Ecological Economics 144 (2018) 139–147

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Farmers' Adaptation to Climate Change, Its Determinants and Impacts on Rice Yield in Nepal

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ARTICLE INFO

Keywords:
Adaptation
Climate change
Endogenous switching
Nepal
Rice

ABSTRACT

This paper explores the factors that influence farmers' decision-making in adopting climate change adaptation strategies and how these adaptations impact on farm yields. We employ a simultaneous equations model to investigate the differential effects of adaptation on adapters and non-adapters. An endogenous switching mechanism is employed to account for selectivity bias. Based on a survey of 422 rice farmers in Nepal, our results show that farmers' education, access to credit and extension services, experience with climate change impacts such as drought and flood, information on climate change issues, belief in climate change and the need to adapt all variously determine their decision-making. We find that the adaptation strategies employed by farmers significantly increase rice yields. Furthermore, results indicate that both adapters and non-adapters would benefit from the adaptation of the identified strategies. This study, therefore, provides supportive evidence for policy makers to take into consideration farmers' existing knowledge and skills in adapting to climate change. The findings show that it is imperative to involve farmers in climate change adaptation planning processes if the full benefits of such policy action are to be realized.

1. Introduction

There is a growing consensus that the impact of climate change has a highly negative effect on the agriculture sector and that farmers in least developed and developing countries are the hardest hit (Bandara and Cai, 2014; Kahsay and Hansen, 2016; Parry et al., 2004; Schellnhuber et al., 2013; Wheeler and Von Braun, 2013). Studies indicate that even moderate increases in temperature will have negative impacts on the major cereal crops including rice, maize and wheat (Knox et al., 2012; Morton, 2007; Sarker et al., 2014). Also, the literature indicates the crucial need to enhance farmers' adaptive capacity (Huq et al., 2004; Seo, 2011) which requires a better understanding of adaptation strategies and the implications of such adaptations in farm productivity (Di Falco and Veronesi, 2013). While a significant body of research exists to assess the impact of climate change on agriculture and adaptation strategies, further research is needed to understand whether farmers' adaptation strategies support farm productivity.

While climate-induced yield loss in agriculture is becoming a serious concern, some studies indicate that agriculture might benefit from future climate change if suitable adaptations are implemented (Di Falco et al., 2011; Dixon et al., 2003; Kabir et al., 2017; Kahsay and Hansen, 2016; Reid et al., 2007; Tingem and Rivington, 2009). Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001). Adaptations are categorized according to various criteria, including the planning horizon (short-term or long-term), timing (reactive or anticipatory), form (technical, institutional, legal, behavioral or educational), and actors involved (private or public) (Füssel, 2007; Smit and Skinner, 2002). Adaptations are further distinguished between autonomous adaptations - which occur in a system as a matter of course - and planned adaptations which require or result from deliberate policy decisions (Smith et al., 2000). Stage (2010) distinguishes between autonomous adaptation-decisions made by private firms and households and planned adaptation where decisions are made by government bodies.

Smallholder farmers in many least developed and developing countries have been making adjustments in their management practices in response to climate change impacts. These adaptations are of an autonomous nature, defined as the ongoing implementation of existing knowledge and technology by farmers themselves, in response to experienced changes in climate (Leclère et al., 2013). From the viewpoint of food security, it is important to investigate whether such autonomous adaptations enhance farm productivity.

A number of studies have analyzed the benefits of adaptation on crop yield. However, many of them took into account only a few

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http://dx.doi.org/10.1016/j.ecolecon.2017.08.006
Received 26 February 2017; Received in revised form 24 July 2017; Accepted 7 August 2017

adaptation strategies (Waha et al., 2013) and were focused on the global, regional or national level (Challinor et al., 2014). Such studies have been crucial to planning adaptation strategies at a macro level. However, studies focusing on community, household and farm level are necessary to identify and design effective adaptation strategies at the local level. Moreover, few studies have assessed the impact of adaptation on farm productivity taking into account the actual adaptations adopted by farmers (Di Falco et al., 2011; Huang et al., 2015). Di Falco et al. (2011) examined the impact of adaptation on farm household food productivity in Ethiopia finding that adaptation increases food productivity and that the farm households that did not adapt would benefit the most from adaptation. Huang et al. (2015) found that adaptation to extreme weather events through adjustments in farmers' management practices significantly increases rice yield in China.

There exists ample literature on farmers' adaptation to climate change in developing countries (Alam et al., 2016; Alauddin and Sarker, 2014; Kabir et al., 2017; Ngigi et al., 2017). However, one of the challenges in studying adaptations in small scale farming is the identification of true adaptation, as many changes in agricultural management and technology do not necessarily represent this (Huang et al., 2015; Lobell, 2014). As well, adaptation in agriculture varies across countries. Farmers practice different adaptation strategies depending on the varying climatic, social, economic and institutional factors (Below et al., 2012; Deressa et al., 2009). For these reasons information on the implications of actual adaptation used by farmers on crop yields will be useful for effective adaptation planning.

