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Causal Impact of the Adoption of Soil Conservation Measures on Farm Profit, Revenue and Variable Cost in Darjeeling District, India

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ECONOMICS & THE ENVIRONMENT

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Abstract

This study attempts to evaluate the effects of on-farm soil conservation practices on farm profit and its components, revenue, and variable cost. Since farmers self-select themselves as adopters of a particular type of conservation measure, there could be a problem of selection bias in evaluating their soil conservation practices. We address the selection bias by using propensity score matching. The comparison includes not merely adoption status but also adoption intensity, to see if the adoption of multiple conservation measures results in higher estimates of impact than the adoption of fewer conservation measures. We use the logit and conditional logit model to determine propensity scores. We use primary survey data from the Darjeeling district of the Eastern Himalayan region for the year 2013. Our results from the binary adoption case suggest that there is no difference in the profits for the winter and monsoon seasons taken separately. Although revenues from adoption are higher, these appear to be associated with higher variable costs, thus resulting in no difference in profits. Furthermore, while the joint adoption of contour, afforestation, and bamboo plantation, or even just two of these measures, can lead to a significant gain in revenues, they also increase costs. The causal impact of the simultaneous adoption of soil conservation measures on per acre total revenue varies between INR 4560 and 5302 in the winter season and between INR 3469 and 5115 in the monsoon season. The causal impact of these soil conservation measures on the per acre variable cost ranges from INR 3209 to 5345 during the winter season and from INR 2969 to 3657 in the monsoon season.

JEL Classification: Q240, Q150, C210

Keywords

Soil conservation, Adoption, Propensity score matching

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1. Context and Objectives

A great deal of farming in the world takes place in mountainous areas, which are ecologically fragile. It is in these areas that the question of the availability of arable land is the most serious and the problem of soil erosion the most acute because the slopes are unstable and therefore do not allow for 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 much earlier in mountainous regions than in the plains beyond which irreversible erosion occurs, which would have serious implications in the long run for the productive capacity of land, in general, and for crop productivity, in particular (Walker and Young, 1986).

The problem with soil erosion is multifaceted. First and foremost, there can be the negative impact of on-site soil erosion on agricultural yield (Mbaga-Semgalawe and Folmer, 2000). However, the adoption of proper soil and water conservation measures can limit soil erosion and reduce the resulting top soil loss. In principle, farmers will implement soil conservation measures on their own farms if they perceive a present or future negative impact of soil erosion on crop production. Some such farm-level measures widely adopted worldwide include terracing, contour bunding, revegetation, agro-forestry, crop mixture, fallow practices, land drainage system and crop residue management (Stocking and Murnaghan, 2001). Although soil conservation measures have many regulating services (for e.g., carbon sequestration, nutrient conservation, 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 and revenue and in lowering variable costs.

The present study seeks to estimate the extent to which farm-level adoption of soil conservation measures impacts farm profit and its constituents, revenue and cost. Our attempt here is to provide the causal estimates of the impact, in particular, the average impact of farm-level soil conservation measures on adopters, i.e., the average treatment effect on the treated (ATT).[1] This study thus assesses the on-site impacts of soil conservation. We use the *propensity score matching* (PSM) methodology to measure the impact of adoption of various conservation practices on farmer profit, revenue and variable cost. In identifying the causal impact, the maintained assumption is that the decision on farm-level adoption is based on observable household, farm-level and 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. The 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

[1] The average impact of the adoption of soil conservation measures on farmers who adopt them is the average treatment effect on the treated (Heckman and Vytlacil, 2007).

compare the expected values of farm profit, revenue and cost between adopters and non-adopters to estimate the impact of adoption of plot-level soil conservation measures. Along with considering soil conservation as a binary variable, i.e., adoption and non-adoption, we also consider whether several (say, two or more) soil conservation measures adopted by a farmer would have a greater impact on farmer profits than, say, the adoption of only two measures and, thus, broaden the scope of adoption. Following Imbens (2001) and Lecher (2001 & 2002), the study thus incorporates a multiple adoption framework by defining k different and mutually exclusive soil conservation measures or adoptions.

We estimate the causal impact of soil conservation measures on farm profits and its components by using survey data from the Darjeeling district of the Teesta River Basin of the Eastern Himalayan Region. In this study we have a situation with two types of intervention. The first type of intervention details the soil conservation measure adopted by a farmer at his/her own farm, which is termed on-farm adoption or simply *adoption*. The second type of intervention refers to the soil conservation measures introduced in some of the sub-watersheds by the West Bengal Government (i.e., the state government) with the help of the Government of India, under the Teesta River Valley Programme. Soil conservation at the sub-watersheds can either complement or indirectly substitute for the adoption of measures at the farm (Feder and Slade, 1985). Therefore, we consider sub-watershed treatment as one of the observed covariates to estimate the 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 cases where there is simultaneous adoption of multiple soil conservation measures. Since the maintained assumption is that observable characteristics govern adoption, we perform a sensitivity analysis to assess the potential for selection of unobservables, which suggests that our estimates are as sensitive to hidden bias as those in other studies on technology adoption in agriculture.

