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Abstract

Plastic pond has attracted huge attention as water harvesting technology, since it is reported to be cost-effective and adoptable in various geographical settings such as sloping land. Therefore, it is expected to contribute to poverty reduction for smallholder farmers. Despite its importance, there has been no research on the issue, and thus this paper identifies the impact of plastic-pond technology on agriculture. We focus on vegetable farming for which adoption of plastic ponds gains some popularity and implemented questionnaire surveys of 1,001 farmers in Nepal. With the data, endogenous switching regression is applied by taking vegetable income and adoption of plastic ponds as dependent variables in regime and selection equations, respectively, because it enables to take into account endogeneity in technology adoption and to measure the impact via counterfactual experiments. The selection equation shows that adoption of plastic ponds is enhanced by credit access, investment, improved seeds, education and agricultural training. The regime equations find that vegetable incomes for nonadopters are affected by several factors such as age, education, livestock, land value, credit access, investment and improved seeds, while the only two determinants of livestock value and credit access are important for vegetable incomes of adopters. This implies that plastic ponds fundamentally change the structure of vegetable farming. The counterfactual experiment demonstrates that vegetable income of nonadopters would increase by 33% if nonadopters adopt plastic ponds, which is significant to improve food security and welfare of farmers. Overall, the plastic pond shall be a promising technology in not only Nepal and but also many other developing nations.

Key Words: Counterfactual experiment; plastic-pond technology; endogenous switching regression; vegetable farming in Nepal

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Contents

Nomenclature

ASC Agriculture Service Center

ATT Average Treatment on Treated

ATU Average Treatment on Untreated

DADO District Agriculture Development Office

FIML Full Information Maximum Likelihood

NPR Nepalese Rupee

VDC Village Development Committee

WDR Western Development Region

1 Introduction

The largest share of the GDP (34%) comes from agriculture in Nepal, and vegetables occupy one third of the agricultural GDP (FAO representation in Nepal, 2011, Government of Nepal, 2013). There has been a significant rise in per capita availability of vegetables from $66.7kg$ to $86.4kg$ during the periods between February 2001 and September 2008, since food habits of Nepalese people change with rapid urbanization in the way that vegetables are highly demanded (FAO representation in Nepal, 2011). Vegetables cannot be grown in the areas located at the low altitudes of Nepal and in neighboring Indian states. Given these circumstances, vegetable crops are reported to provide about 10 times higher income per unit of land than cereals and other crops especially in rainy and autumn seasons (Shrestha et al., 2007). Vegetable farming offers a comparative advantage to smallholder farmers who are under poverty and deprived of other income generation activities, and thus becomes a crucial production activity for poverty reduction in Nepal (Shrestha et al., 2007).

Vegetable farming in Nepal has been rainfed and 80% of total annual rainfall is concentrated during summer seasons (June to September). Therefore, it is important whether or not each smallholder farmer has water harvesting technology. If farmers are equipped with water harvesting technology, they can cultivate land and reap vegetable crops during spring and winter seasons. The vegetable production and income are expected to increase with water harvesting technology compared with rainfed farming (Raut et al., 2011). However, conventional water harvesting technologies are not applicable to the area whose slope is more than 10 degree, implying that many farmers in Nepal cannot adopt the conventional technologies and suffer from water scarcity (Brown and Kennedy, 2005). Under such biophysical difficulties, a plastic pond has recently attracted huge attention as a possible promising technology, since it is adoptable in various geographical settings such as sloping land. Thus, this paper estimates the impact of plastic ponds on vegetable farming.

Water scarcity has posed a serious concern on agriculture in not only Nepal but also many places of the world. Importance of water conservation and micro-irrigation technologies has been addressed. Recent empirical research mostly focuses on some type of deficit, drip, and sprinkler technologies, however, these works are restricted to explore farmers' behaviors for adoption of these technologies (Li et al., 2000, Namara et al., 2007, Baguma and Loiskandl, 2010, Alcon et al., 2011, 2014). On the other hand, there is another group of studies that jointly examine the adoption of technologies and their production or farm incomes within a single empirical framework (see, e.g., Fuglie and Bosch, 1995, Asfaw et al., 2012, Noltze et al., 2013, Di Falco and Veronesi, 2013). These works differ from the previous group of researches in that an endogeneity problem (self-selection problem) that arises in simultaneous decisions for technology selection and other activities of productions at each farmer's level is addressed by applying an endogenous switching model. These works evaluate the impact of adoption for different agricultural technologies (practices) on crop production (agricultural yield and farmers' incomes), whereas none of them focus on water harvesting technologies.

In the context of Nepal, there are some researches to identify the factors influencing drip irrigation adoption on vegetable farming, suggesting some positive impact of the technology for smallholder farmers (Upadhyay, 2004, Upadhyay et al., 2005). However, these works neither quantify how much the technology adoption gives impacts on agriculture compared to nonadoption, nor consider selection biases. It is reported that traditional maize-based farming system could be replaced by vegetable farming system, and around 40% of steep sloping land (Bari) can potentially be covered with vegetables in Nepal (Tiwari et al., 2010). In this trend, vegetable crops become more important than ever and are expected to increase farm gross margins indicating that vegetable crops may help alleviate rural poverty if they are well integrated in Nepalese smallholder farming (Brown and Kennedy, 2005). The plastic pond is now considered a good candidate of the technologies to improve vegetable farming in Nepal due to its cost and convenience.

Having said that plastic pond technology is cost-effective for smallholder farmers and can locally be constructed even in sloping land, yet its impact on vegetable farming has not been identified. Here, we contribute to the existing literature on the impact of plastic ponds by taking a concrete example from Nepal in two ways. First, it provides an empirical study on adoption of plastic-pond technology and its impact on smallholder vegetable farming by utilizing the 1,001 household-level data. Second, we estimate and compare the actual and counterfactual vegetable incomes for both adopters and nonadopters of the plastic-pond technology via counterfactual experiments.[1] Some researches on technology selection and agricultural production fail to represent the true impact due to the endogeneity (self-selection bias). This issue is addressed by utilizing an endogenous switching regression model and the associated counterfactual experiments in our research. With this approach, we aim to find the effect of plastic-pond technology on vegetable farming and to examine whether the technology can contribute to poverty reduction and the welfare of smallholder farmers in Nepal. More specifically, we answer the following questions:

1. What are the socioeconomic and agro-ecological characteristics affecting the adoption of plastic-pond technology in Nepal?

