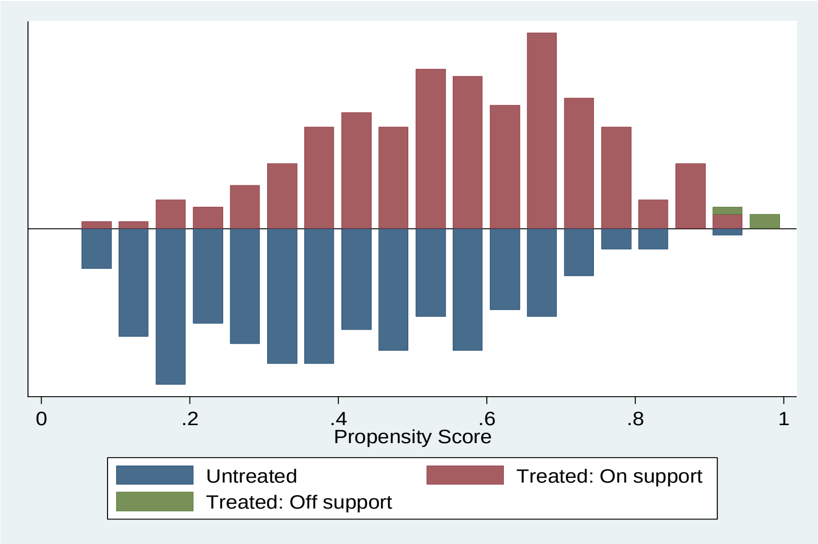
[15] See Singha C, 2016 for the detailed description of calculation of these components.

percent level of significance) and variable cost (5 percent level of significance). The t-statistic suggests that adopters tend to earn higher farm profit per acre and bear higher variable costs for farming.

6.1 Comparing Adopters of Two or More Measures with Non-adopters

The estimates from the binary logit and probit model of the propensity score of adoption are presented in Appendix Table 1. We use Model 3 of Appendix Table 1 to estimate propensity score. The distribution of propensity scores for the winter crop are presented in Graph 1 for the binary adoption case and Graphs 1 (a) and Graph 2 (a) to 2 (e) for the multiple adoption case. These graphs suggest that there is a substantial region of common support over which matching can be undertaken.

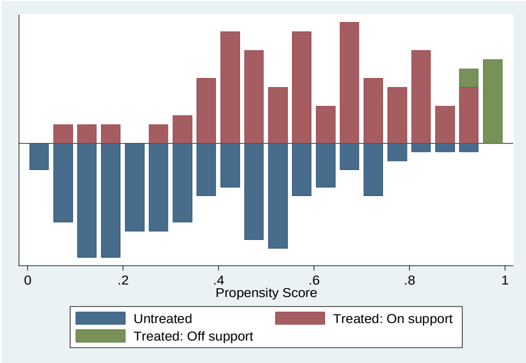
Graph 1: Propensity Score Graph of Binary Adoption



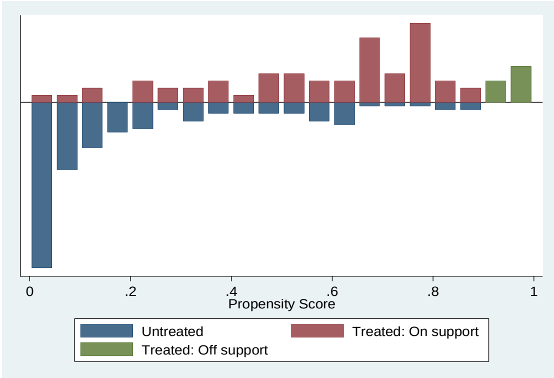
Source: 1) Based on primary survey carried out in Darjeeling District, West Bengal, India in the year 2013.
Note: 1) Propensity Graph shows the distribution of the propensity score for the winter crop, propensity score has been estimated by using binary logit model.