In this study, we assess the actual adaptations adopted by farmers in rice farms and examine the impacts on rice yields. More specifically, we assess the strategies that rice farmers adopt to minimize the negative impact of long-term changes in climatic conditions, factors affecting farmers' decision to adapt and investigate the impact of adaptation strategies on rice yield in Nepal. We employ a simultaneous equations model with endogenous switching to take into account selectivity bias and to investigate the differential impact of adaptation on adapters and non-adapters. To identify true climate change adaptations, we link the farmers' adjustment in farm management with particular climate change impacts in rice production. More precisely, we asked farmers whether they have noticed any changes in the local climatic condition, and if yes, what have been the impact of such changes on rice production, and what specific adjustments were made to deal with these changes. Understanding the determinants of farmers' actual adaptation to climate change and implications for crop productivity seem particularly relevant because many least developing countries including Nepal are in the process of designing and implementing climate change adaptations.

2. Background and Data

2.1. Background

Nepal is a small country covering an area of 147,181 km^2, broadly divided into three ecological regions. They are the Terai, the Hill and the Mountain. The Terai constitutes 23% of total land area of which about 38% is cultivated and is of relatively high agricultural potential. This region largely consists of flat land that extends from 60 m above sea level (masl) up to 500 masl. The most important crops grown are rice, wheat, maize and oilseeds. It is relatively better off than the other two regions in terms of social and economic infrastructure development. The Hill region constitutes 42% of total land area of which about 15% is cultivated. The region comprises steeply sloped lands with several small valleys and is in the range of 500 to 2500 masl. Maize and rice based cropping systems are predominant. The rice based cropping system is generally practiced in wetlands and maize based cropping system in drylands. The Mountain constitutes 35% of the total land area of which about 4% is cultivated. The region ranges in altitude from 2500 to 8848 masl and consists of steeply sloped lands and snow covered mountains with few valleys. Barley, buckwheat and potato are the major staple crops with livestock also playing an important role.

In Nepal, agriculture has historically been a dominant sector, contributing about 35% of total gross domestic product and employing 70% of the population (MoAD, 2012). Rice is one of the most important staple crops. It is grown by 76% of agricultural households (Sanogo and Amadou, 2010) and covers about 1.4 million ha which comprises 46% of the cultivated land (MoAD, 2012). Although rice has special significance and economic importance for Nepal, growth in production and productivity have been poor and prone to fluctuations (MoF, 2013). The average rice yield is 3.17 t/ha (MoAD, 2012) which is low compared to other South Asian countries.

Nepalese farmers grow rice under uncertain environments where rain-fed farming accounts for nearly two-thirds of total cultivation (MoAD, 2012). Prolonged droughts and unseasonal rains have a substantial effect on rice farming in Nepal. For example, due to unfavorable weather conditions, nationally the area under rice cultivation and production fell by 7.2% and 11.3% respectively in 2012/13 compared to the previous year (MoF, 2013).The extent of variability is illustrated by the severe drought in 2006 which produced a 13% reduction in the rice area planted (Gumma et al., 2011). A number of studies have indicated that there is significant potential to enhance rice productivity in developing countries (Alauddin and Sharma, 2013; Huang et al., 2015). Thus in view of the critical importance of rice to the Nepalese economy and its sensitiveness to climate change impacts, it is of particular importance to identify and adopt climate change adaptation strategies that could increase rice productivity.

The existing literature on the effects of climate change on Nepal's agriculture sector focuses on three areas. First, a number of studies analyze temperature and rainfall trends (Practical Action, 2009; Shrestha et al., 2000; Shrestha et al., 1999). The second category of studies focus on assessing the impact of climate change on the agriculture sector output (Eriksson et al., 2009; Malla, 2009) and the third area is the identification of adaptation practices (Chhetri et al., 2012; Maraseni, 2012; Nayava, 2010). An important issue that has been largely ignored in the literature is the link between climate change adaptation and farm productivity. Nepal is in the process of planning and implementing local and national adaptation programs and plans. This study is therefore timely in providing data which can assist policy makers in designing and promoting practical and robust adaptation strategies.

2.2. Data

This research was conducted in two major rice producing regions: the Terai and the Hill. Administratively, the country is divided into 75 districts. In this research, two districts from each of the two ecological regions were selected: Kaski and Dhading from the Hill region and Chitwan and Rupandehi from the Terai region. The field study was conducted by means of randomly selecting two village development committees (VDCs)[1] in each district. The unit of analysis is the farming household, which is the decision making unit in the agricultural production process.

The selection of farming households from the VDC involved two steps. First, four wards in each VDC were selected randomly. We obtained a list of households in the selected wards from the office of the VDC. Then we identified households involved in farming in each randomly selected ward. In the next step, we selected farming households from each ward through simple random sampling. We contacted households' heads and asked about their availability and interest in participating in the survey. We selected 15 households from each ward, producing a total sample size of 480. Of these 58 were not involved in

[1] A VDC is an administrative unit in Nepal similar to a municipality which is further divided into nine wards. Each ward constitutes one to several villages.

Table 1
Variable names, definitions and descriptive statistics for the sample.