2. Study Area

2.1 Description of study area

The Darjeeling district of West Bengal is located in the eastern part of the Himalayas and comes under the warm perhumid eco-region.[2] The altitude of the hills within the district varies between 300 feet to 10,000 feet. The soils in the steep hill slopes are shallow and excessively drained, carrying a severe erosion hazard. The soils of the foot hill slopes and valleys, on the other hand, are moderately deep, well-drained and loamy in texture carrying a 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 affected by frequent landslides, slips and erosion of river banks. As a result, the Teesta and 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, chillies, peas, tomato, spinach and beans as well as fruits like orange and pineapple. 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. But the agricultural sector is also beginning to play a more important role in the region, in terms of absorption of the work force, given the gradual decline in the tea industry in the post-independence period. At the same time, during the past 50 years or so, the district has experienced a falling land-man ratio due to population growth and the ever-increasing demand on land for housing, road construction, agriculture and grazing, which has resulted in deforestation. All these human interventions have produced large quantities of sediments in water bodies. Evidently, both geological and man-made causes have played a role in soil erosion in the region (Tirkey and Nepal, 2010).

[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

2.2 Soil conservation measures in the study area

Soil conservation measures, as noted earlier, may be categorised as on-site and off-site measures. Among the farm-level (on-site) soil conservation measures adopted by farmers are contour bunding, afforestation, bamboo plantation, orchard plantation, terracing, tree belt (plantation of trees on the farm boundary), broom plantation, and grass stripping.[4] Though the list is exhaustive, it is not mutually exclusive. Of 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, whereas the other measures help maintain a permanent vegetative cover on the farm to protect the top soil from erosion. The measures vary, however, with respect to their effectiveness vis-a-vis soil conservation.

The off-site measures are undertaken mainly by the Teesta River Valley Programme for Soil Conservation. The Government of West Bengal (the state government) started implementing the Teesta River Valley Programme to control soil erosion in 1977, with the help of the Government of India (central government), the unit of treatment being the sub-watershed (National Land Use and Soil Conservation Board, 1992). The Teesta River Valley Programme, which was implemented by the State Forest Department, introduced several off-site measures, including afforestation, broom/fodder cultivation, orchard plantation, belly benching and stream bank control, to avoid landslides (by reducing the force of water through engineering construction and vegetation to minimize the removal of soil particles of the site); construction of catch water drains (which divert the water flow and reduce soil erosion);[5] and slip control/stabilization (i.e., technical measures to mitigate landslides) (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 depended on a census to select the sub-watersheds. This sample includes 19 treated sub-watersheds and 16 untreated sub-watersheds.[6] Figure 1 presents the sub-watershed of the Teesta River Valley region delineated using the satellite image of the Landsat Operational Land Imager.

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 (ArcView software).[7] The total number of selected villages in the sample was 37, of which 18 villages were revenue villages and 19 forest villages.[8]

We then selected a uniform number of households from each village. Since our budget could support approximately 450 sample households, we reallocated the 450 in equal proportion to all the 37 villages, which brought the total number of observations surveyed from each village to 12. Since no formal listings of the households were available, our enumerators compiled a list of household heads and determined the location of the household by approaching one or more village or hamlet elders. On average, a village consisted of 150 households. Therefore, once this list was compiled, we selected 12 households by random sampling with replacement from the prepared list. Among these, we found roughly 75 percent of households to have adopted at least one soil conservation measure (in addition to terracing). Our survey[9] also showed virtually all the households to own, in addition to a homestead, a

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[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, U.N. http://www.fao.org/ag/ca/africa trainingmanualcd/pdf%20files/08WATER.PDF, October 23, 2015).

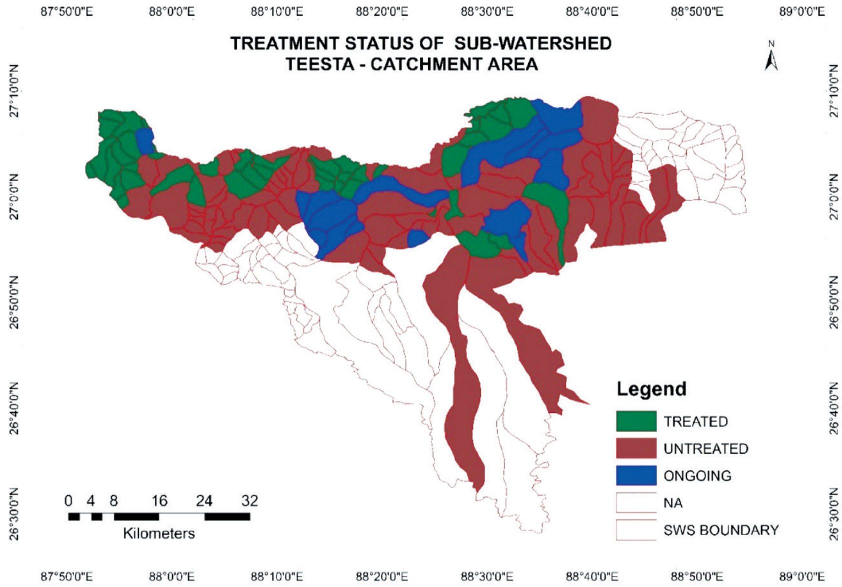
[5] Unabridged Dictionary, http://www.merriam-webster.com/dictionary/catchwater, October 23, 2015.

[6] For a detailed discussion of sub-watershed selection, see Singha, 2016.

[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).