Graph 2: Propensity Score Graph of Multiple Adoption

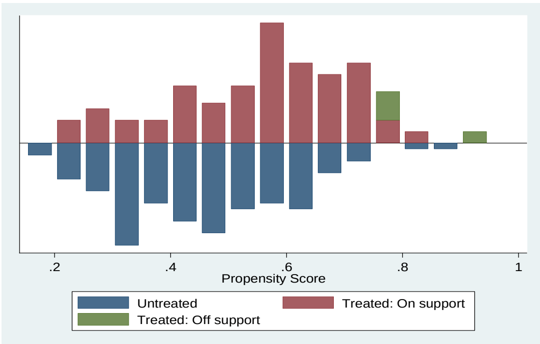
a) Propensity Score Graph None and 2



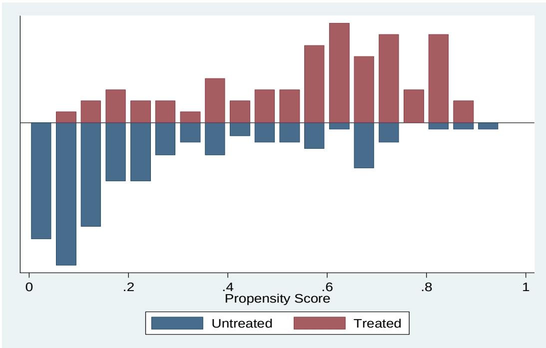
b) Propensity Score Graph None and 3



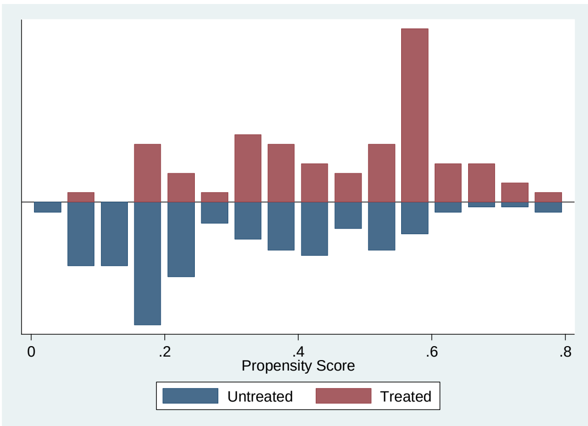
c) Propensity Score Graph 1 and 2



d) Propensity Score Graph 1 and 3



e) Propensity Score Graph 2 and 3



Source: 1) Based on primary survey carried out in Darjeeling District, West Bengal, India carried out in the year 2013.
Note: 1) Propensity Graph shows the distribution of the propensity score for the winter crop, propensity score has been estimated by using conditional choice probability

For PSM estimates to be valid, the characteristics of adopters and non-adopters should balance after matching. We use the two-sample t-test for difference in means to evaluate if this is indeed the case. Table 3 reports post-matching two sample t-tests (absolute p-value of mean difference) for both binary and multiple adoption cases. We find that post matching (see Column 2 of Table 3) for binary adoption case, these differences have been eliminated for all socioeconomic variables, market access variables and farm characteristics variables. However, there are still differences in some covariates in the multiple adoption case, because matching for the multiple adoption case has been implemented on the sub-sample.

Table 3: Post Matching Two sample t-test

Variables	**Absolute p-value of mean difference**					
	Comparing Adopters with Non-Adopters	**Comparing Adopters of Multiple Measures with Fewer Measures**				
		None and 2	**None and 3**	**1 and 2**	**1 and 3**	**2 and 3**
Number of Observations	432	245	192	232	179	185
Socio Economic Variables						
Years of Education of Household Head (Years)	0.4	0.3	0.8	0.5	0.2	0.5
Household Member between age 14-65 (%)	0.4	0.9	0.7	0.96	0.5	0.6
Experience of household head in agriculture (Years)	0.9	0.5	0.6	0.2	0.02	0.8
Market Access Variables						
Distance to Nearest Local Market From farm (IMeters)	0.7	0.9	0.95	0.8	0.6	0.6
Distance to all-weather Road (Meters)	0.3	0.06	0.11	0.4	0.2	0.5
Farm Characteristics						
Area of the farm in Acre (unit)	0.8	0.7	0.3	0.9	0.4	0.9
Altitude of the farm (Meter)	0.5	0.08	0.96	0.4	0.9	0.9
Soil Colour	0.4	0.4	0.3	0.3	0.8	0.9
Soil Stoniness	0.1	0.2	0.4	0.14	0.3	0.5

Source: 1) Based on primary survey carried out in Darjeeling District, West Bengal, India carried out in the year 2013.

Notes: 1) In binary adoption, Adopter => observations who adopted at least two soil conservation practices from stone bunding, afforestation and bamboo plantation, Non-adopter => observations who adopted at most one soil conservation practice, 2) In Multiple Adoption, None=> no soil conservation practice adopted, 1=> adoption of any one soil conservation practice from stone bunding, afforestation and bamboo plantation, 2=> adoption of any two soil conservation practices from stone bunding, afforestation and bamboo plantation, 3=> adoption of all three practices, 3) Soil Colour and Soil Stoniness have been reported by the respondent according to a hedonic scale, Scale of Soil Colour: Gray- 1, Reddish- 2, Brown- 3, Black- 4, Scale of Soil Stoniness: High Stoniness- 1, Medium Stoniness- 2, Low Stoniness- 3, Non stony- 4

The results of the causal effect of adoption on various outcomes are reported in Table 4. The total number of adopters is 211 and of non-adopters is 221. We find that ATT is statistically significant for per acre profit (estimated impact of Rs. 1683 per acre) at 10 percent level of significance, per acre total revenue (estimated impact of Rs. 5,029 per acre) and per acre variable cost (estimated impact of Rs 3,346 per acre) during the monsoon season at 1 percent level of significance. During the winter season, however, ATT is insignificant for all the outcome variables.[16] The ATT of these outcomes are 28, 30 and 31 percent of mean outcomes of matched non-adopters.

Table 4: Impact of Adoption of Soil Conservation Practices on Farm Profit, Revenue and Variable Cost: Comparing Adopters with Non-Adopters

1	2	3	5	6	7	8	9
Outcome	**Season**	**ATT**	**T Value**	**ATT as % of matched non-adopter**	**Non-adopters (on support)**	**Adopters (On support)**	**Critical Level of γ**
Per Acre Profit (In Rs)	Winter	225 (677)	0.33	2.5	219	202	NA
Per Acre Total Revenue (In Rs)		1335 (1022)	1.31	6.8	219	202	NA
Per Acre Total Variable Cost (In Rs)		1110 (746)	1.49	10.5	219	202	NA
Per Acre Profit (In Rs)	Monsoon	1683* (982)	1.71	28	162	221	1..08
Per Acre Total Revenue (In Rs)		5029***(1397)	3.6	30	162	221	1.81
Per Acre Total Variable Cost (In Rs)		3346***(1011)	3.3	31	162	221	1.87

Source: 1) Based on primary survey carried out in Darjeeling District, West Bengal, India carried out in the year 2013.