Variable	Description	Sample mean	Std. Dev.
Yield	Rice output (kg/ha)	4013.707	1645.101
Adaptation	Dummy = 1 if the farming household adapted to climate change, 0 otherwise	0.720	0.452
Area	Area under rice in hectare	0.498	0.508
Fertilizers	Chemical fertilizers use per hectare (kg)	190.430	129.446
Labour	Labour use per hectare (days)	104.640	26.606
Seeds	Seeds use per hectare (kg)	42.346	17.572
Other cost	Total cost of bullocks/tractors for land preparation, pesticides and material per hectare (NRs)	2268.656	2241.713
Age	Age of the household head	47.160	13.700
Education	Education of the household head. Dummy = 1 if the household head had attained > 5 years of schooling, 0 otherwise	0.557	0.341
Family size	Family size	5.820	2.498
Assets	Value of household farm assets	9282.250	3684.909
Non-farm	Dummy = 1 if any member in the family involved in non-farm job, 0 otherwise	0.650	0.478
Credit	Dummy = 1 if the household has access to credit, 0 otherwise	0.540	0.499
Extension	Dummy = 1 if household has received information from extension agent, 0 otherwise	0.480	0.500
Market	Distance from house to market (km)	14.454	14.259
Institution	Dummy = 1 if any member in the household was member of agricultural related groups and organizations, 0 otherwise	0.650	0.476
Drought	Dummy = 1 if the household was affected by drought during the last five years, 0 otherwise	0.520	0.500
Flood	Dummy = 1 if the household was affected by flood during the last five years, 0 otherwise	0.470	0.500
Plots	Number of farm plots under rice cultivation	2.270	1.204
Terai	Dummy = 1 if the household is located in Terai region, 0 otherwise	0.530	0.500
Hill	Dummy = 1 if the household is located in Hill region, 0 otherwise	0.470	0.500
Climate information	Dummy = 1 if the household received information on climate change, 0 otherwise	0.340	0.473
Climate belief	Dummy = 1 if the respondent believes climate has changed in the local area, 0 otherwise	0.880	0.324
Adaptation belief	Dummy = 1 if the respondent believes adaptation minimizes negative climate change impacts in rice production, 0 otherwise	0.590	0.492

rice production.

A combination of two different methods was used for data collection. They include focus group discussions (FGDs) and household surveys. The data collection was carried out from October 2015 to January 2016. One focus group discussion was conducted in each VDC, the participants consisting of 8–10 farmers who were long-time residents and including both men and women. An informal, semi-structured discussion format lasting about 2 h was used for the FGD. This was used to collect information regarding general characteristics of villages under study, perception about climate change and adaptation strategies. To ensure that the adaptation practices that farmers adopt were a consequence of climate change and not due to other pressures, we asked three contingent questions[2]; 1) do you perceive any changes in the local climatic condition in the last 15–20 years? If yes, what are they? 2) What have been the impacts of these changes in rice production? 3) What have you done to deal with these changes? The identified adaptation practices were then included in the household survey questionnaire to examine the actual adaptations by the sampled households.

Household surveys were commenced following completion of FGDs. Prior to administering the questionnaire a pre-testing with non-sampled households was carried out to examine the applicability of the questionnaire. The survey questionnaire was finalized incorporating the inputs from pre-testing and focus group discussion. The household survey was carried out through a face to face interview with the decision maker of the sampled farming households, who could be an adult of any gender. The interview was conducted in Nepali language and took approximately 1 h to complete.

Table 1 presents descriptive statistics for the surveyed households. It shows that 72% of the farming households adopted at least one adaptation strategy for their rice farm in response to the changes in local climatic conditions. Details of the farmer's perceived climate change impacts and adaptation strategies are presented in Annexes 1 and 2. In this paper, the households that adopted at least one adaptation strategy are termed "adapters" and those not adopting a strategy "non-adapters". Table 2 presents differences in the characteristics of adapters and non-adapters. The average rice yield for adapters was 981.4 kg/ha - higher than that of non-adapters, suggesting that adoption of climate change adaptation plays a significant role in enhancing rice yield. It is also evident that the quantity of fertilizer use is significantly higher for adapters than non-adapters. As well, adapters grew rice in a larger number of plots compared to non-adapters. There are significant differences between adapters and non-adapters in terms of education of the household head, family size, farm assets in the household and involvement in non-farm work. Also, there are significant differences between adapters and non-adapters in access to credit, extension, distance to market and membership in farmers' organizations.

Table 2
Farm and household characteristics of adapters and non-adapters.

Variables	Adapters		Non-adapters		Difference
	Mean	Std. Dev.	Mean	Std. Dev.	
Adaptation	1.000	0.000	0.000	0.000	
Yield	4292.781	1577.936	3311.370	1606.730	981.411***
Area	0.514	0.535	0.456	0.431	0.058
Fertilizers	200.497	185.455	165.094	229.848	35.403*
Labour	102.967	86.587	108.848	86.874	− 5.881
Seeds	42.203	27.052	42.706	28.952	− 0.502
Other cost	1101.000	1614.064	867.188	674.294	233.812
Age	46.500	12.864	48.820	15.540	− 2.320
Education	0.630	0.484	0.380	0.486	0.250***
Family size	5.630	2.368	6.280	2.754	− 0.650**
Assets	9500.000	11,621.611	7133.070	2949.909	2366.930**
Non-farm	0.720	0.449	0.470	0.501	0.250***
Credit	0.610	0.489	0.380	0.488	0.230***
Extension	0.550	0.499	0.310	0.464	0.240***
Market	13.580	11.688	16.654	19.157	− 3.074**
Institution	0.700	0.460	0.540	0.500	0.160**
Drought	0.530	0.500	0.500	0.502	0.030
Flood	0.520	0.500	0.340	0.476	0.180***
Plots	2.420	1.217	1.880	1.086	0.540***
Terai	0.410	0.492	0.640	0.482	− 0.230***
Hill	0.590	0.492	0.360	0.482	0.230***
Climate information	0.400	0.490	0.180	0.389	0.220***
Climate belief	0.950	0.224	0.720	0.453	0.230***
Adaptation belief	0.670	0.470	0.400	0.492	0.270***

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

[2] These questions were also included in the household survey questionnaire.