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



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

Figure 1: Delineated sub-watershed boundary in Darjeeling

single plot of land which they cultivate. Given that rental markets for land are relatively rare in this area, evidence of leased-out land was negligible. Where farmers had more than one plot (though negligible in number), we asked questions related to the largest plot.

Our survey, which was carried out in the calendar year of 2013, collected data on the post-monsoon crop (May to July) and the winter crop (September to December). Although we tried to revisit all the households of the first phase in the second phase of our survey, i.e., for the winter crop, we were unable to locate approximately 5 percent of the sample households during this round. In such instances, we visited the adjacent household. Enumerators interviewed an adult in the household, the interview conducted in Nepali, which is the native language of households in the study area. Approximately 65 percent of our respondents were male, the rest being female. Though we visited, in all, 444 households, we dropped 52 sample households from the post-monsoon season and 12 sample households from the winter in the final data analysis because of questions regarding the reliability of information provided.

4. Conceptual Framework

A fundamental problem in causal inference is that it is impossible to observe the outcome and its counterfactuals on the same farmer (Holland, 1986), a solution for which would be to use a randomized control trial, in which soil conservation measures are assigned randomly though this can rarely be implemented practically. For this reason, we relied on quasi-experimental techniques, such as the PSM methodology, to deal with the problem of the missing counterfactual. This section discusses the problem of selection bias in studying the causal impact of soil conservation measures and how PSM can be used to overcome it.

In Section 2, we listed the different types of soil conservation measures used by farmers.[10] Here, we specify as adopters those who have adopted at least two measures from contour bunding, afforestation and bamboo plantation.

[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 by the farmers were stone terracing, stone/contour bunding, plantations of woody perennials, bamboo plantations, and terracing. Since only a few used stone terracing, we decided to exclude this soil conservation practice from the analysis. Though 90 percent of the farmers reported adopting terracing as a soil conservation measure, we consider terracing as a "no conservation measure" for the purposes of our study.

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

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

To estimate ATT, we need to determine the outcome of the counter factual state, which is to observe the counter factual outcome of the adopter of the soil conservation measure in a non-adoption state. Thus,

$$ATT = \mathrm{E}[\pi(1) \mid D = 1] - \mathrm{E}[\pi(0) \mid \mathrm{D} = 1] \quad (1)$$

where π is the outcome variable, i.e., farm profit and its components, namely, revenue and variable cost. Although the outcome for the adopter in the non-adoption state, that is, $\mathrm{E}[\pi(0) \mid D = 1]$ cannot be observed, it is possible to estimate the difference:

$$\mathrm{E}[\pi(1)\ D = 1] - \mathrm{E}[\pi(0) \mid D = 0] \quad (2)$$

This is the difference in 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 even in the absence of any soil conservation measure (Duflo *et al.*, 2007). For instance, determinants of soil conservation measures and outcome variables share many factors (for e.g., socio-economic characteristics, input-output market access, farm characteristics).[11] In general, outcomes on farms with soil conservation measures do not represent the outcome on farms without soil conservation measures due to the non-random or voluntary nature of 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 is 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 socio-economic, farm, market access and sub-watershed and village characteristics.

We assume that these covariates are all exogenous. Specifically, the conditional independence can be written as follows:

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

The second assumption is common support which is written as follows:

Assumption 2. Common support: $0 < P(D = 1 \mid Z) < 1$ (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 refers to "stable unit treatment value assumption" (SUTVA) (Aakvik, 2001) – according to which a farmer's adoption of soil conservation measures does not depend on another farmer's adoption.

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:

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

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

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 $P(Z)=P(D=1 \mid Z)$ 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, we have defined adoption in the following manner: a farmer is considered an adopter if he adopts at least two of the following measures: contour bunding, afforestation and bamboo plantation. However, as there are multiple soil conservation techniques 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. To address this issue, we define different adoption groups by the number of soil conservation measures a farmer adopts.[12] But the number of soil conservation measures does not follow any natural order and it is not 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 measures. 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 $\{\pi^0,\ldots\ldots,\pi^3\}$. 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

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

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

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

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 variable costs):

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

[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 them, it belongs to adoption category 2, and so on.

- 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 Tables 1 and 2. Since we neither know the actual propensity score nor 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] We also incorporate village and sub-watershed specific variables like dummy for forest village, dummy for village belonging to very high soil erosion prone sub-watershed, and dummy for village belonging to treated sub-watershed.[14] Since the government also undertook technical and vegetative measures to tackle the problem of soil erosion on some sub-watersheds in the study area, and this could 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 Rosenbaum (2002) to choose covariates for the probability of adoption, selecting only those covariates if group difference, i.e., mean difference between adopters and non-adopters, meets the threshold t –value 1.5 (Guo and Fraser, 2009). 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 covariates like age of the household head, household size, proportion of household members with at least 10 years of schooling, and soil texture.

For the multiple adoption case, we use the Multinomial Logit Model to get $p^0,\ldots\ldots\ldots,p^3$ and compute $P^{r|rs} = \dfrac{p^r}{p^r + p^{s'}}$, which is 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).

6. Econometric Results

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 color and soil stoniness). Though we will not go into a detailed discussion of Table 1, we wish to underline that these differences in covariates provide support for the use of matching techniques to assess the causal impact of on-farm soil conservation measures.