2. Does adoption of plastic ponds affect the determinants of vegetable farming?

3. What is the impact of plastic-pond technology on vegetable incomes of nonadopters (adopters) if nonadopters (adopters) adopt (do not adopt) it?

The results show that adoption of plastic ponds is enhanced by credit access, investment, improved seeds, education and agricultural training. We also find that vegetable incomes for non-adopters are

[1]Actual vegetable incomes here are observed incomes from adopters and nonadopters. Counterfactual vegetable incomes are incomes inferred from an endogenous switching regression model when adopters do not adopt the technology or when non-adopters adopt the technology. Comparing actual values with counterfactual ones, we can quantify the impact of the plastic-pond technology on the income when adopters (nonadopters) do not adopt (adopt) the technology. The procedure for the comparison between actual and counterfactual incomes is what we call "counterfactual experiments" and we compute their percent change of the two. This procedure shall be detailed later.

affected by several factors such as age, education, livestock, land value, credit access, investment and improved seeds, while the only two determinants of livestock value and credit access are important for vegetable incomes of adopters. This implies that plastic ponds fundamentally change the structure of vegetable farming. The counterfactual experiment demonstrates that vegetable incomes of nonadopters would increase by 33% if the nonadopters adopt plastic ponds, which is significant to improve food security and welfare of Nepalese smallholder farmers.

2 Plastic ponds and study area

2.1 Plastic ponds

Plastic-pond technology is commonly adopted in mid-hill agroecology of Nepal, where conventional irrigation is difficult to be arranged in steep slopes (FAO, 2011, Sugden et al., 2014, WOCAT, 2008b). Plastic ponds contrast from the traditional-earthen ponds in that they protect seepage and infiltration of stored water using high density polyethylene sheet called silpaulin which is water, rot and weather proof and lined with dog-out earthen ponds (WOCAT, 2008b). With this technology, vegetable crops are irrigated commonly with polythene pipes, bucket, sprinkler and drip kits. Such water harvesting technology is being successfully implemented as an alternative for conventional irrigation technology in some similar biophysical settings of India and Ethiopia (Samuel and Satapathy, 2008, Yosef and Asmamaw, 2015).

The plastic pond is low-cost and a simple technology that farmers can easily adopt for the production of on-season and off-season vegetables in sloping land of Nepal, compared with concrete ponds and other micro-irrigation technologies (Sugden et al., 2014). For instance, drip technology, which is argued as low-cost irrigation technology, has some drawbacks in rural farming households. First, they are not suitable for sloping land, and drip kits are reported to have problems such as clogging of drip-pipe holes and not readily available in local markets (WOCAT, 2008a). Most importantly, constant maintenance of water harvesting facilities associated with such drip, sprinkler and other micro-irrigation technologies is essential for the continuous water supply, and organizing such facilities in a timely manner becomes too complex for farmers with limited education (Kalu, 2003, Upadhyay et al., 2005, WOCAT, 2008a).

We have collected the information about plastic ponds through our survey. The average initial fixed cost for establishing a plastic pond of 60,000 liters is 14,571 Nepalese rupee (hereafter, NPR, it is approximately equivalent to 148 US dollars) with a life span of more than 8 years (See table 1 and figures 1, 2(a) and 2(b)). It stores water ranging from 8,000 to 100,000 liters, although a 60,000-liter plastic pond is the most common one. The maintenance cost is expected to reduce further in the next span of more than 8 years, since only the replacement for the broken parts of silpaulin plastic is needed.

[Table 1 about here.]

[Figure 1 about here.]

[Figure 2 about here.]

As mentioned earlier, 80% of the mean annual rainfall is concentrated during the monsoon (June to September) in Nepal, while the rest is experienced during the pre-monsoon (March to May) and winter seasons (October to February) (Shrestha, 2000). Therefore, households experience long water shortage and farming is exacerbated by frequent long dry spell and erratic rainfall. Thus, plastic-pond technology is expected to efficiently supply water for the crops and it permits smallholder farmers to grow both seasonal and off-seasonal vegetables, particularly, cauliflowers, cabbages, tomatoes and so on. Earthen ponds are indigenous technologies for the mid-hill regions of Nepal and they can be renovated in the form of plastic-pond technology as local adaptation strategies to smallholder farmers (FAO, 2011).

2.2 Study area

Nepal is divided into three ecological belts running from east to west, the plain land (tarai) in the south nearby to India, the mid-hills in the center and the high-hills in the North along with the boarder of China. The mid-hill ecology consists of 42% of total geographical area in Nepal and ranges from $800m$ to $1800m$ steeply sloping land. The cropping pattern, topography and land management of all the regions of mid-hill ecology demonstrate similar characteristics. Moreover, the mid-hill ecological zones of the western development region (WDR) are chosen as our study site (see figure 1), because the WDR has high percentage of rural households engaged in agriculture of 84.2% (Field coordination office, UN, 2011).

In our research site, two types of arable land are owned by the farming households. The Khet is highly productive fertile flat land and used for the rice cultivation (Oriza sativa). The other type of land is Bari, less fertile and steeper land, with low water-holding capacity. Maize-based cropping system is a predominant farming system in the Bari land in which farmers rely on millets, cowpea and other leguminous crops for agricultural production. Average farm size is $0.70ha$ per household in the study site. Only 40% of the agricultural land is irrigated, but are predominately rainfed with rivers and streams so that water supply is highly dependent on summer monsoon. The mean annual rainfall for overall Nepal is $1767.5mm$ and this region receives less rainfall as compared with eastern and central regions (Shrestha, 2000). Thus, erratic rainfall during monsoon and long dry spells directly exacerbate the livelihood of the people in this region.