3. Modelling Adaptation to Climate Change and Rice Yield

We model the adoption of climate change adaptation, under the assumption that farmers choose between adaptation and non-adaptation. Here our assumption is that farmers adopt climate change adaptation strategies if it generates net benefits. Following Di Falco et al. (2011), we model the climate change adaptation decision and its impact on rice yield in a two stage-framework. In the first stage, we use a selection model for climate change adaptation. Let Y_{Ai} be the net benefit farmer i derives from adaptation and Y_{Ni} the net benefit from non-adaptation. The farmer will normally choose the adaptation if the net benefits derived by doing so are higher than derived by not adopting the adaptation (Abdulai and Huffman, 2014). That is $Y_{Ai} > Y_{Ni}$.

The net benefits of adaptation as perceived by the farmers are unknown to the researcher. However, as the farmers' characteristics and adaptation attributes are observed during the survey period, the net benefits derived from climate change adaptation can be represented by a latent variable A^*, which is not observed but can be expressed as a function of the observed characteristics and attributes.

$$A_i^* = Z_i\alpha + \eta_i \text{ with } A_i = 1 \text{ if } A_i^* > 0 \text{ and 0 otherwise} \quad (1)$$

where A_i is a binary variable that equals 1 for farming households that adopt climate change adaptation strategies and 0 otherwise. α is a vector of parameters to be estimated. The error term η with mean zero and variance $\sigma^2\eta$ captures measurement errors and factors unobserved to the researcher but known to the farmer. The vector Z represents farm and household characteristics that influence the farmers' decision to adopt climate change adaptation strategies. The empirical literature on farmers' adaptation to climate change provides several indications of the determinants of adaptation. It is generally believed that a higher level of farmers' education is associated with better access to information on improved technologies. Thus, farming households with a higher level of education of the household head are more likely to employ climate change adaptation strategies (Deressa et al., 2009). Studies on adoption of improved agricultural technologies indicate that household size has a positive effect on adoption. A large family means a greater labour force, which would induce households to adopt labour-intensive agricultural technology (Croppenstedt et al., 2003; Deressa et al., 2009). Furthermore, it is argued that as the opportunity cost of labour is typically low in rural areas of most developing countries, farm households with more labour can therefore be expected to take up adaptations (Hassan and Nhemachena, 2008).

Information provided by extension agents facilitate farmers' decisions on how and when to use new innovations including climate change adaptation strategies. Deressa et al. (2009) and Hassan and Nhemachena (2008) show the positive association between farmers' access to extension services and adaptation to climate change. Furthermore, farmers can get information on improved farm management practices and innovations from farmers' organizations and social networks thereby increasing the likelihood of adoption (Abdulai and Huffman, 2014). Similarly, information on climate change increases the probability of using different crop varieties as an adaptation strategy against climate change impacts (Deressa et al., 2009).

For resource-poor farmers, the involvement of family members in non-farm activities may reduce financial constraints, inducing them to use productivity increasing inputs. Deressa et al. (2009) indicate that non-farm income increases the likelihood of planting trees, changing planting dates and using irrigation as adaptation options. However, it is also argued that participation in non-farm activities may impede the involvement in farm production activities (Abdulai and Huffman, 2014). Deressa et al. (2009) found that access to credit has a positive and significant impact on the likelihood of using soil conservation, changing plating dates and using irrigation as adaptation strategies to climate change impacts in the Nile basin of Ethiopia. Moreover, Hassan and Nhemachena (2008) reveal a strong positive influence of access to credit services on the probability of adopting adaptation measures. Their study further shows that better access to markets is critical for helping African farmers adapt to climate change.

We included household characteristics such as age, education, family size, possession of farm assets, involvement in non-farm activities and farm characteristics such as number of plots under cultivation, whether the farm household was affected by droughts and floods. As is typical in least developed countries, many farmers in Nepal suffer from information, market and credit constraints which are important factors in determining the adoption of adaptation strategies. Thus before they can consider applying climate change adaptation strategies to their farmlands, farmers must have information on climate change, an understanding of the changes in local climatic conditions and equally an understanding of how adaptation minimizes negative climate change impacts. Furthermore, in order to capture demographic factors, access to infrastructure and soil types that vary by geographical region, we also included agro-ecological dummies.