Table 2 compares differences by season in the three outcome variables (profit, revenue and variable cost per acre).[15] It shows that adopters bear a significantly higher cost than non-adopters in the winter season. However, we do not see any significant difference in other outcome variables for the winter crop. On the other hand, in the monsoon season, the mean difference is positively significant with regard to farm profit per acre (at the 10 percent level of significance), total revenue per acre (at the 10 percent level of significance) and variable cost (at the 5 percent level of significance). The t-statistic suggests that adopters tend to earn higher farm profits per acre and bear higher variable costs for farming.

[13] See Teklewood *et al*., 2014; Wossen *et al*., 2015; Mbaga-Semgalawa and Folmer 2000; Sidibe 2004 and Singha 2016 for details.

[14] ibid

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

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 who have at least 10 years of schooling	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 color	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) A primary survey carried out in Darjeeling District, West Bengal, India, 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, the 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 color 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 color: grey- 1, reddish- 2, brown- 3, black – 4; Scale of soil stoniness: high stoniness- 1, medium stoniness- 2, low stoniness-scale 3, non-stony- 4.

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 (INR)	8230 (360)	8060 (651)	8394 (329)	-334
	Per acre total revenue (INR)	19855 (435)	20478 (693)	19256 (531)	1221
	Per acre variable cost (INR)	11624 (361)	12418 (605)	10862 (401)	1556**
Monsoon	Number of observations	392	230	162	NA
	Per acre profit (INR)	7037 (424)	7617 (578)	6214 (7334)	1403*
	Per acre total revenue (INR)	20570 (594)	21699 (794)	18967 (879)	2732**
	Per acre variable cost (INR)	13532 (404)	14081 (497)	12752 (676)	1328*

Source: 1) Based on a primary survey carried out in Darjeeling District, West Bengal, India, 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) INR => Indian Rupee.

6.1 Comparing adopters of two or more measures with non-adopters

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

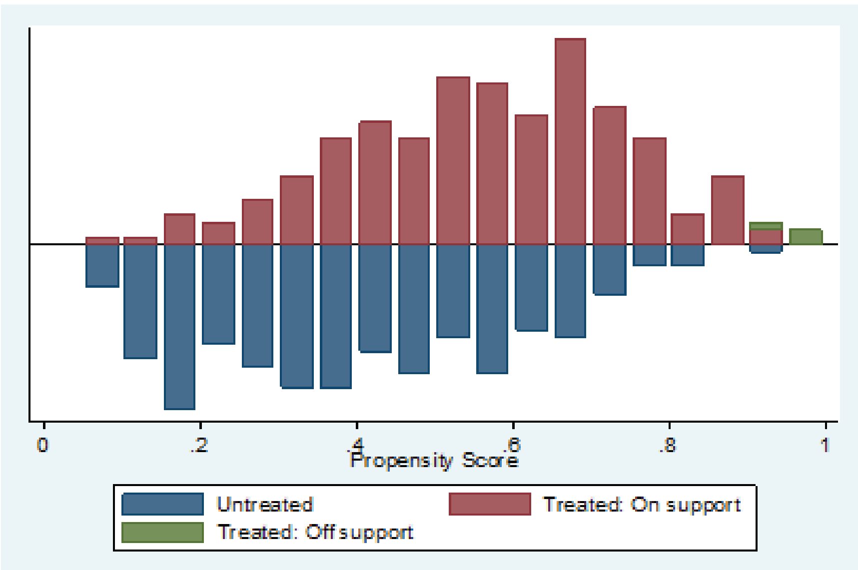
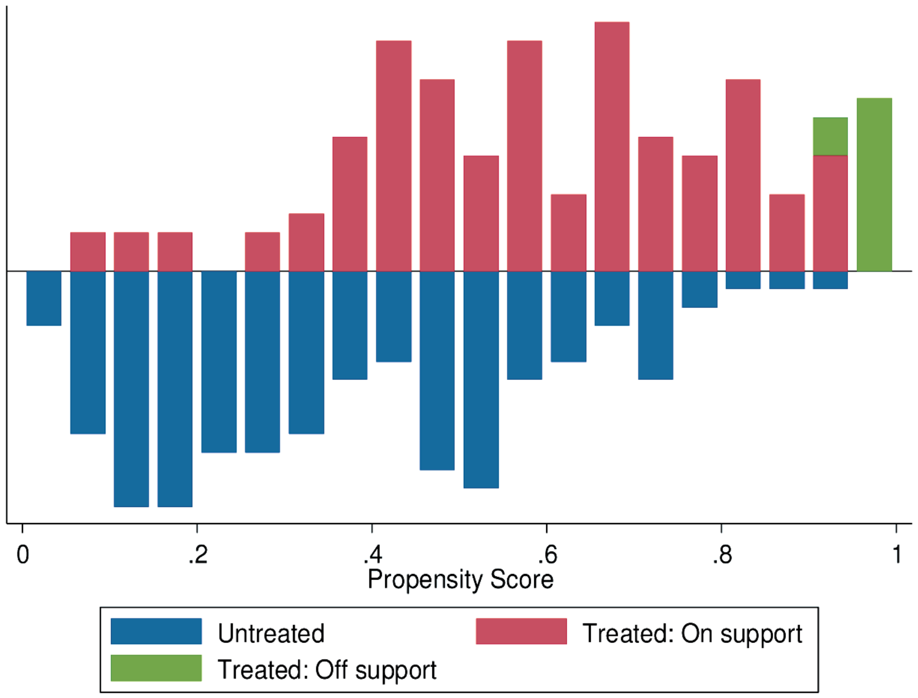