Notes: 1) Standard deviation in parentheses, 2) ***, ** and * indicate significance at 1, 5 and 10 percent respectively, 3) ATT is based on equation (4) 4) Adopter => observations who adopted at least two soil conservation practices from stone bunding, afforestation and bamboo plantation, Non-adopter => observations who adopted at most one soil conservation practice, 5) γ = hidden bias, the estimator that captures the effect of unobservables on adoption of soil conservation measure (Aakvik, 2001), 6) NA=> Not Applicable, 7) Rs=> Indian National Rupees

[16] The total number of observations is reduced in the post-monsoon season, as the risk of animal-induced crop damage deters some from cultivation, (14 non-adopters reported this reason). We also omitted 26 observations in the post-monsoon season due to non-reliability in reporting.

These results suggest that soil conservation measures lead to significant increase in yield for adopters and, although this higher yield comes with higher costs, the impact on farm revenues is positive in the rainy season. The variable cost component consists largely of labour cost. Therefore, the positive and significant ATT of total variable cost per acre during the monsoon season may be suggestive of complementarity between labour-demand and on-farm soil conservation (Pattanayak and Burty, 2005).

Defining adoption in the way we have, may in this part be, responsible for our finding a lack of impact in the winter season. For a more nuanced analysis of the role of adoption, one sensitive to the fact that adoption consists of multiple soil conservation measures, we turn to multiple adoption comparisons. As noted above, these compare the outcomes of those who adopt two measures versus those that adopt none; those who adopt three measures versus those that adopt none; those who adopt two measures versus those that adopt one; those who adopt three measure versus those that adopt one; those who adopt three measures versus those who adopt two.

6.2 Comparing Adopters of Multiple Measures with Those Who Adopt Fewer Measures

We conduct pair-wise comparison of four soil conservation adoption groups for each outcome variable. The estimation results of Multinomial Logit is given in Appendix Tables 2.

Tables 5 and 6 report the ATT for the outcome variables per acre profit, total revenue and variable cost for winter crop and monsoon crop, respectively. These tables present the pair-wise comparison of outcome variables between two adoption groups. For instance, the third row of Tables 5 and 6 compares the difference in farm profit per acre between farms that adopted one soil conservation measure and farms that adopted two soil conservation measures. Similarly, the fourth row of these tables compares farm profit between farms that adopted one soil conservation measure and farms that adopted three soil conservation measures.

Table 5: Impact of adoption of soil conservation practices on Farm Profit, Revenue and Variable Cost (Winter Crop)

1	2		3	4	5	6		7
Outcome	**Number of Soil Conservation Measures Control Treatment**		**ATT**	**T Value**	**ATT as % of matched non-adopter**	**On Support Treatment Control**		**Critical Level of γ**
Per Acre Profit (In Rs)	None	2	311 (883)	0.35	3.6	126	108	NA
	None	3	1351 (1278)	1.06	15.6	126	58	NA
	1	2	371 (891)	0.42	4.53	113	112	NA
	1	3	-618 (1351)	0.46	6.63	113	66	NA
	2	3	-42 (1387)	-0.03	-0.5	129	66	NA
Per Acre Total Revenue (In Rs)	None	2	-407 (1290)	-0.32	2.09	126	108	NA
	None	3	4560** (2097)	2.17	24.28	126	58	1.25
	1	2	-427 (1286)	-0.33	-2.26	113	112	NA
	1	3	3278 (2074)	1.58	17.07	113	66	1.06
	2	3	5302*** (1809)	2.93	30.88	119	66	1.55
Per Acre Total Variable Cost (In Rs)	None	2	-718 (935)	-0.77	6.59	126	108	NA
	None	3	3209** (1509)	2.13	31.62	126	58	1.25
	1	2	-798 (964)	-0.83	-7.45	113	112	NA
	1	3	3896** (1524)	2.56	39.43	113	66	1.72
	2	3	5345*** (1285)	4.16	63.4	119	66	2

Source: 1) Based on primary survey carried out in Darjeeling District, West Bengal, India carried out in the year 2013.

Notes: 1) Standard deviation in parentheses, 2) ***, ** and * indicate significance at 1, 5 and 10 percent respectively, 3) ATT is based on equation (4) of Chapter 4, 4) In Multiple Adoption, None=> no soil conservation practice adopted, 1=> adoption of any one soil conservation practice from stone bunding, afforestation and bamboo plantation, 2=> adoption of any two soil conservation practices from stone bunding, afforestation and bamboo plantation, 3=> adoption of all three practices, 5) γ = hidden bias, the estimator that captures the effect of unobservables on adoption of soil conservation measure (Aakvik, 2001), 6) NA => Not Applicable.

Table 6: Impact of adoption of soil conservation practices on Farm Profit, Revenue and Variable Cost (Monsoon Crop)

1	2		3	4	5	6		7
Outcome	**Number of Soil Conservation Measures**		**ATT**	**T Value**	**ATT as % of matched non-adopter**	**On Support**		**Critical Level of γ**
	Control	**Treatment**				**Control**	**Treatment**	
Per Acre Profit (In Rs)	None	2	1436 (1359)	1.06	21.06	65	109	NA
	None	3	684 (1457)	0.47	10.25	65	78	NA
	1	2	1457 (1433)	1.02	22.24	97	128	NA
	1	3	694 (1794)	0.39	10.71	97	101	NA
	2	3	-285 (1254)	-0.23	-3.98	129	96	NA
Per Acre Total Revenue (In Rs)	None	2	2480 (2370)	1.05	12.38	65	109	NA
	None	3	3654* (2058)	1.78	20.63	65	78	1.3
	1	2	5115*** (1796)	2.85	29.57	97	128	1.58
	1	3	3469* (2053)	1.69	19.88	97	101	1.36
	2	3	550 (1733)	0.32	2.69	129	96	NA
Per Acre Total Variable Cost (In Rs)	None	2	1044 (2282)	0.6	7.9	65	109	2
	None	3	2970* (1700)	1.75	26.92	65	78	1.5
	1	2	3658*** (1242)	2.94	34.03	97	128	1.98
	1	3	2775* (1528)	1.8	25.31	97	101	1.52
	2	3	837 (1094)	0.76	6.32	129	96	NA