In our study field, traditional cereals-based farming systems are still popular and characterized by high population density, poor soil, low rainfall and remote location. However, to overcome difficulties in tackling with poverty and to meet family expenses, cash crop production has been growing rapidly in mid-hills of Nepal. As the Bari land (steep land) is not suitable for rice cultivation, farmers are attracted to vegetable farming such as off-season tomatoes, cucumbers, hot chilies, radish, early cauliflowers and cabbages. Thus, dry-season irrigation permits farmers to grow both on-season and off-season vegetables throughout a year and this is possible through storing runoff water during monsoon using plastic-pond technology. It reduces the vulnerability of vegetable farmers by overcoming seasonal fluctuations of streams on which the conventional vegetable farming relies upon. As cereals are mostly used for household consumption and animal feed, vegetable is expected to be a strong source of incomes in this region.

"Ward" is the smallest administrative unit and typically 9 wards constitute the Village Development Committee (VDC). However, development and administrative-related offices are located in the district headquarter. Most of the VDC offices in this region can only be accessed by gravel roads. The District Agriculture Development Office (DADO) and agricultural service centers (ASC) under DADO provide agricultural training service. Although the DADOs seek to adopt group approach to deliver agricultural training service to farmers, many farmers still have no access to the service due to the geographical difficulties, limited governmental budgets and staffing.

Private agrovets are the major input providers and they supply improved/hybrid seeds, pesticides, fertilizers and services to farmers.[2] However, farmyard manure still constitutes the major share of total nutrient supply. Due to undulating topography, animals cannot help but being major sources of farm energy. Regarding to credit, cooperative and farmer-group issued loan, yet the issued loan is not adequate for lucrative investments. Overall, this region is characterized by smallholder farmers with low use of external inputs such as chemical fertilizers, and contribution of women still plays a significant role in agriculture.

3 Data and methodology

3.1 Survey design

This study relies on the household level cross-sectional data surveyed from July to September of 2014 on the WDR of Nepal. The rationale behind choosing the WDR as our major research site is that it is a predominately agricultural region of Nepal where 84.2% of people are farmers (Field coordination office, UN, 2011). The cropping pattern, topography and land management in all the regions of mid-hill ecology demonstrate similar characteristics. Our research site consists of 11 districts in mid-hill ecological zones of the WDR (figure 1). The DADO is the pioneer for dissemination of plastic-pond technology and each district office provided a farmers' list for random sampling.

[2] Agrovets are agricultural local shops that can be seen in many rural parts of Nepal. They sell necessary equipment, inputs and others for agricultural production.

Initially, pretesting was conducted to evaluate the validity of our questionnaire. Focus-group discussions, interaction with local farmers, extension workers and input suppliers were carried out, providing important information to refine our questionnaire to the final form. Based on the farmers' list provided by respective DADOs, a stratified random sampling technique was used to select both adopters and nonadopters of plastic ponds from each district. A total number of 1,071 samples that include 357 adopters and 714 nonadopters were randomly selected and interviewed. Due to missing values, 1,001 samples were finally used for our analysis that comprises 357 adopters and 644 nonadopters.

Our questionnaire was framed to collect information on socioeconomic and agro-ecological characteristics of adopters and nonadopters of plastic-pond technology. The questionnaire was divided into 10 sections which include farm household characteristics, farming activities, costs and other relevant questions regarding plastic ponds, crops and agriculture income, land tenure, other household income sources and assets. On average, 30 to 45 minutes long interview was conducted in each farming household. The first author administered this survey and 20 local experienced interviewers were deployed.

3.2 Methodology

We use total vegetable income as a final measure for the impact of plastic-pond technology on vegetable farming. In small-scale farming in Nepal, vegetable production is diversified to consider nutritional status (food security), or farmers' production decision is made to maximize their agricultural income rather than to maximize their production volume or yield. Therefore, each farmer even in the same region raises a different array of crops and vegetables depending on the socio-economic, agro-ecological and geographical characteristics. In this case, agricultural production or yield for vegetables cannot be a uniform basis for comparison of vegetable-farming performance.

For instance, the farmer's earning or nutritional contribution from tomatoes are higher than those of cabbages, cauliflowers and other vegetable crops, whereas yield of cabbages and cauliflowers may be higher than that of tomatoes. In this case, farmers are likely to choose growing tomatoes, irrespective of their yield or production volume. This illustrates that using agricultural yield or production volume from a single crop or an array of different vegetable crops does not represent the impact of plastic ponds on the welfare of farmers. This motivates us to evaluate the impact of plastic-pond technology using vegetable incomes.

In the case of Nepal, the decisions for vegetable farming and plastic-pond adoptions are jointly made. Some unobservable characteristics, say skill, innovation, and attitude in farming households may affect not only adoption of agricultural technology but also farming decisions, leading to endogeneity and self-selection problems in the model (see, e.g., Di Falco and Veronesi, 2013). Therefore, if we do not take account of the endogeneity that arises in vegetable farming and adoption of plastic-pond technology, the true impact on vegetable farming cannot be estimated. Therefore, we use endogenous switching regression that enables to jointly consider the adoption of plastic-pond technology and vegetable farming within a single framework. It further allows us to implement counterfactual experiments for answering what the impact of plastic ponds is, if nonadopters adopt plastic-pond technology or if adopters do not adopt it.

An endogenous switching regression model follows two steps. In the first step, it models the decision of whether or not farmers adopt the technology, and in the second step, it models the outcome of vegetable farming depending on farmers are adopters or nonadopters. More specifically, in the first step, the farmers are assumed to decide whether to adopt plastic-pond technology based on the expected outcome measure for vegetable farming. The farmer adopts the technology if the expected outcome of adopting plastic-pond technology is greater than that of nonadoption. Let expected outcomes household i obtained by adopting and non-adopting plastic-pond technology be $I^*_{i,PPA}$ and $I^*_{i,PPN}$, respectively. Farmers are assumed to adopt plastic-pond technology if $I^*_{PPA} > I^*_{PPN}$. Note that $I^*_{ij}, j = \{PPA, PPN\}$ are not observable, while whether each farmer adopts or not is observable.

The first-step equation is called "selection equation" and estimated using probit regression as follows:

$$\begin{aligned} & I^*_{ij} = \mathbf{Z}_i \boldsymbol{\alpha} + \eta_i, \quad j = \{PPN, PPA\} \\ & I = 1 \text{ if } I^*_{i,PPA} > I^*_{i,PPN} \\ & I = 0 \text{ otherwise.} \end{aligned} \tag{1}$$

where I^*_{ij} is a latent variable that captures expected outcomes from adoption decisions by household i, vector $\mathbf{Z}_i$ represents variables that affect adoption decisions such as socio-economic and agro-ecological characteristics for household i, $\boldsymbol{\alpha}$ is a vector of parameters to be estimated, and η_i is a random error term with mean zero and variance σ^2_η.