In the second stage, the effect of adaptation on rice yield is modelled through a rice yield function in log(Y) under the representation of production technology, which can be defined as:

$$Y = f\,(A, X, \beta) + \varepsilon \quad (2)$$

where Y is the rice quantity produced per hectare specified in the log form, A refers to adaptation which takes a value of 1 if a farm household adopts adaptation strategies, and 0 otherwise. X is a set of explanatory variables that include production inputs specified in log form (e.g., fertilizers, labour, seeds) and household and farm characteristics included in Z. β is a vector of parameters to be estimated and ε is the error term. However, this approach of examining the impact of adaptation on rice yield taking adaptation as a dummy variable might yield biased estimates because it assumes that adaptation is exogenously determined while it is potentially endogenous (Di Falco et al., 2011). Another potential econometric challenge in such approach is the sample selection bias problem given the adapting farmers may have systematically different characteristics from the farmers that did not adapt. Furthermore, unobservable characteristics of households and farms may affect both the households' decision to adapt and their rice yield, resulting in inconsistent estimates of the effect of adaptation on rice yield (Di Falco et al., 2011).

To deal with the endogeneity problem, we estimate a simultaneous equations model of climate change adaptation and rice yield employing an endogenous switching regression model with full information maximum likelihood. For the model to be identified, it is important to use selection instruments that affect the adaptation decision of farming households, but do not affect the rice yield per hectare among the households that did not adapt. In our study, the variables climate information, climate belief and adaptation belief (Table 1) are used as the selection instruments. Results in Table 3 and Annex 3 show that these variables can be considered as valid selection instruments.

We employ an endogenous switching regression model to account for selection bias in our estimation of the impact of climate change adaptation on rice yield. In the switching regression approach, farm households are partitioned into two regimes according to their adaptation decision (adaptors and non-adaptors). Given the households' decision to apply adaptation strategies, a separate outcome function is specified for adaptors and non-adaptors.

$$\text{Regime 1: } Y_{Ai} = X_{Ai}\beta_A + \varepsilon_{Ai} \text{ if } A_i = 1 \quad (3a)$$

$$\text{Regime 2: } Y_{Ni} = X_{Ni}\beta_N + \varepsilon_{Ni} \text{ if } A_i = 0 \quad (3b)$$

where Y_{Ai} and Y_{Ni} are the rice quantity produced per hectare specified in log for adapters and non-adapters respectively. The vectors β_A and β_N are the parameters to be estimated.

The three error terms η, ε_A and ε_N in Eqs. (1), (3a) and (3b) are assumed to have a trivariate normal distribution, with zero mean and the following covariance matrix:

Table 3
Endogenous switching regression results for adaptation and impact of adaptation on rice yields.

Variable	Adaptation	Rice yield (log)	
		Adapters	Non-adapters
Constant	− 3.041**	6.927***	4.096***
	(1.401)	(0.265)	(0.700)
Fertilizers (log)	0.229**	0.089***	0.065
	(0.106)	(0.019)	(0.052)
Labour (log)	− 0.219	0.048	0.172*
	(0.170)	(0.031)	(0.094)
Seeds (log)	− 0.119	0.161***	0.025
	(0.177)	(0.035)	(0.097)
Other cost (log)	0.058	− 0.052	0.284***
	(0.187)	(0.033)	(0.097)
Age	− 0.001	0.002	0.009***
	(0.007)	(0.001)	(0.003)
Education	0.358**	0.143***	0.254**
	(0.176)	(0.036)	(0.099)
Family size	− 0.032	0.013*	− 0.019
	(0.036)	(0.007)	(0.019)
Assets	0.000	0.000***	0.000**
	(0.000)	(0.000)	(0.000)
Non-farm	0.288	− 0.062*	− 0.208**
	(0.178)	(0.036)	(0.108)
Credit	0.414**	0.028	0.117
	(0.172)	(0.034)	(0.105)
Extension	0.340*	0.212***	0.022
	(0.184)	(0.035)	(0.106)
Market	− 0.005	− 0.003	0.006**
	(0.007)	(0.002)	(0.003)
Institution	− 0.360	0.063	0.034
	(0.314)	(0.040)	(0.099)
Drought	0.817***	− 0.003	0.085
	(0.237)	(0.040)	(0.137)
Flood	1.281***	− 0.033	− 0.026
	(0.206)	(0.034)	(0.119)
Plots	0.146*	0.001	0.016
	(0.084)	(0.015)	(0.048)
Area	0.090	− 0.106**	− 0.276*
	(0.304)	(0.046)	(0.150)
Terai	0.920**	0.274***	0.918***
	(0.360)	(0.061)	(0.196)
Climate information	1.432***		
	(0.253)		
Climate belief	0.991***		
	(0.263)		
Adaptation belief	0.502**		
	(0.200)		
σ_A		0.269*** (0.011)	
σ_N			0.471***(0.031)
ρ_A		0.212(0.114)*	
ρ_N			− 0.053(0.277)

Standard errors in parenthesis.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

$$\mathrm{Cov}(\eta, \varepsilon_A, \varepsilon_N) = \sum = \begin{pmatrix} \sigma_\eta^2 & \sigma_{\eta A} & \sigma_{\eta N} \\ \sigma_{A\eta} & \sigma_A^2 & \sigma_{AN} \\ \sigma_{N\eta} & \sigma_{NA} & \sigma_N^2 \end{pmatrix}$$