Source: 1) Based on primary survey carried out in Darjeeling District, West Bengal, India carried out in the year 2013.
Notes: 1) Standard deviation in parentheses, 2) ***, ** and * indicate significance at 1, 5 and 10 percent respectively, 3) ATT is based on equation (4) of Chapter 4, 4) In Multiple Adoption, None=> no soil conservation practice adopted, 1=> adoption of any one soil conservation practice from stone bunding, afforestation and bamboo plantation, 2=> adoption of any two soil conservation practices from stone bunding, afforestation and bamboo plantation, 3=> adoption of all three practices, 5) γ = hidden bias, the estimator that captures the effect of unobservables on adoption of soil conservation measure (Aakvik, 2001), 6) NA => Not Applicable.

In the winter season (Table 5), for all categories of comparisons, there appear to be no significant impact on per acre profits. However, when revenues are examined, it is clear that farmers who adopt three conservation measures have higher revenues than those who adopt no measures, or those who adopt two measures; the remaining comparisons yield insignificant differences in revenue. Adopters of three measures have Rs. 4,560 higher revenue than those who do not adopt (at 5 percent level of significance) and Rs. 5,302 higher revenue than those who adopt only two measures (at 1 percent level of significance). These ATTs are 24 and 31 percent respectively of mean value of non-adopter group. For per acre total variable cost, ATT is significant for the group-wise comparison between no adoption measure and three adoption measures, one adoption measure and three adoption measures and two adoption measures and three adoption measures. The ATTs as percentage mean value of non-adopters are higher in per acre variable costs as compare to revenues.

The number of farmers who adopted two soil conservation measures is 139. Among them, only 30 percent adopted contour bunding; therefore, the composition of soil conservation of this group is largely driven by measures such as afforestation and bamboo plantation. On the other hand, 72 farmers have adopted all the soil conservation measures. However, all the farmers in both groups reported that they did not invest in the maintenance of contour bunding in last five years. This provides suggestive evidence of the importance of certain types of conservation measures, although, as stated earlier, there was no reason *ex ante* to associate larger numbers of adopted measures with greater intensity of soil conservation.

The ATT on profit is insignificant. The positive causal impact of the simultaneous adoption of all soil conservation measures on revenue per acre does not lead to any significant change in farm profit, since the variable cost of cultivation also increases with the adoption of more measures. The weak complementarity relation between labour demand and soil conservation could be a plausible reason for this, as explained above in the binary adoption case.

In the monsoon season, a similar picture emerges (Table 6). The estimated ATT for per acre profits is insignificant across all comparisons, but that for total revenue is positive and significant when we compare those who adopt two measures versus those who only adopt one, or those who adopt three measures versus those who adopt only one or none. These differences are significant at the 1 percent level and 10 percent level respectively. Like winter season, the ATTs as percentage of mean revenue of non-adopter is lower than mean variable cost of non-adopters. Therefore, these higher revenues do not translate into higher profits, as per acre variable costs for these groups are also higher by Rs 3,657, Rs 2,969 and Rs 2,775, respectively.

Overall, these estimates of impact suggest that a simultaneous adoption of two or more soil conservation measures leads to higher revenues but also comes with higher costs. These findings extend the earlier analysis, which suggested no impact on profits but a positive impact on revenues in the monsoon season (but not the winter crops). All the gains of soil conservation measures seem to come from the adoption of a particular combination of such measures, viz., from the simultaneous adoption of contour, afforestation, bamboo plantation and terracing. This disaggregated analysis, thus, provides richer insight into which particular measures lead to the highest increase in revenues.

7. Sensitivity Analysis

Technology adoption in agriculture is also influenced by factors like perception of soil erosion (Mbaga-Semgalawa and Folmer, 2000), risk attitude (Shiveley, 2001), neighbourhood adoption, discount rate of farmer, slope of the farm, etc. Our estimate of the causal impacts of adoption does not account for or measure these factors. If adopters and non-adopters (or different groups of adopters) differ in the above-mentioned unobservables, and if these unobservables affect the adoption and outcome variables, the estimated ATT will be biased. To check the sensitivity of the estimated ATT, we conducted a sensitivity analysis in the case of significant ATT, following the concepts discussed in Aakvik (2001), Becker and Caliendo (2007), Hujer et al. (2004) and Diprete and Gangl (2005). The sensitivity analysis in these literatures is termed the Rosenbaum Bounds.

This involves a sensitivity analysis, assuming differing levels of unobservable factors affecting adoption, and examining if these change the inference regrading impact (Hujer et al, 2004, Aakvik, 2001). If the inference changes due to minute changes in unobservables, then the results are considered sensitive to the maintained assumption of adoption being explained largely by observables.