Figure 2: Propensity score graph of binary adoption

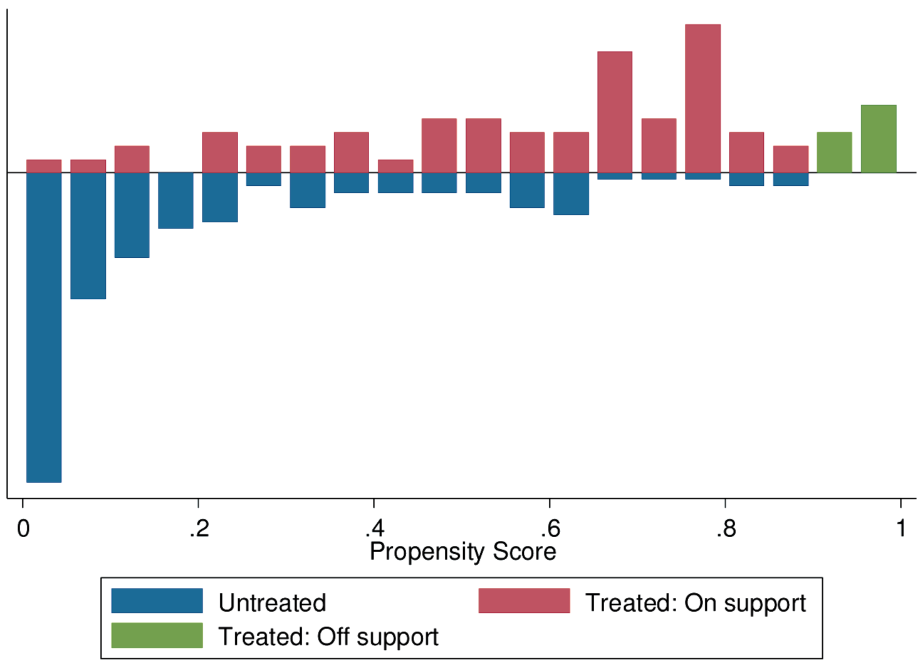
Source: 1) Based on the primary survey carried out in Darjeeling District, West Bengal, India in the year 2013.

Note:1) The Propensity Graph shows the distribution of the propensity score for the winter crop. The propensity score has been estimated by using the binary logit model.

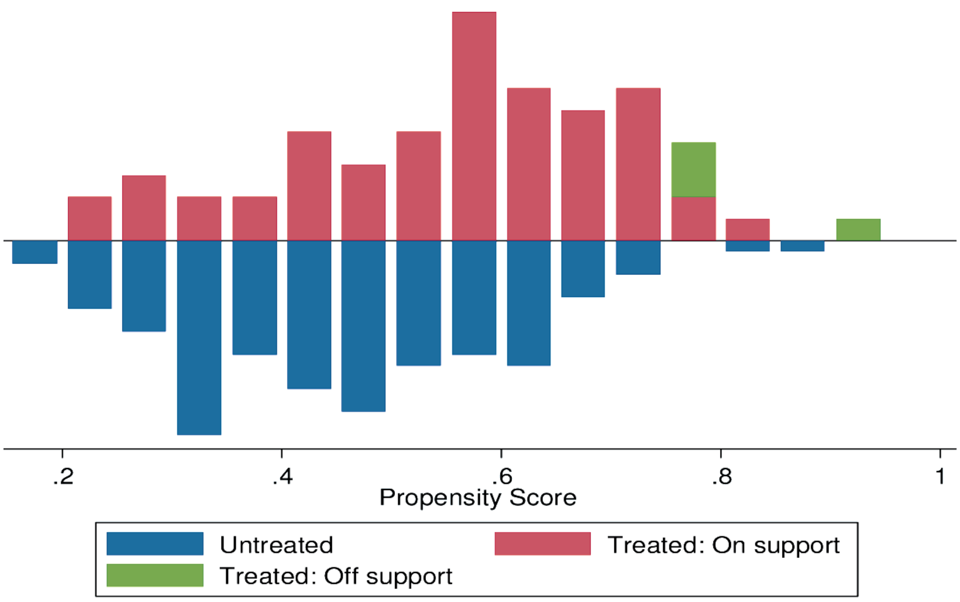
Figure 3: Propensity Score Graph of Multiple Adoption