Where Var $(\varepsilon_A) = \sigma_A^2$, Var $(\varepsilon_N) = \sigma_N^2$ and Var $(\eta) = \sigma_\eta^2$, Cov $(\varepsilon_A, \varepsilon_N) = \sigma_{AN}$, and Cov $(\varepsilon_A, \eta) = \sigma_{A\eta}$, and Cov $(\varepsilon_N, \eta) = \sigma_{N\eta}$. Since Y_{Ai} and Y_{Ni} are not observed simultaneously the covariance between ε_{Ai} and ε_{Ni} is not defined. The error term of the sample selection Eq. (1) η_i is correlated with the error terms of the outcome Eqs. (3a) and (3b). Hence the expected values of ε_{Ai} and ε_{Ni} conditional on the sample selection, are non-zero (Lee and Trost, 1978), given as:

$$E[\varepsilon_{Ai} \mid A_i = 1] = \sigma_{A\eta} \frac{\varphi(Z_i\alpha)}{\phi(Z_i\alpha)} = \sigma_{A\eta}\lambda_{Ai}$$

and,

$$E[\varepsilon_{Ni} \mid A_i = 0] = -\sigma_{N\eta} \frac{\varphi(Z_i\alpha)}{1 - \phi(Z_i\alpha)} = \sigma_{N\eta}\lambda_{Ni}$$

where $\varphi(.)$ is the standard normal probability density function, and $\phi(.)$ is the standard normal cumulative density function. The terms λ_A and λ_N refer to the inverse Mills ratio evaluated at $Z_i\alpha$ and are incorporated into outcome equations to account for sample selection bias. In this study, we used the full information maximum likelihood method suggested by Lokshin and Sajaia (2004) which simultaneously estimates the two equations - that is, the selection and outcome equations. The signs and significance levels of the correlation coefficients (ρ) from the estimates are of particular interest. These are the correlation coefficient between the error term ηi of the selection equation and error terms ε_A and ε_N of the outcome Eqs. (3a) and (3b) respectively. Specifically, there is endogenous switching, if either ρ_A or ρ_N is significantly different from zero, which would result in selection bias.

The endogenous switching regression model can be used to compare the expected rice yield of the adapting farm household and the non-adapting household, which are defined as respectively:

$$E[Y_{Ai} \mid A_i = 1] = X_{Ai}\beta_A + \sigma_{A\eta}\lambda_{Ai} \tag{4}$$

$$E[Y_{Ni} \mid A_i = 0] = X_{Ni}\beta_N + \sigma_{N\eta}\lambda_{Ni} \tag{5}$$

Similarly, the expected value of the adapter had the household chosen not to adapt, and the expected value of the non-adapter had the household chose to adapt are given, respectively, as:

$$E[Y_{Ni} \mid A_i = 1] = X_{Ai}\beta_N + \sigma_{N\eta}\lambda_{Ai} \tag{6}$$

and

$$E[Y_{Ai} \mid A_i = 0] = X_{Ni}\beta_A + \sigma_{A\eta}\lambda_{Ni} \tag{7}$$

The change in the rice yield due to adoption of climate change adaptation strategies can be calculated as the difference between Eqs. (4) and (6), which is termed the average treatment effect (TT):

$$TT = E[Y_{Ai} \mid A_i = 1] - E[Y_{Ni} \mid A_i = 1] = X_{Ai}(\beta_A - \beta_N) + (\sigma_{A\eta} - \sigma_{N\eta})\lambda_{Ai} \tag{8}$$

Similarly, we can calculate the effect of the treatment (adaptation) on the untreated (non-adapted) (TU) for the household that did not adapt as the difference between Eqs. (5) and (7):

$$TU = E[Y_{Ni} \mid A_i = 0] - E[Y_{Ai} \mid A_i = 0] = X_{Ni}(\beta_N - \beta_A) + (\sigma_{N\eta} - \sigma_{A\eta})\lambda_{Ni} \tag{9}$$

Following Di Falco et al. (2011), we used the expected rice yield described in Eqs. (4)–(7) to calculate the heterogeneity effects. Farm household that adapted may have produced more than farm households that did not adapt regardless of their adaptation decision – that is, because of unobservable farm and household characteristics. For the group of households that decided to adapt, this heterogeneity effect is measured as the difference between Eqs. (4) and (7):

$$BH1 = E[Y_{Ai} \mid A_i = 1] - E[Y_{Ai} \mid A_i = 0] = (X_{Ai} - X_{Ni})\,\beta_{Ai} + \sigma_{A\eta}(\lambda_{Ai} - \lambda_{Ni}) \tag{10}$$

Similarly, for the group of households that decided not to adapt, the heterogeneity effect is the difference between Eqs. (6) and (5):

$$BH2 = E[Y_{Ni} \mid A_i = 1] - E[Y_{Ni} \mid A_i = 0] = (X_{Ai} - X_{Ni})\,\beta_{Ni} + \sigma_{N\eta}(\lambda_{Ai} - \lambda_{Ni}) \tag{11}$$

4. Results and Discussions

In this section, we first examine the determinants of adoption of climate change adaptation strategies, and then the impact of adaptation on rice yield of farming households. As indicated previously, the

endogenous switching regression model employing the full information maximum likelihood approach estimates both the adaptation and outcome equations jointly.

4.1. Determinants of Climate Change Adaptation

The second column of Table 3 presents the results of the adaptation equation representing the determinants of adaptation. The coefficient of education is positive and significant suggesting that better educated farmers are more likely to employ adaptation strategies in response to climate change impacts. Empirical evidence from Ethiopia (Deressa et al., 2009) and Bangladesh (Alam et al., 2016; Alauddin and Sarker, 2014) where farmers with better education were likely to adapt, supports this finding. Nevertheless, in our study area, about 44% of the farmers had attained less than five years of schooling. This suggests the need for easier access to education among farmers in order to increase the uptake of the adaptation strategies.