In the second step, we evaluate the determinants of vegetable income depending on whether farmers are adopters or nonadopters of plastic ponds. These second-step equations are called "regime equations," and the estimation can be made with the following specification: For plastic-pond nonadopters, the estimation is specified as

$$\text{Regime equation 1 for plastic-pond nonadopters}: \ Y_{i,PPN} = \mathbf{X}_{iN} \boldsymbol{\beta}_{PPN} + \epsilon_{iN} \tag{2}$$

For adopters, it is specified as

$$\text{Regime equation 2 for plastic-pond adopters}: \ Y_{i,PPA} = \mathbf{X}_{iA} \boldsymbol{\beta}_{PPA} + \epsilon_{iA}. \tag{3}$$

where $Y_{i,PPN}$ and $Y_{i,PPA}$ are the vegetable incomes for nonadopter i and adopter i of plastic-pond technology, $\mathbf{X}_{iN}$ and $\mathbf{X}_{iA}$ are a set of the independent variables for equations (2) and (3), $\boldsymbol{\beta}_{PPN}$ and $\boldsymbol{\beta}_{PPA}$ are the parameters to be estimated for nonadopters and adopters, and ϵ_{iN} and ϵ_{iA} are random error terms with variances of σ_N^2 and σ_A^2, respectively.

The variables included in $\mathbf{X}_{iN}$ and $\mathbf{X}_{iA}$ should be contained in $\mathbf{Z}_i$ in equation (1), implying that $\mathbf{Z}_i$ must have at least one more variable that is not included in equations (2) and (3). Access to agricultural training and distance from the agriculture service center are additional instrumental variables in $\mathbf{Z}_i$. The η_i, ϵ_{iN} and ϵ_{iA} are error terms of selection and regime equations, respectively and are assumed to have a trivariate normal distribution with zero mean vectors and the following covariance matrix:

$$\mathrm{Cov}(\eta_i, \epsilon_{iN}, \epsilon_{iA}) = \begin{bmatrix} \sigma_\eta^2 & \sigma_{\eta N} & \sigma_{\eta A} \\ \sigma_{\eta N} & \sigma_N^2 & \sigma_{NA} \\ \sigma_{\eta A} & \sigma_{NA} & \sigma_A^2 \end{bmatrix}. \tag{4}$$

where σ_η^2 is assumed to be unity. $\sigma_{\eta N}$ is the covariance of η_i and ϵ_{iN}. $\sigma_{\eta A}$ is the covariance of η_i and ϵ_{iA}. σ_{NA} is the covariance of ϵ_{iN} and ϵ_{iA}. However, σ_{NA} is not defined as the outcome variable for a given household and is not observed at a given time as described in Maddala (1983).

The unobservable characteristics of farm households that determine the choice of plastic-pond technology also affect the vegetable income of the households in each regime. Therefore, full information maximum livelihood (FIML) estimation is applied to simultaneously measure selection and regime equations using the endogenous switching regression model that takes account of sample self-selection problems. A series of these estimations for parameters $\boldsymbol{\alpha}, \boldsymbol{\beta}_{PPN}$ and $\boldsymbol{\beta}_{PPA}$ in equations (1) to (3) is executed in STATA using the "move-stay" command developed by Lokshin and Sajaia (2004).

Based on the estimates of $\boldsymbol{\beta}_{PPN}$ and $\boldsymbol{\beta}_{PPA}$, we calculate both conditional and unconditional expectation of vegetable incomes for both adopters and nonadopters of the technology. In this type of research, we cannot observe vegetable incomes in counterfactual situations, i.e., (i) when plastic-pond adopters do not adopt the technology and (ii) when nonadopters adopt the technology. Therefore, we estimate their counterfactual value via estimated $\boldsymbol{\beta}_{PPN}$ and $\boldsymbol{\beta}_{PPA}$ by considering plastic-pond adoption as a treatment. To calculate average treatment on treated (hereafter, ATT), we need to differentiate the actual vegetable income (observed) and its counterfactual for adopters. Similarly, average treatment on untreated (hereafter, ATU) is calculated as the difference between the actual (observed) and counterfactual incomes for nonadopters. For the calculation of ATT and ATU, our research basically follows the procedures taken by Di Falco and Veronesi (2013) that compares the performance of climate change adaptation strategies in Ethiopian agriculture via calculating ATT and ATU.

Expected vegetable income of adopters (observed) with plastic-pond adoption is

$$\mathbb{E}(Y_{i,PPA}|I = 1) = \mathbf{X}_{iA}\boldsymbol{\beta}_{PPA} + \sigma_{\eta A}\lambda_{PPA}. \tag{5}$$

Expected vegetable income of adopters without plastic-pond adoption (counterfactual) is

$$\mathbb{E}(Y_{i,PPN}|I=1) = \mathbf{X}_{iN}\boldsymbol{\beta}_{PPN} + \sigma_{\eta N}\lambda_{PPA}. \tag{6}$$

Expected vegetable income of nonadopters without plastic-pond adoption (observed) is

$$\mathbb{E}(Y_{i,PPN}|I=0) = \mathbf{X}_{iN}\boldsymbol{\beta}_{PPN} + \sigma_{\eta N}\lambda_{PPN}. \tag{7}$$

Expected vegetable income of nonadopters with plastic-pond adoption (counterfactual) is

$$\mathbb{E}(Y_{i,PPA}|I=0) = \mathbf{X}_{iA}\boldsymbol{\beta}_{PPA} + \sigma_{\eta A}\lambda_{PPN}, \tag{8}$$

where $\lambda_k, k = \{PPA, PPN\}$ are inverse Mills ratios of the two regime equations, respectively.