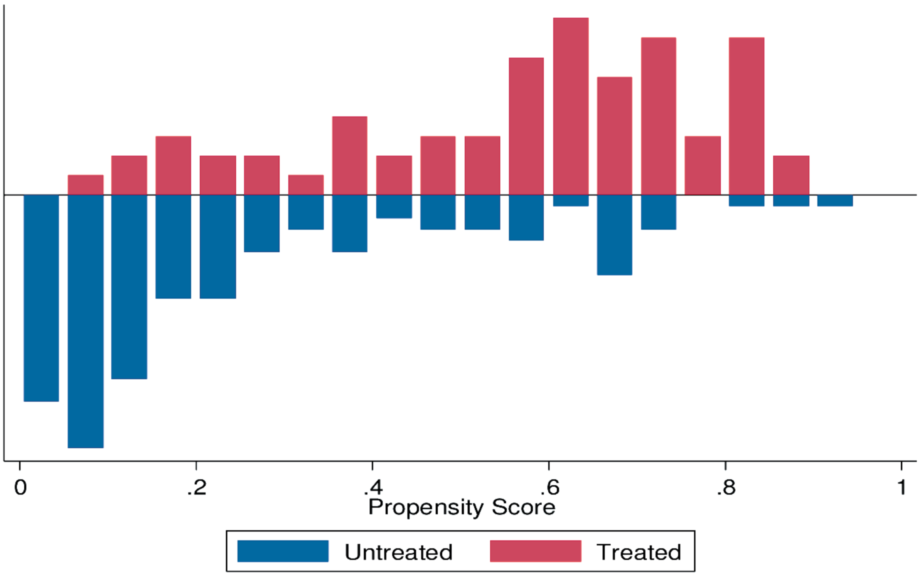
a) Propensity score Graph None and 2



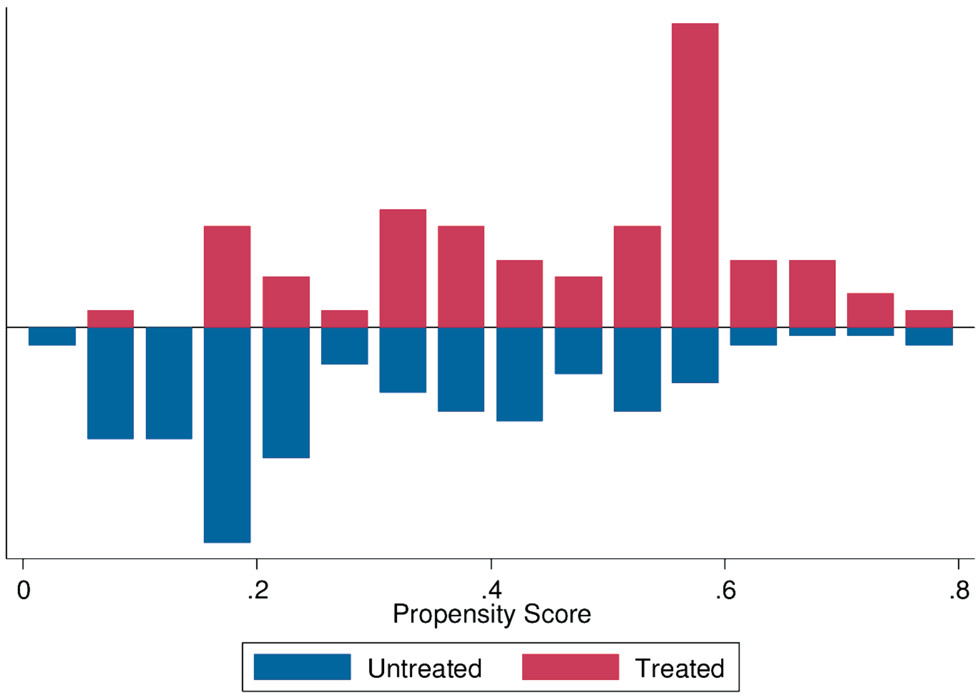
b) Propensity Score Graph None and 3



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 a primary survey carried out in Darjeeling District, West Bengal, India, in the year 2013.

Note: 1) The Propensity Graph shows the distribution of the propensity score for the winter crop. The propensity score has been estimated by using the 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 the post-matching two sample t-tests (the absolute p-value of mean difference) for both binary and multiple adoption cases. As evident from column 2 of Table 3, post-matching for the binary adoption case eliminates the differences for all socio-economic, market access 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 in the sub-sample.

Table 4 reports the results of the causal effect of adoption on various outcomes, which shows the total number of adopters to be 211 and non-adopters to be 221. We find that ATT is statistically significant for per acre profit (with an estimated impact of INR 1683 per acre) at the 10 percent level of significance and for per acre total revenue (with an estimated impact of INR 5,029 per acre) and per acre variable cost (with an estimated impact of INR 3,346 per acre) during the monsoon season at the 1 percent level of significance. During the winter season, on the other hand, the ATT is insignificant for all the outcome variables. The ATT of these outcomes are 28, 30 and 31 percent of the mean outcomes of matched non-adopters.

These results suggest that soil conservation measures lead to a significant increase in yield for adopters. 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. Hence, the positive and significant ATT of the 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).

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 adopters of 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						
Education of household head (years)	0.4	0.3	0.8	0.5	0.2	0.5
Household member between ages 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 (in meters)	0.7	0.9	0.95	0.8	0.6	0.6
Distance to all-weather road (in 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 (in meters)	0.5	0.08	0.96	0.4	0.9	0.9
Soil color	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 a primary survey carried out in the Darjeeling District, West Bengal, India, 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 color and soil stoniness have been reported by the respondent according to a hedonic scale.Scale of soil color: grey-1, reddish- 2, brown- 3, black- 4; Scale of soil stoniness: high stoniness- 1, medium stoniness- 2, low stoniness- 3, non-stony- 4.