The credit variable is positive and significant, indicating that farming households with access to credit are found to be more likely to adopt adaptation strategies. The positive effect of access to credit in the adaptation decision is consistent with the finding of Di Falco et al. (2011). Similarly, our finding suggests that farmers who received information from extension agents are shown to be more likely to adapt to climate change. The literature therefore supports the positive effects of extension services on adaptation (Deressa et al., 2009; Hassan and Nhemachena, 2008). About 50% of farmers in the study area did not have access to extension and credit, which indicates the need of such services for effective adaptation.

The coefficient of both drought and flood are positive and significant, suggesting that farming households affected by drought and flood in the last five years are more likely to employ climate change adaptation strategies on their farms than those that are not affected. This finding upholds that of Alauddin and Sarker (2014) who reported that the greater the drought severity, the greater is the likelihood of farmers adopting supplementary irrigation and switching to water saving non-rice and horticultural crops to adapt to climate change in Bangladesh.

The sign for variable plots is also positive and the coefficient significant, indicating that households cultivating rice in a greater number of plots are more likely to adopt adaptation strategies. This may be because such households are more likely to take the risk of adopting innovations at least in one of their many plots. The ecological region dummy is also significantly positive, indicating that farmers are more likely to employ adaptation strategies in the Terai region compared to farmers in the Hill region.

Interestingly, the effects of the climate information, climate belief and adaptation belief are all statistically significant. Specifically, the positive and significant coefficient of climate information indicates that the farmers who are obtaining information on climate change are more likely to adapt to climate change. This positive effect of access to climate information on use of adaptation strategies is in line with other studies (Alam et al., 2016; Alauddin and Sarker, 2014; Deressa et al., 2009). Similarly, those farmers who believe that the local climatic conditions have changed are more likely to adapt. Furthermore, farmers who believe that adaptation minimizes the negative impact of climate change on rice production are more likely to employ adaptation strategies.

4.2. Impact of Adaptation on Rice Yield

We examine the impact of climate change adaptation on rice yield by following three approaches. First, we compare the average rice yield of adapting and non-adapting households. The results show that the average rice yield of adapting farm households is significantly higher than non-adapting households (Table 2, second row). Second, we estimate a linear regression model of rice production that includes climate change adaptation as a dummy variable, taking the value 1 if the farming households applied at least one adaptation strategy in response to climate change impact, and 0 otherwise. This approach indicates that the impact of adaptation on rice yield is significantly positive[3] (Annex 4). However, both approaches can be misleading and should be avoided in evaluating the impact of adaptation in rice yield as they assume that adaptation is exogenously determined while it is a potentially endogenous variable (Di Falco and Veronesi, 2013). The difference in rice yield may indeed be caused by unobservable characteristics of the farming households.

Table 4
Impact of adaptation on expected rice yield; treatment and heterogeneity effects.

Sub-samples	Decision stage		Treatment effects
	To adapt	Not to adapt	
Households that adapted	(a) 4158.445 (63.342)	(c) 3351.039 (95.832)	TT = 807.405*** (117.252)
Households that did not adapt	(d) 3806.943 (105.879)	(b) 3120.404 (120.645)	TU = 686.861*** (160.616)
Heterogeneity effects	BH_1 = 351.501*** (123.379)	BH_2 = 230.956*** (154.075)	

Standard errors in parenthesis.
*** Significant at the 1% level.

In the third approach, we employ the endogenous switching regression model to account for the endogeneity problem. The results presented in column (3) and (4) of Table 3 account for the endogenous switching in the rice yield function. An interesting finding is the signs and significances of the covariance terms ρ_A and ρ_N. The results show that the covariance term for the adapters is statistically significant, indicating that self-selection occurred in adaptation. Thus, adaptation to climate change may not have the same effect on the non-adapters, if they choose to adapt (Abdulai and Huffman, 2014; Lokshin and Sajaia, 2004). Moreover, the differences in the coefficients of the rice yield equation between the farming households that adapted and those that did not adapt suggest the presence of heterogeneity in the sample. The results in Table 3 indicate that education of the household head, value of farm assets and area under rice are important factors in explaining higher rice yield in both farming households that adapt and did not adapt. However, age of the household, family size, access to extension services and distance to market appear to have differentiated impacts on the rice yield of adapters and non-adapters.

The expected rice tonnage produced per hectare under adapted and not adapted conditions, estimates for the average treatment effects and heterogeneity effects are presented in Table 4. Cells (a) and (b) represent the expected rice production per hectare observed in the sample. The expected rice produced per hectare by the farming households that adapted is about 4158 kg, while it is about 3120 kg for the not adapting group of farming households. This indicates that, on average, the farming households that adapted produced about 33% (that is 1038 kg) more than farming households that did not adapt. The last column of Table 4 presents the average treatment effects, which show the impact of adaptation on rice yields. These treatment effects account for the selection bias arising from the fact that adapters and non-adapters may be systematically different (Abdulai and Huffman, 2014). Cell (c) represents the expected rice production per hectare by the adapting households if they had decided not to adapt and cell (d) represents the expected rice production per hectare by the not adapting households if they decided to adapt. Farming households who actually adapted would have produced about 807 kg (24%) less if they had not adapted. Similarly, farming households who actually did not adapt, would have produced about 687 kg (22%) more if they had adapted.