Using equations (5) and (6) yields ATT as follows:

$$\text{ATT} = \mathbb{E}(Y_{i,PPA}|I=1) - \mathbb{E}(Y_{i,PPN}|I=1). \tag{9}$$

Likewise, using equations (7) and (8) yields ATU as follows:

$$\text{ATU} = \mathbb{E}(Y_{i,PPA}|I=0) - \mathbb{E}(Y_{i,PPN}|I=0). \tag{10}$$

Computation of equations (9) and (10) follows the procedures introduced by Lokshin and Sajaia (2004) and gives us further insight on the impact of plastic-pond technology when nonadopters adopt the technology or when adopters do not adopt the technology.

4 Results

4.1 Sample descriptive statistics

Table 2 presents the definitions of each variable in the model. Tables 3 and 4 show summary statistics of the variables and the income components for households, respectively, by dividing the total samples of $N = 1,001$ into adopters and non-adopters. As you can see from table 3, vegetable incomes significantly differ between adopters and nonadopters. Also, agriculture and remittance are the two key potential income-generating components for Nepalese rural households (table 4). Another important point is that vegetable income occupies 60% of crop incomes for total household samples, indicating that vegetable is an important cash crop in Nepal (table 4). Overall, agricultural income appears to be dominant and a key source of household income. Vegetable income is a main part of income for plastic-pond adopters, while remittance is a main part of income for nonadopters. From these tables, it can be hypothesized that plastic ponds affect how households earn vegetable incomes through their adoption decision.

[Table 2 about here.]

[Table 3 about here.]

[Table 4 about here.]

4.2 Regression results

We first focus on the adoption of plastic ponds in the selection equation (1). Second, we explain the factors affecting the vegetable income estimated by equations (2) and (3), depending on whether farmers are adopters and non-adopters. Finally, we present the results of counterfactual experiments to illustrate the effectiveness of plastic ponds on raising vegetable income.

4.2.1 Determinants of technology adoption in the selection equation

The estimation result of equation (1) is summarized in the second column of table 5. Recall that this result is derived from running probit regression within endogenous switching regressions for a dichotomous choice of plastic-pond adoption. In this study, two instrumental variables are administered: access to agricultural training and distance from the household to the agriculture service center.[3] This allows us to answer the first research question: "What are the socioeconomic and agro-ecological characteristics affecting the adoption of plastic-pond technology in Nepal?" Overall, the results follow our expectation in the context of Nepalese farming system.

[Table 5 about here.]

The education of household heads, credit access, credit investment in agriculture, improved seeds and agricultural training are the statistically significant variables with positive sign. These variables induce farming households to adopt plastic-pond technology. An exception is the variable of "other irrigation" which is statistically significant and negatively affects the likelihood of plastic-pond adoption. If farmers have already had some other irrigation facilities, they do not have incentives to adopt

[3] We refer to agricultural training as governmental services through DADOs that are circulated to farmers in the forms of mass media such as radio, brochure, leaflets, farmer groups and field visits made by the junior agricultural technicians. Unfortunately, the agricultural-training coverage of Nepal still remains low due to the geographical difficulties, limited governmental budgets and staffing. More specifically, villages and farmers for agricultural training are chosen in a random manner by convenience of governmental offices. Therefore, access to agricultural training can be considered "exogenous." We consider access to agricultural training as appropriate for instrumental variables because it can be hypothesized to directly affect the decision of plastic-pond adoption, but it does not directly affect the vegetable income. It affect vegetable incomes only through plastic-pond adoption. To check the econometric validity of "access to agricultural training" and "distance to ASC" as instrumental variables in endogenous switching regressions, we have run the Hausman tests and Hansen J tests. We fail to reject the null hypotheses, implying that the validity of these instrumental variables is confirmed.

plastic ponds. In what follows, we interpret the results of statistically significant variables with positive sign one by one.

First, we report the results in relation to the "education" in determining the plastic-pond adoption. Our results basically pinpoint the roles of education of household heads to affect adoption of this technology. In the patriarchal society of Nepal, fathers (male counterparts) or household heads dominate the adoption-decision process in most households. Thus, their education level positively affects the decision to adopt plastic ponds for betterment of their livelihood. It appears that educated farmers better understand the importance of plastic ponds and we identify some spillover effects of education to other less educated or illiterate farmers, although these effects are too difficult to be quantified in the survey.

In the rural agrarian scenario of Nepal, many people are illiterate and less educated. In this case, the non-formal education "agricultural training" is the essential part of agricultural development. Our result clearly suggests the importance of agricultural training for smallholder farmers to adopt plastic ponds. As mentioned earlier, DADOs and ASCs are the organizations that deliver agricultural training services to farming communities. Unfortunately, however, the agricultural-training coverage of Nepal still remains low due to the geographical difficulties, limited governmental budgets and staffing. Therefore, many farmers do not have access to agricultural training, and expansion of agricultural training should be considered an important future policy.

Improved seed is usually considered one of the most immediate and direct inputs to increase crop yields in general. In Nepalese agriculture, farmers that use improved seeds are usually more innovative and progressive in the given communities. Therefore, they are more likely to select the plastic-pond technology. We also find the credit access and credit investment in the agriculture as key driving forces for technology adoption. For instance, Shakya and Flinn (1985) find credit availability and the associated investment as the key factors for adoption of production practices and technologies in eastern Nepal. The finding is consistent with our results.

4.2.2 Determinants of vegetable income in the regime equations

The third and fourth columns of table 5 represent the vegetable income functions for nonadopters and adopters, respectively, and the analysis in the regime equations answer "does adoption of plastic ponds affect the determinants of vegetable farming?" As you can see from the two columns, the results are different from each other. Note that the dependent variable is the logarithm of vegetable incomes for smallholder farmers represented by NPR to express the impact by percentage.

The most notable result is about the credit access. Farmers with credit access can have higher vegetable incomes by 42% for nonadopters and by 70% for adopters, compared to farmers without credit access. This suggests that credit helps an increase in vegetable income through easing financial constraints to procure external inputs for vegetable farming in Nepal. For instance, many adopters may want to rely on credits for the purchase of additional silpaulin plastic or some other external inputs such as chemical fertilizers. Such cash transfers to procure new external inputs can potentially improve the welfare of smallholder farmers. Unfortunately, however, credit flow in Nepal still entails lengthy and time-consuming procedures. Cash crops such as vegetables now attract attention as an extra income generating activity. However, raising such cash crops is capital-intensive, compared with traditional cereal farming. In this sense, credit availability in agriculture is a necessary step to increase agricultural incomes. Our results clearly illustrate that point and suggests a necessity of improving credit flow systems for smallholder farmers in Nepal.