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 INR)	Winter	225 (677)	0.33	2.5	219	202	NA
Per acre total revenue (in INR)		1335 (1022)	1.31	6.8	219	202	NA
Per acre total variable cost (in INR)		1110 (746)	1.49	10.5	219	202	NA
Per acre profit in INR)	Monsoon	1683* (982)	1.71	28	162	221	1..08
Per acre total revenue (in INR)		5029***(1397)	3.6	30	162	221	1.81
Per acre total variable cost (in INR)		3346***(1011)	3.3	31	162	221	1.87

Source: 1) Based on a primary survey carried out in the Darjeeling District, West Bengal, India, in the year 2013.
Notes: 1) Standard errorsin 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) = hidden bias, the estimator that captures the effect of unobservables on the adoption of soil conservation measures (Aakvik, 2001), 6) NA=> Not Applicable, 7) INR =>Indian Rupee

Measuring soil conservation into adoption and non-adoption preclude the estimation of the causal impact of different types of soil conservation measures on the same set of outcome variables. Hence, we turn to multiple adoption comparisons for a more nuanced analysis of the role of adoption, which means one sensitive to the fact that adoption consists of multiple soil conservation measures. As noted above, these compare the outcomes of those who adopt two measures versus those who adopt none; those who adopt three measures versus those who adopt none; those who adopt two measures versus those who adopt one; those who adopt three measure versus those who 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 comparisons of four soil conservation adoption groups for each outcome variable. Appendix Table 2 gives the estimation results of the Multinomial Logit. Tables 5 and 6 report the ATT for the outcome variables per acre profit, total revenue and variable cost for the winter and monsoon crops, respectively. These tables present the pair-wise comparison of outcome variables between two adoption groups. For instance, the fifth row of Tables 5 and 6 compares the differences in farm profit per acre between farms that adopted one soil conservation measure and farms that adopted two soil conservation measures. Similarly, the sixth 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 INR)	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 INR)	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 INR)	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 a primary survey carried out in Darjeeling District, West Bengal, India, 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 from stone bunding, afforestation and bamboo plantation;5) = hidden bias, the estimator that captures the effect of unobservables on adoption of soil conservation measures (Aakvik, 2001); 6) NA =>not applicable, 7) INR => Indian Rupee.

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 INR)	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 INR)	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 INR)	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 the primary survey carried out in Darjeeling District, West Bengal, India, 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 practicesstone bunding, afforestation and bamboo plantation;5) = hidden bias, the estimator that captures the effect of unobservables on adoption of soil conservation measure (Aakvik, 2001); 6) NA => Not Applicable, 7) INR => Indian Rupee.

In the winter season (Table 5), there appears to be no significant impact on per acre profits for all categories of comparison. However, an examination of revenues makes it 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 INR 4,560 higher revenue than those who do not adopt any measures (at the 5 percent level of significance) and INR 5,302 higher revenue than those who adopt only two measures (at the 1 percent level of significance). These ATTs are 24 and 30 percent, respectively, of the mean value of the non-adopter group. The ATT is significant, in the case of the per acre total variable cost, for the group-wise comparison between the no adoption measure and the three adoption measures, the one adoption measure and the three adoption measures, and the two adoption measures and the three adoption measures. The ATTs, as a percentage mean value of the non-adopters, are higher for the per acre variable costs as compared to revenues.

The number of farmers who have adopted the two soil conservation measures is 139. Since only 30 percent among them have adopted contour bunding, the soil conservation measures of this group largely consist of measures such as afforestation and bamboo plantation. In comparison, 72 farmers have adopted all the soil conservation measures listed although farmers in both groups reported that they had not invested in the maintenance of contour bunding in the last ten years. Though this could constitute evidence of the importance of certain types of soil conservation measures, there is no reason ex ante, as stated earlier, to associate the preference for certain types of conservation measures among farmers with the greater effectiveness of these measures.

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 as 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 (see Table 6). The estimated ATT for per acre profits is insignificant across all comparisons although that for total revenue is positive and significant when we compare those who adopt two measures against those who only adopt one, or those who adopt three measures against those who adopt only one or none. These differences are significant at the 1 percent and 10 percent levels, respectively. As in the case of the winter season, the ATTs as a percentage of the mean revenue of the non-adopter is lower than the mean variable cost of non-adopters. Therefore, these higher revenues do not translate into higher profits as the per acre variable costs for these groups are also higher by INR 3,657, INR 2,969 and INR 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 with higher costs attached. These findings extend those of the earlier analysis, according to which the adoption of two or more measures left no impact on profits but a positive impact on revenues in the monsoon season though not in the winter season. All the gains from 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 insights 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, and slope of the farm. 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 is termed the Rosenbaum Bounds in the literature. This involves a sensitivity analysis, assuming that differing levels of unobservable factors affect adoption, and examining if these change the inference regarding 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 adopting soil conservation measures be given by:

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

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 $\gamma = 0$ (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 and j is a non-adopter. Let us also assume that F follows the logistic distribution.