Let the probability of a farmer to adopt soil conservation measures be given by:

$$P_i = P(Z_i, u_i) = P(D = 1 \mid Z_i, u_i) = F(bZ_i + \gamma u_i) \tag{7}$$

Here, *Z* is a set of observables as defined in Section 4; u_i is the unobserved characteristics of the individual, farms, etc., of observation i; and b and γ are the effects of observed and unobserved parameters, respectively, on the adoption decision. In case γ = 0 (i.e., there is no hidden bias), the adoption of soil conservation is fully determined by the observed characteristics *Z*. In case γ is different from zero, any two individuals with the same set of *Z* can have different probabilities of adoption.

Let us consider matched pairs of farmers *i* and *j*, where *i* is an adopter, while *j* is a non-adopter. Let us also assume that F follows the normal distribution.

$$\frac{\frac{P_i}{1-P_i}}{\frac{P_j}{1-P_j}} = \frac{P_i(1-P_j)}{P_j(1-P_i)} = \frac{\exp(bZ_j - \gamma u_j)}{\exp(bZ_i - \gamma u_i)} = \exp\{\gamma(u_i - u_j)\} \tag{8}$$

Vector Z does not appear on the right hand side in the expression above, as both *i* and *j* have the same covariates, since they are matched, and Z is cancelled out (Becker and Caliendio, 2007; Faltermeier and Abdulai, 2009). The sensitivity analysis proceeds by varying the value of γ. For simplicity, we consider the value of u to be either 0 or 1. For example, if the farmer's perception of soil erosion is the unobserved omitted variable, then for a farmer who perceives soil erosion as a problem for cultivation, u_i=1 or otherwise (i.e. u_i=0).

expλ=1 is the baseline scenario. Its implication is that two farmers with similar observables are also similar in unobservables, i.e., there is no unobserved selection bias. Similarly, $\exp\gamma$ =2 implies that two farmers who look similar in terms of the probability of adoption differ by a factor of two in their odd ratio of adoption. The above-mentioned odds ratio must lie between $\left[\frac{1}{e^{\gamma}}, e^{\gamma}\right]$

(Aakvik, 2001). We vary the value of γ in the interval [1, 2], commonly used in similar studies in social sciences (Keele, 2010). The Rosenbaum bound sensitivity analysis reports p-values from Wilcoxon signed-rank tests for the ATT.[17] For each value of γ, it computes a notional significance level "p-critical". This "p-critical" value constitutes the bound on the significance level of ATT in the case of endogenous adoption of on-farm soil conservation measure (Diprete and Gangl, 2005).

We report the critical level of hidden bias (value of γ) with "p-critical"= 0.10, in the last column of Tables 4, 5 and 6, but only for those estimated ATT that are statistically significant. In Table 4, the presence of hidden bias at 1.26 implies that positive significant change in per acre total revenue in the monsoon crop due to soil conservation measures should be viewed critically if γ = 1.81 or beyond. In other words, observations that look similar in observables differ by the odds of adoption of soil conservation measure by 81 percent. The critical value of γ = 1.81 suggests, simply, that the confidence interval of per acre total revenue due to adoption includes zero if the odd ratio of adoption between adopter and non-adopter varies by 1.81 because of an unobservable (Faltemeier and Abdulai, 2009). In the same table, the critical hidden bias of per acre total variable cost in winter season is also 1.87. Tables 5 and 6 report critical value of γ (Column 6). In some instances, like the group-wise comparison of ATT in Tables 5 and 6 on per acre variable costs, that the hidden bias is equal to 2 or beyond suggests that the magnitude and significance of ATT in the multiple adoption case is less sensitive due to unobservables than in the binary adoption case. It suggests farmers (and farms) that are similar in observables; even if they differ in the odds ratio by 100 percent, the causal interpretation of soil conservation on the concerned outcomes are still intact. The Lower the critical value of γ, the higher is the hidden bias; and the converse also is true. Therefore, adoption of multiple soil conservation measures in per acre total

[17] See Diprete and Gangl (2005) for details.

variable cost is associated with lower hidden bias due to the higher critical value of γ. All these values are well within the acceptable range as noted in studies by Faltemeier and Abdulai (2009) and Hujer (2004) and in the example cited in Keele (2010).

8. Conclusions and Policy Implication

This study attempts to estimate the causal impact of adoption of soil conservation measures such as contour, afforestation and bamboo plantation on per acre farm profits, revenues and costs, using our survey data for 432 farmers in the Teesta Valley, where the problem of soil erosion is severe. Our maintained assumption is that we are able to capture factors that influence farmers' decision to adopt different types of soil conservation measures on their farm. We use this maintained assumption to create a counterfactual comparison group using matching techniques. In addition to binary adoption, we also compare if the impact of adopting multiple adoption measures is greater than that of adopting fewer conservation methods. The results from the PSM methodology suggest no difference in the per acre profits in the winter and monsoon seasons. Revenues from adoption are higher, but are associated with higher variable costs; therefore, there is no difference in profits. Clearly, not all soil conservation measures are equally effective in providing significant gains in outcome. Our results show that joint adoption of contour, afforestation and bamboo plantation is more efficient, and that at least two from these measures can provide a significant gain in revenues (and costs). The causal impact of multiple soil conservation measures on per acre total revenue varied between Rs 4560 to 5302 in the winter season and Rs 3469 to 5115 in the monsoon season. The causal impact of multiple adoption of soil conservation practice on per acre variable cost were between Rs 3209 to 5345 during winter season and Rs 2969 to Rs 3657. But the impact of adoption of multiple soil conservation measures on per acre per acre farm profit remained insignificant, since increased revenues were accompanied by higher costs. The ATTs as percentage of mean value of matched non- adopter is lower for per acre revenue (ranges between 25 to 31 percent is the winter season and 21 to 30 in the post-monsoon season) as compare to costs (ranges between 32 to 63 percent in the winter season and 27 to 34 percent in the monsoon season). It is likely that farms that have adopted these measures are able to maintain their soil quality at the same level as non-adopters. Perhaps, this explains why there is no difference in profits. The Rosenbaum bounds test suggests the presence of unobservable factors and that these affect adoption, but their magnitude is not very different from that found in other studies.