Age and education of household heads are identified to have significant effects on nonadopters, while such effects are not found for adopters. Age of nonadopters affects vegetable incomes in a single-peaked way, while education positively affects the incomes. Agricultural productions in Nepal are mostly labor-intensive especially when no capital inputs such as irrigation facilities are utilized. In this sense, age and education can affect vegetable income in a significant way. On the other hand, adopters do not have such effects, illustrating the fact that adoption of plastic ponds stabilizes water supply for vegetable farming so that farmers may be released from labor-intensive works.

Surprisingly, improved/hybrid seeds show a similar fashion with education indicating its significant effect only to nonadopters. Improved seeds have a pronounced positive effect on vegetable incomes by 51.7% only for nonadopters. This may be due to the fact that plastic-pond adoption works very efficiently in the way that whether farmers use improved seeds or not does not matter in vegetable farming for adopters. This appears to illustrate that stable water supply throughout a year including on- and off-seasons via the plastic-pond adoption is a key for the success of the Nepalese vegetable farming.

Total cultivated land is significant and positive at 10% level for nonadopters, but it is negative and insignificant for adopters. Such a difference may arise due to the fact that vegetable farming does not require huge land and can be considered capital-intensive in Nepal once irrigation technologies are equipped. In other words, it is very difficult for Nepalese farmers to raise vegetables without irrigation facilities in a productive manner due to geographical and technological reasons. Therefore, total cultivated land could be significant, but comes with economic insignificance of small positive impact 1.4% for nonadopters. In contrast, adopters of plastic ponds can supply water to vegetable crops, implying that total cultivated land becomes insignificant.

Land value in Nepal is determined by slope, fertility, altitude and proximity to the road, market and other factors. Since we control slope and fertility of land in the regression, land value can be considered to represent a change of altitude, proximity to the road or market and others. Land value is found to have a significant negative effect on vegetable income for nonadopters. With a 1% increase in land value, there is a 5% decrease in vegetable incomes, holding the slope and fertility status of land fixed. This appears to suggest that farmers are less attracted to vegetable farming when they have lucrative real estates or land. Recently, there is an increasing trend of agricultural land especially that is in proximity to the road and nearby markets being transformed into real estate. Our result may be considered to be consistent with this event.

The total livestock asset is significantly positive for nonadopters, but significantly negative for adopters. A 1% increase in livestock value raises the vegetable income by 5.6% for nonadopters, whereas a 1% increase in livestock value would decrease the vegetable income by 4.9% for adopters. This heterogeneous effect of livestock value may be due to difference of farming types between nonadopters and adopters. In most cases, nonadopters practice diversified farming in the way that they try to grow a variety of crops and livestock in a single growing season to avoid the risk of food production and self-consumption. On the other hand, adopters practice more intensified farming focusing on vegetables as cash crops. For diversified farming of nonadopters, their vegetable farming basically follows traditional practices utilizing animals and farmyard manure of livestock, and thus livestock value can positively affect vegetable farming. In contrast, adopters concentrate more on vegetable farming as cash-generating production. Therefore, a trade-off in the allocation of various inputs between vegetable and livestock farming may exist. In this case, these two production activities can be substitutability each other.

Overall, we find that adoption of plastic ponds fundamentally affects the determinants of vegetable farming in Nepal. For nonadopters, there are many factors that affect vegetable incomes with statistical significance, while there are only two significant factors for adopters. Considering a real situation of vegetable farming, it is consistent with our hands-on experience in the field and our intuition. Most farming is rain-fed in Nepal, and in order for farmers to be productive in vegetable farming, it is essential to have water harvesting technologies as a first priority. Once plastic ponds are adopted, many factors that were important for nonadopters could be insignificant, demonstrating how vegetable farming is affected by the existence of plastic ponds.

4.3 Counterfactual analysis and treatment effects

Table 6 presents the results of counterfactual analysis using the estimates from endogenous switching regression to calculate the actual (observed) and counterfactual vegetable incomes for both adopters and nonadopters as well as to compute the percent change between them as an impact of plastic-pond technology. In reality, we never observe the individual farmer being as both adopters and nonadopters of the technology and the corresponding incomes for both cases. In this situation, a majority of researches till date made a comparison between two mean values of adopters and nonadopters only on the basis of observed values. However, a simple comparison between the observed mean values is reported to mislead the true impact of the technology adoption (see, e.g., Maddala, 1983, Di Falco and Veronesi, 2013).

To overcome this problem, endogenous switching regression is applied to estimate the counterfactual incomes for each of adopters and nonadopters and compares them with actual incomes. This specifically tries to answer the question: "What is the impact of plastic-pond technology on vegetable incomes of nonadopters (adopters) if nonadopters (adopters) adopt (do not adopt) it?" The differences between actual and counterfactual values estimated through endogenous switching regressions are represented as the average treatment on untreated (ATU) and average treatment effect on treated (ATT) (see equations (9) and (10)).

[Table 6 about here.]

Table 6 demonstrates the large significant and positive impact of ATT implying that adopters of plastic ponds would decrease their income by approximately 28% if they had not adopted it. Similarly, ATU is calculated by comparing the observed and the counterfactual values of vegetable income for nonadopters. The ATU value of 33% signifies that nonadopters would increase vegetable income of this magnitude if plastic-pond technology was adopted by nonadopters for vegetable farming. The 33% increase in vegetable incomes of nonadopters amounts to 4,976 NPR $\left(= 14,928 \times \frac{33}{100}\right)$, suggesting that the gross annual vegetable income becomes approximately 20,000 after installing a plastic pond (table 3). This implies that the vegetable income even from the first year exceeds the initial fixed cost of 14,571 NPR for installing plastic ponds (see table 1). Also, additional costs associated with plastic ponds will not incur from the second year, considering the fact that plastic ponds last for more than 8 years (table 1). Thus, the benefit of plastic ponds are significant enough to improve the welfare of smallholder farmers. In summary, nonadopters would be improved with higher vegetable incomes and better food security from being adopters than remaining as nonadopters.