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

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).

exp (γ) = 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 (γ) = 2 implies that two farmers who look similar in terms of the probability of adoption differ by a factor of two in their odds ratio of adoption. The above-mentioned odds ratio must lie between $\left[\frac{1}{exp\ (\gamma)}, exp\ (\gamma)\right]$ (Aakvik, 2001). We vary the value of γ in the interval [1, 2], something commonly used in similar studies in the social sciences (Keele, 2010). The Rosenbaum Bound sensitivity analysis reports p-values from Wilcoxon signed-rank tests for the ATT.[16] 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 measures (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. The presence of hidden bias at 1.81 in Table 4 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 measures by 81 percent then the significant ATT on per acre variable cost may be questionable. 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 the winter season is also 1.87. Tables 5 and 6 report the critical value of γ (column 7). In some instances, like the group-wise comparison of ATT in Tables 5 and 6 on per acre variable costs, the fact that the hidden bias is equal to 2 or beyond suggests that the magnitude and significance of ATT in the multiple adoption case are less sensitive due to unobservables than in the binary adoption case. It suggests that for farmers (and farms) that are similar in observables, the causal interpretation of soil conservation on the concerned outcomes is still intact even if they differ in the odds ratio by 100 percent. The lower the critical value of γ, the higher the hidden bias though the converse is also true. Therefore, the impact of the adoption of multiple soil conservation measures on the per acre total variable cost is associated with a 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 the 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. On the basis of our maintained assumption that it is possible to capture the factors that influence the farmers' decision to adopt different types of soil conservation measures on their farms, we create a counterfactual comparison group using matching techniques. In addition to binary adoption, we also compare the number of measures adopted by each farmer in order to see if the number of measures adopted has an impact on per acre farm profits, revenues and costs. The results from the PSM methodology suggest no difference in the per acre profits in the winter and monsoon seasons. Although revenues from adoption are higher, they also come with higher variable costs, so that there is no difference in profits. Evidently, not all soil conservation measures are equally effective in providing significant gains in outcome. Our results show that the joint adoption of contour bunding, afforestation and bamboo plantation is more efficient and that at least two of these measures can lead to a significant gain in revenues (though also costs). The causal

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

impact of multiple soil conservation measures on per acre total revenue varies between INR 4560 and 5302 in the winter season and INR 3469 and 5115 in the monsoon season. The causal impact of the adoption of multiple soil conservation practices on the per acre variable cost came to between INR 3209 and 5345 during the winter season and INR 2969 and 3657 in the monsoon season. But the impact of the adoption of multiple soil conservation measures on per acre farm profits remained insignificant since increased revenues were accompanied by higher costs. The ATTs as a percentage of the mean value of the matched non-adopter is lower for per acre revenue (ranging between 25 and 31 percent in the winter season and between 21 and 30 percent in the monsoon season) as compared to costs (ranging between 32 and 63 percent in the winter season and 27 and 34 percent in the monsoon season). The likely explanation is that farmers who have adopted these measures are able to maintain their soil quality at the same level as non-adopters, which perhaps explains why there is no difference in profits between adopters and non-adopters. The Rosenbaum Bounds test suggests the presence of unobservable factors which 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 for farming in an ecologically fragile ecosystem like the Himalayas. Most adoption measures, apart from providing environmental benefits, help to diversify farmer income. Of these, contour bunding is the most expensive and only 30 percent of the farmers in our sample adopted contour bunding while over 75 percent of such adopters in our sample reported not spending on maintenance of contour bunds in the last 10 years given the high expenses associated with it. It is therefore important to facilitate farmers' access to credit. Though afforestation is also effective, with a number of off-site and on-site environmental benefits, it takes a major portion of land out of farm production for years, thus incurring a huge opportunity cost for the farmer. Alternative incentive mechanisms to encourage afforestation, such as the incentive design—for example, a contract between farmers and government (or a private agency)—to sequester carbon through afforestation would address this issue, particularly, if such contracts carry a monetary incentive which would encourage farmers to participate. Immediate benefits of such adoption are financial stability to the farmer, sustainable farm practices, and the mitigation of Green House Gas emissions through carbon sequestration (Antle and Diagana, 2003).

This study is not without limitations. One major limitation is that the study is based on a partial equilibrium analysis of adoption decisions of farmers and has considered impacts only at the farm level. However, as noted above, the impacts of such action both by the government and the individual farmer are bound to extend beyond the river basin carrying general equilibrium implications for the supply of farm products and prices in the local economy. An analysis of these effects is merited in future work.

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Appendix

Table 1: Estimates of factors influencing adoption of soil conservation measures (binary adoption)

VARIABLES	Model 1 (Probit Model)	Model 2 (Logit Model)	Model 3 (Logit Model)
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 who have at least 10 years of schooling (%)	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 color$$	0.15** (0.075)	0.24* (0.127)	0.224* (0.124)
Soil stoniness$$$	-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	432	432	432

Sources: 1) Based on a primary survey carried out in Darjeeling District, West Bengal, India, 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 color 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 color: grey- 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, the Sediment Yield Index is 1450 and above. The "Sediment Yield Index" is calculated as the "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, the Forest Department of West Bengal has taken soil conservation measures.

Table 2: Multinomial logit estimates of factors influencing the adoption of soil conservation measures (multiple adoption)

Variables	1 Adoption measure	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 ages 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 color$$	-0.053 (0.162)	0.016 (0.16)	0.77***(0.21)
Soil stoniness$$$	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	432		

Sources: 1) Based on a primary survey carried out in Darjeeling District, West Bengal, India, 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 color and soil stoniness have been reported by the respondent according to a hedonic scale.Scale of soil color: grey- 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, the Sediment Yield Index is 1450 and above. The "Sediment Yield Index" is calculated as the "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, the Forest Department of West Bengal has taken the soil conservation measures.

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