The adoption of multiple soil conservation measures, such as contour bunding, afforestation and bamboo plantation, may be an essential precondition of farming in an ecologically fragile ecosystem like the Himalayas. Most adoption measures—apart from providing several environmental benefits—help to diversify farmer income. But contour bunding is the most expensive of all soil conservation measures. Only 30 percent of the farmers in our sample adopted contour bunding, and over 75 percent of such adopters in our sample report not spending on maintenance of counter bunds in the last 10 years, and high expenses as the reason. Therefore, it is important to facilitate farmers' access to credit. Afforestation is also effective, with a number of off-site and on-site environmental benefits, but requires taking a major portion of land out of farm production for years, and thus has huge opportunity cost for the farmer. Therefore, it is also essential to develop alternative incentive mechanisms to encourage afforestation, such as the incentive design—i.e., contract between farmers and government (or a private agency)—to sequester carbon through afforestation. The contract must involve a monetary incentive for farmers to be able to participate. Immediately, it can serve three purposes: financial stability to the farmer, sustainable farm practices and the mitigation of Green House Gas emission through carbon sequestration (Antle and Diagana, 2003).

However, there are limitations of this study. One major limitation is that the study based on a partial equilibrium analysis of adoption decisions of farmers, and has also considered impact only at the farm level. However, as noted above, impacts of action both by the government and the individual farmer can have large scale impacts that extend beyond to the river basin as a whole, and also have general equilibrium implications on the supply of farm products and prices in the local economy. An analysis of these effects is merited in further work.

References

Aakvik, A. (2001), 'Bounding a Matching Estimator: The Case of a Norweign Training Program', *Oxford Bulletin of Economics and Statistics* 63(1): 115-140.

Abdulai, A., and W.E. Huffman (2005), 'The Diffusion of Agricultural Technologies: Crossbred-Cow Technology in Tanzania', *American Journal of Agricultural Economics* 87(3): 645-659.

Annual Admin Report 2012 Darjeeling, Retrieved December 14 2014, [Available At] http://darjeeling.gov.in/admin_rpt/Annual_Admin_Report201112.pdf

Antle, J. M., and B. Diagana (2003), 'Creating Incentive for the Adoption of Sustainable Agricultural Practices in Developing Countries: The Role of Soil Carbon Sequestration', *American Journal of Agricultural Economics* 85(5): 1178-1184.

Becker, S., and M. Caliendo (2007), 'Sensitivity Analysis for Average Treatment Effects', The *Stata Journal* 7(1): 71-83.

Caliendo, M., and S. Kopeinig (2008), 'Some Practical Guideline For The Implementation of Propensity Score Matching', Journal *of Economic Survey* 22 (1): 31-72.

Desta, L. and Adugna B. (2012), *A Field Guide on Gully Prevention and Control. Eatern Nile Subsidiary Action Program*, Eastern Nile Technical Regional Office, Addis Ababa

DiPrete, T. A. and M. Gangl (2005), 'Assessing Bias in the Estimation of Causal Effects: Rosenbaum Bounds on Matching Estimators and Instrumental Variable Estimation with Imperfect Instruments', WZB, Duke University.

Duflo, E., R. Glennerster, and M. Kremer (2007), 'Using Randomization in Develoment Economics Research: A Toolkit', Discussion Paper No. 6059. Centre for Economic Policy Research, London.

Faltemeier, L. and A. Abdulai, (2009), 'The Impact of Water Conservation and intensification evidence for rice farmers in Ghana', *Agricultural Economics* 40: 365-379.

Feder, G. and R. Slade (1985), 'The Role of Public Policy in the Diffusion of Improved Agricultural Technique', *American Journal of Agricultural Economics* 67(2): 423-428.

Godtland, E. M., E. Sadoulet, A. D. Janvry, R. Murgai and O. Ortiz (2004), 'The Impact of Farmer Field Schools on Knowledge and Productivity: A Study of Potato Farmers in the Peruvian Andres', *Economic Development and Cultural Change* 53(1): 63-92.

Government of India (2011), 'A-5 State Primary Census Abstract. Retrieved 29 December 2015', [Available At] http://www.censusindia.gov.in/2011census/ hlo/pca/ PCA_pdf/PCA-CRC-1900.pdf

Guo, S., and Fraser M.W. (2009), *'Propensity Score Analysis: Statistical Methods and Applications'* Los Angeles: Sage Publication, pp: 138-140.

Hahn, J. (2010), 'Propensity Score' in S. N. Durlauf and L. E. Blume, (eds) *Microeconomnetrics*, New York: Palgrave Macmillan, pp. 194-196.

Heckman, J. J., and E. J. Vytlac (2007), 'Econometric Evaluation of Social Programe, part 1: Causal Models, Structural Models and Econometric policy Evaluation', in J. J. Heckman and L. Edward (eds), *Handbook of Econometrics*. *Vol. 6B*, Chicago: Elsevier, pp. 4780-4874.

Holland, P. W. (1986), 'Statistics and Causal Inference', Journal *of the American Statistical Association* 81(396): 945-960.