The findings indicate that the decision to adopt plastic-pond technology under a Nepalese farming situation seems to be rational. As mentioned earlier, in rainy and autumn seasons, majorities of marketable vegetable cannot be grown in lower plains and neighboring states of India and thus, rainy and autumn are off-seasons for the mid-hill growers. In this context, intervention with plastic-pond technology to vegetable farming seems to benefit large masses of rural farmers in Nepal on the basis of our counterfactual experiments. The result clarifies how a small change in the cost-efficient micro-irrigation technology of plastic ponds for vegetable farming can lead to a positive shift on vegetable income compared to rain-fed traditional vegetable farming.

5 Conclusion

This study analyzed the data obtained from the survey of 1,001 mid-hill farming households of Nepal in 2014, and estimated the impact of plastic-pond technology on the vegetable income of farmers by applying endogenous switching regression model. We find that the plastic-pond adoption is associated with higher education, credit access, credit investment in agriculture, improved seeds and agricultural training, but negatively associated with availability of other irrigation schemes. Our results demonstrate that vegetable incomes for nonadopters are affected by several factors such as age, education, livestock, land value, credit access, investment and improved seeds, while the only two determinants of livestock value and credit access are important for vegetable incomes of adopters, implying that plastic ponds fundamentally change the structure of vegetable farming.

We also conducted counterfactual analysis with the endogenous switching regressions, and estimated the actual and counterfactual vegetable incomes for both adopters and nonadopters to quantify the impact of plastic ponds. It is identified that there would be a decline of 28% in vegetable income if adopters would not have adopted this technology. On the other hand, nonadopters are estimated to increase their vegetable income by 33% if they would adopt this technology. In Nepalese farming, a large share of produced cereal is still used for household consumption and animal feed. In this type situations, vegetable farming is a strong source of cash generating activities to meet households' expenditures as well as to improve their welfare. An increase of vegetable incomes by 33% could be considered significant on livelihoods for Nepalese smallholder farmers. Such a positive impact on household vegetable incomes through small investment of approximately 148 US$ for simple micro-irrigation technology of plastic ponds should not be ignored.

Socioeconomic and biophysical conditions in Nepal are huge obstacles in adopting large-scale or standard irrigation technologies for smallholder farmers. At the same time, there is urgency for Nepalese farmers to reduce the vulnerability of farming by overcoming low agricultural productivity, its associated uncertainty and seasonal climate fluctuations through the intervention. It is our belief that our research suggests one effective intervention for smallholder farmers to overcome such difficulties in not only Nepal but also other developing nations, i.e., plastic-pond technology. Nowadays, new problems in tackling with poverty and meeting family expenses are reported to be rapid urbanization and out-migration of the young male counterparts in Nepal. These two problems appear to worsen the situations of Nepalese agriculture. In the future research, we should incorporate these issues to consider how to enhance farming incomes in Nepal.

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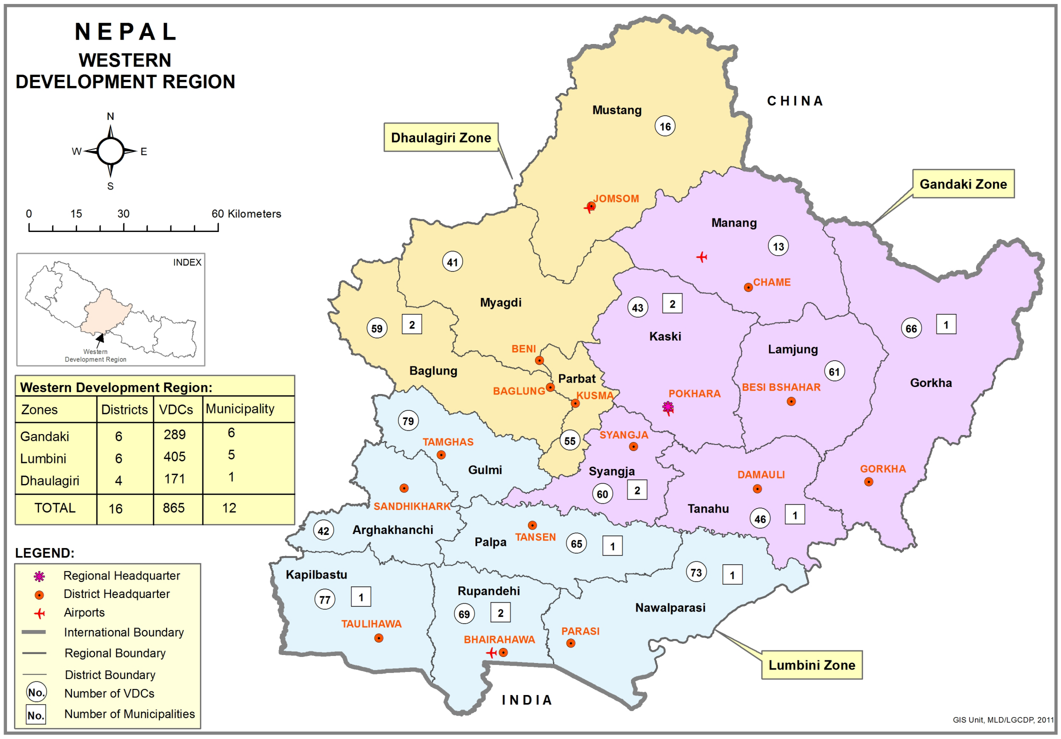
List of Figures

Figure 1: Study area



(a) Plastic pond for vegetable farming

(b) Steep sloping land with rain-fed farming

Figure 2: Plastic pond and field for vegetable farming in Nepal

List of Tables

Table 1: Average quantities of items for establishing a plastic pond of 60,000 liters

Item	Average quantity
Total cost for plastic (silpaulin) and other kits	14,571 NPR
Irrigated area for vegetable crop	3.5 ropani[b]
Life span of plastic pond	more than 8 years
Sample size	174[c]

[a] The exchange rate at the time of survey was 1 US$ = 98.03 NPR where NPR represents Nepalese currency.
[b] One hectare is equivalent to 19.965 ropani.
[c] The 55% of plastic ponds adopted by farmers in our survey is the one of 60,000 liters. In other words, 174 out of 357 adopters have used plastic ponds of that size.