Hujer, R., M. Caliendo, and S. L. Thomsen (2004), 'New Evidence on the Effect of Job Creation Schemes in Germany -a matching approach with threefold heterogeneity', *Research in Economics* 58(4): 257-302.

Imbens, G. (2001), 'The Role of the Propensity Score in Estimating Dose-Response Function', *Biometrica* 87(3):706-710.

India.gov.in, 'Archive. Soil and Water Conservation', Retrieved 12 December 2014, [Available at] http://www.archive.india.gov.in/sectors/agriculture/index.php?id=28

Kalimpong Soil Conservation Division (2010), 'Annual Report 2009-2010', Directorate of Forest, Govt. of West Bengal, Soil Conservation (North) Circle.

Kurseong Soil Conservation Division (2011), 'Annual Report 2010-2011', Directorate of Forest, Govt. of West Bengal, Soil Conservation (North) Circle.

Keele, L. (2010), 'An overview of rbounds: An R package for Rosenbaum bounds sensitivity analysis with matched Data', Retrieved 15 December 2014 [Available at] http://www.personal.psu.edu/ ljk20/ rbounds%20vignette.pdf

Kaisse, M., B. Shiferaw, and G. Muricho. 2011, 'Agricultural Technology, Crop Income and Poverty Alleviation in Uganda', *World Development* 39(10): 1784-1795

Lechner, M. (2002), 'Program Heterogeneity and Propensity Score Matching An Application To The Evaluation of Active Labour Market Policies', *The Review of Economics & Statistics* 84(2): 205-220.

Lechner, M. (2001), 'Identification and Estimation of Causal Effects of Multiple Treatments Under the Conditional Independence Assumption' in M. Lechner and F. Pfeiffer (eds). *Econometric Evaluation of Labour Market Policies.* Heidelberg: Physica, pp. 1-18.

Maharashtra Forest Department, 'Conservation of forest villages into revenue village and settlement of other old habitations. Retrieved December 17 2014', [Available At] http://mahaforest.gov. in/fckimagefile/Handbook-13.pdf

Mbaga-Semgalawe, Z., H. Folmer (2000), 'Household adoption behaviour of improved soil conservation of the Morth Pare and West Usambara Mountain', *Land Use Policy* 17(4): 321-336.

National Land Use and Conservation Board (1992), 'Evaluation Studu of Soil Conservation In the River Valley Project of Teesta Catchment', Department of Agriculture and Cooperation Ministry of Agriculture, Government of India.

Pattanayak, S. K. and D. T. Burty (2005), 'A Spatial Complementarity of Forests and Farms: Accounting For Ecosystem Services', *American Journal of Agricultural Economics* 87(4): 995-1008.

Scherr, S. J. (1999), 'Soil Degradation A Threat to Developing Country Food Security by 2020?', Discussion Paper No. 27, International Food Policy Research Institute, Washington D.C.

Shively, G. E. 2001, 'Poverty, Consumption Risk and Soil Conservation', *Journal of Development Economics* 65 (2):267-290.

Singha, C. (2016), 'Adoption and Valuation of Soil Conservation Measures: An Analysis of the Teesta Watershed Programme', PhD Dissertation, Delhi University

Soil and Land Use Survey of India, 'Micro Watershed Atlas of India. Retrieved May 2 2015', [Available At] http://slusi.dacnet.nic.in/dissemination_of_micro_watershed.htm

Stocking, M. and Murnagham, N. (2001), *Handbook for the Field Assessment of Land Degradation*, London: Earth scan Publications Ltd.

Teklewood, H., M. Kassie, and B. Shiferaw (2014), 'Adoption of Multiple Sustainable Agricultural Practices in Rural Ethiopia', *Journal of Agricultural Economics* 64(3): 597-623.

Tirkey and Nepal (2010), 'Tea Plantation in the Darjeeling Hills Geo-Ecological Impact and Livelihood Implications', Retrieved December 30 2014 [Available At] http://www.nepjol.info/ index.php/HN/article/viewFile/7104/5766

TNAU Agritech Portal, 'Agronomy-definition-meaning and scope. Agro-climatic zones of India and Tamil Nadu-Ago ecological zones of India', Retrieved July 26 2015 [Available At] http://agridr.in/tnauEAgri/eagri50/AGRO101/lec07.pdf

United Nation Environment Programme (UNEP). (2014), *UNEP Year Book Emerging Issues In Our Global Environment*. Nairobi.

Walker, D. J. and D. L. Young (1986), 'The Effect of Technical Progress on Erosion Damage and Economic Incentive for Soil Conservation', *Land Economics* 62(1): 83-93.

West Bengal District Gazetteers Darjeeling (2010), Government of West Bengal, Calcutta.

Appendix Table 1: Logit Estimates of Factor Influencing Adoption of Soil Conservation Measures