Table 2: Description of variables

Variables	Description
Vegetable income	Income generated from vegetable crops between August 2013 and July 2014 (NPR)[1]
Age	Age of the household heads
Household size	Number of household members
Education	Number of years of schooling for household heads
Total cultivated land	Units of land owned by households (ropani)[2]
Total livestock value	Log value of total livestock owned by each household (NPR)
Total land value	Log value of total land owned by each household (NPR)
Credit access	Dummy variable of 1 if the credit is available, otherwise 0
Credit investment in agriculture	Dummy variable of 1 if the credit is invested in agriculture, otherwise 0
Improved and hybrid seeds	Dummy variable of 1 if improved/hybrid seeds are available and used, otherwise 0
Fertility status of land	Dummy variable of 1 if soil is fertile, otherwise 0
Slope of the land	Dummy variable of 1 if the land is flat, otherwise 0
Access to other irrigation	Dummy variable of 1 if other irrigation is available, otherwise 0
Access to agricultural training	Dummy variable of 1 if there is access to agricultural training, otherwise 0
Distance to ASC[3]	Distance from the house to agricultural training centers (km)

[1] Nepalese rupee (local currency) is represented as NPR. The exchange rate at the time of our survey was about 1 US$≈98.03 NPR.

[2] 19.965 ropani is equal to one hectare.

[3] ASC denotes agricultural service center.

Table 3: Summary statistics of variables

Variables	Total sample $N = 1,001$		Nonadopters $N = 644$		Adopters $N = 357$	
	Mean	SD	Mean	SD	Mean	SD
Vegetable income (NPR)	75,105	185,670	14,928	27,853	183,658	277,608
Age	45.58	12.75	45.55	13.13	45.61	12.07
Household size	6.13	3.28	5.90	2.77	6.45	4.03
Education (years)	5.86	4.43	5.20	4.30	7.05	4.2
Total cultivated land (ropani)	14.31	13.29	12.29	10.44	17.95	16.70
Total livestock value (log value)	10.15	3.21	9.93	3.26	10.54	3.07
Total land value (log value)	12.44	4.04	12.07	4.10	13.11	3.85
Credit access (access $= 1$)	0.73	0.45	0.64	0.48	0.88	0.32
Credit investment in agriculture (yes $= 1$)	0.47	0.49	0.33	0.47	0.72	0.45
Improved and hybrid seed (access $= 1$)	0.75	0.43	0.62	0.48	0.87	0.15
Land fertility status (high fertility $= 1$)	0.18	0.38	0.18	0.38	0.26	0.44
Slope status (flat $= 1$)	0.21	0.41	0.22	0.42	0.20	0.40
Other irrigation (yes $= 1$)	0.17	0.38	0.18	0.39	0.17	0.38
Agricultural training (yes $= 1$)	0.39	0.49	0.15	0.35	0.84	0.37
Distance from home to ASC	9.03	9.88	10.03	10.26	7.20	8.89

[1] Nepalese rupee (local currency) is represented as NPR. The exchange rate at the time of our survey was about 1 US$≈98.03 NPR.

[2] 19.965 ropani is equal to one hectare.

Table 4: Income compositions (NPR)

Income sources	Total sample		Nonadopters		Adopters	
	Mean	SD	Mean	SD	Mean	SD
Income from vegetables	75,105	185,670	14,928	27,853	183,658	277,608
Income from cereals	46,446	361,861	28,456	37,441	78,900	603,029
Income from livestock	37,668	262,505	34,079	323,710	44,141	65,058
Income from remittance	112,706	303,293	130,428	351,690	80,737	182,751
Income from non-farm	56,627	145,984	46,554	117,555	74,798	185,443
Income from other sources	54,474	167,001	46,907	165,916	68,124	168,315
Total household income	408,748	745,657	320,733	695,467	567,519	805,554

Table 5: Estimation results of endogenous switching regressions

	Selection equation	Regime equation	
		Nonadopters	Adopters
Age	.009	.084***	0.0323
	(.025)	(.028)	(.032)
Square age	−.0001	−.0007**	−.0004
	(.0003)	(.0003)	(.0003)
Household size	.007	.006	.011
	(0.018)	(.023)	(.017)
Education	.027**	.075***	.015
	(.013)	(.016)	(.017)
Total cultivated land (ropani)	.006	.0104*	−0.0001
	(.005)	(.006)	(.004)
Total livestock value (log value)	.018	.056***	−.049**
	(.018)	(.019)	(.022)
Total land value (log value)	.011	−.050***	.018
	(.014)	(.016)	(.018)
Access to credit (access = 1)	.274*	.422***	.705***
	(.143)	(.139)	(.211)
Credit investment in agriculture (yes = 1)	.482***	.154	.207
	(.113)	(.141)	(.161)
Improved/hybrid seeds (access & yes = 1)	1.202***	0.517***	.017
	(.212)	(.149)	(.479)
Fertility status (high = 1)	.180	.160	−.011
	(.140)	(.191)	(.153)
Slope status (flat = 1)	−.212	−.137	.022
	(.131)	(.156)	(.166)
Other irrigation (yes = 1)	−.414***	−.074	−0.180
	(.136)	(.165)	(.180)
Agricultural training (yes = 1)	1.717***		
	(.111)		
Distance to ASC (km)	−.008		
	(.006)		
Constant	−3.402***	5.236***	10.430***
	(.663)	(.700)	(1.000)
$\sigma_i, i = \{\eta N, \eta A\}$		1.560***	1.230***
		(0.043)	(0.049)
$\rho_i, i = \{\eta N, \eta A\}$		−.105	−.264*
		(.097)	(.143)
Wald test statistics			83.06***

Table 6: Average treatment effects for the adoption of plastic ponds on household vegetable income

	Observation	To adopt		Not to adopt		Treatment effect	Ln%
		Mean	SD	Mean	SD		
Adopters	357	11.64	0.36	9.11	0.46	ATT: 2.53***	-28
Non-adopters	644	11.36	0.56	8.54	0.60	ATU: 2.82***	33

***significant at 1% level.
ATT $=$ Average Treatment on Treated and ATU $=$ Average Treatment on Untreated (see equations (9) and (10)).