VARIABLES	Model 1	Model 2	Model 3
Socio Economic Variables			
Age of the Household Head (Years)	-0.004 (0.006)	-0.006 (0.01)	
Years of Education of Household Head (Years)	0.029 (0.02)	0.05 (0.035)	0.06** (0.02)
Household size (#)	0.048 (0.038)	0.081 (0.064)	
Household Member between age 14-65 (%)	-0.257 (0.347)	-0.385 (0.59)	-0.263 (0.539)
Proportion of household members studied at least 10 years (%)	0.18 (0.338)	0.294 (0.563)	
Experience of household head in agriculture (Years)	0.012* (0.006)	0.019* (0.01)	0.017** (0.008)
Market Access Variables			
Distance to Nearest Local Market From farm (In Meters)	0*** (0)	0*** (0)	0*** (0)
Distance to all-weather Road (In Meters)	0 (0)	0 (0)	0 (0)
Farm Characteristics			
Farm Size (unit)	0.236*** (0.079)	0.414*** (0.142)	0.409*** (0.139)
Altitude in Meter (unit)	0* (0)	0* (0)	0* (0)
Soil Texture$	0.102 (0.0854)	0.165 (0.142)	
Soil Colour$$	0.15** (0.075)	0.24* (0.127)	0.224* (0.124)
Soil Stoniness$$$	-0.19** (0.093)	-0.31** (0.156)	-0.29* (0.155)
Village and sub-watershed specific variables			
Forest Village Dummy†	-0.147 (0.172)	-0.232 (0.289)	-0.211 (0.289)
Very high soil erosion prone sub-watershed Dummy††	-0.426** (0.16)	-0.678** (0.27)	-0.66** (0.26)
Sub-watershed treatment Dummy†††	0.199 (0.165)	0.315 (0.280)	0.303 (0.277)
Constant	-0.209 (0.595)	-0.363 (0.987)	0.0470 (0.757)
Observations	427	427	427

Sources: 1) Based on primary survey carried out in Darjeeling District, West Bengal, India carried out in the year 2013, 2) †, †† and ††† Kalimpong Soil Conservation Division (2010) and Kurseong Soil Conservation Division (2011)..

Notes: 1) Standard error in parentheses, 2) ***, ** and * indicate significance at 1, 5 and 10 percent respectively, 2) Number of adopters: 211, number of non-adopters:221, 3) Soil Texture, Soil Colour and Soil Stoniness have been reported by the respondent according to a hedonic scale. Scale of soil Texture: Sandy /Coarse--- 1, Loamy/Medium coarse—2, Clay- 3, Silt-4, Scale of Soil Colour: Gray- 1, Reddish- 2, Brown- 3, Black- 4, Scale of Soil Stoniness: High Stoniness- 1, Medium Stoniness- 2, Low Stoniness- 3, Non stony- 4, 4) In very high soil erosion prone sub-watersheds Sediment Yield Index is 1450 and above. "Sediment Yield Index" calculated as "weighted arithmetic mean of the products of the erosion intensity weightage value and delivery ratio over the entire area of the hydrologic unit by using suitable empirical equation" (Soil and Land Use Survey of India, slusi.dacnet.nic.in/rrs.pdf, February 2, 2014), 5) In Treated sub-watersheds forest department of West Bengal has taken soil conservation measures,

Appendix Table 2: Multinomial Logit Estimates of Factor Influencing Adoption of Soil Conservation Measures (Multiple Adoption)

Variables	1 Adoption Measures	2 Adoption Measures	3 Adoption Measures
Socio Economic Variables			
Years of Education of Household Head (Years)	0.02 (0.039)	0.065* (0.038)	0.105** (0.05)
Household Member between age 14-65 (%)	2.035*** (0.696)	0.284 (0.655)	0.359 (0.799)
Experience of household head in agriculture (Years)	-0.007 (0.012)	0.017 (0.011)	0.016 (0.014)
Market Access Variables			
Distance to Nearest Local Market From farm (In Meters)	0 (0)	0 (0)***	0 (0)***
Distance to all-weather Road (In Meters)	0*(0)	0* (0)	0 (0)
Farm Characteristics			
Farm Size (unit)	1.001***(0.23)	1.038***(0.23)	0.96***(0.24)
Altitude in Meter (unit)	0 (0)	0 (0)	0* (0)
Soil Colour[$$]	-0.053 (0.162)	0.016 (0.16)	0.77***(0.21)
Soil Stoniness[$$$]	0.114 (0.202)	-0.297 (0.204)	-0.183 (0.250)
Village and sub-watershed specific variable			
Forest Village Dummy[†]	-0.777**(0.388)	-0.242 (0.380)	-0.471 (0.481)
Very high soil erosion prone sub-watershed Dummy[††]	-0.190 (0.357)	-0.75** (0.376)	-0.532 (0.460)
Sub-watershed treatment Dummy[†††]	0.659* (0.354)	0.391 (0.353)	0.588 (0.415)
Constant	-3.016*** (1.02)	-0.818 (0.974)	-2.783**(1.26)
Observations	427		

Sources: 1) Based on primary survey carried out in Darjeeling District, West Bengal, India carried out in the year 2013, 2) †, †† and ††† Kalimpong Soil Conservation Division (2010) and Kurseong Soil Conservation Division (2011)..

Notes: 1) Standard error in parentheses, 2) ***, ** and * indicate significance at 1, 5 and 10 percent respectively, 3) No adoption measure is the base outcome measure, 4) Soil Colour and Soil Stoniness have been reported by the respondent according to a hedonic scale. Scale of Soil Colour: Gray- 1, Reddish- 2, Brown- 3, Black- 4, Scale of Soil Stoniness: High Stoniness- 1, Medium Stoniness- 2, Low Stoniness- 3, Non stony- 4, 5) In very high soil erosion prone sub-watersheds Sediment Yield Index is 1450 and above. "Sediment Yield Index" calculated as "weighted arithmetic mean of the products of the erosion intensity weightage value and delivery ratio over the entire area of the hydrologic unit by using suitable empirical equation" (Soil and Land Use Survey of India, slusi.dacnet.nic.in/rrs.pdf, February 2, 2014), 6) In Treated sub-watersheds forest department of West Bengal has taken soil conservation measures,