[3] The coefficient of the dummy variable 'adaptation' is positive and significant.

The last row of Table 4 presents the heterogeneity effect. The significant heterogeneity effects imply that there are some important sources of heterogeneity that make farmers who have already adapted better producers than farmers who have not. This is consistent with the findings of Di Falco et al., (2011).

The results of this study suggest that employment of climate change adaptation strategies significantly increase rice yields. The positive effects of adaptation on crop productivity is in line with the findings of Di Falco et al. (2011) in their Ethiopian study and Huang et al. (2015) in their China based study. Our findings show that approximately 72% of the farming households had adopted at least one adaptation strategy in response to adverse impacts of climate change. However, the survey reveals that very few farmers had adopted a wide range of strategies shown in Annexes 1 and 2. This indicates that there are opportunities for a large percentage of farmers in Nepal to improve farm productivity by utilizing the adaptation strategies which have been already been successfully employed by a small number of farmers.

5. Conclusion and Implications

This paper uses household level data to investigate the factors that influence the adoption of climate change adaptation strategies, as well as the impact of adaptation on rice yields among rice farmers in Nepal. Comparison of average rice yields between adapters and non-adapters revealed significant differences. Also, estimation of a linear regression model of rice production, including climate change adaptation as a dummy variable, indicates that adaptation significantly increases rice yield. However, using these two approaches is not enough to study the adoption decision and impact on rice yield, since they do not take into account the effect of other farm and household characteristics. We, therefore, estimate a simultaneous equations model with endogenous switching to account for selectivity bias and capture the differential impact of adaptation on adapters and non-adapters.

The results show that sample selection bias would result if rice yield were estimated without considering the adaptation decision. This indicates that climate change adaptation may not have the same effect on adapters and non-adapters. The findings also show that education has a positive and significant impact on adaptation as well as rice yields of both adapters and non-adapters. This draws attention to the importance of enhancing farmers' education, particularly in rural areas. Access to credit has a positive and significant influence on the probability of adaptation underlining its role in allowing farming households to implement adaptation strategies. The positive and significant impact of extension services on adaptation decisions confirms the importance of the provision of extension services in the rural areas.

Climate information, climate belief, and adaptation belief play an important role in determining farming households to adapt. These results suggest the need of awareness raising and capacity building activities in the rural areas of Nepal that enhance the farmers' awareness of climate change issues. The study reveals that households with a greater number of plots under rice cultivation are more likely to adopt adaptation strategies. Consequently, policies aimed at promoting adaptation to climate change might first demonstrate the benefits of adaptation strategies with household having a greater number of farm plots and subsequently promoting adaptation on a wider scale. The results of this study also indicate that households affected by drought and flood in the last five years were found more likely to implement adaptation strategies in their farmlands.

Adaptation is found to increase rice yields by 33%. Farming households which had adapted would have produced about 24% less rice if they had not adapted. Similarly, farming households which actually did not adapt would have produced about 22% more if they had adapted. These results indicate that use of climate change adaptation strategies can contribute significantly to rice production among farming households in rural areas of Nepal.

Overall, the findings of this study have important policy implications for the adoption of climate change adaptation strategies and increasing farm productivity. In particular, the study suggests that effective policy measures to promote the adoption of climate change adaptation should include the improvement of farmers' education, access to credit facilities and extension services. Furthermore, farmers' awareness raising on climate change issues, their belief in climate change and adaptation are of paramount importance in determining the implementation of adaptation strategies, which could enhance farm productivity. Currently, many least developed countries, including Nepal are in the process of implementing national adaptation plans and programs. While planning and implementation of national and local level adaptation programs are important, these plans should also take into account existing adaptations that farming households are practicing in their farm lands.

There is no doubt that planned adaptation is necessary to deal with the gradual and long-term climatic change. Nevertheless, the immediate response from farmers is critical with regards to sudden fluctuations in weather condition. A single or combination of autonomous adaptation can help to reduce vulnerability to climate variability. But while this study takes into account adaptation as a binary variable, we suggest future studies examine the implications of different types of adaptation strategies on crop yields. Moreover, while adaptation strategies may be effective in supporting farm productivity, these measures may be costly to implement and may also be inconsistent with other societal and environmental objectives. For instance using more chemical fertilizers may lead to deterioration of soil health and changing the planting location of crops may not be sustainable in the long run. Thus, besides farm productivity, the societal, environmental and economic impacts of adaptation strategies are also important. We, therefore, recommend future studies consider multiple criteria to assess the effectiveness of adaptation strategies rather than focusing only on farm productivity.

Annex 1

Farmers' perception on climate change, its impact on rice production and adaptation actions.

Climatic parameters	Associated climate hazards	Farmers perceived effects in rice production	Coping/ adaptation actions acted by farmers
Temperature	Increased temperature	Increased evapotranspiration, thus require more irrigation More infestation of insects and diseases Introduction of new insects and diseases Reduced grain quality Yield reduction	Grow short duration varieties Grow insect and pest resistant varieties Change planting location of varieties Improve irrigation Increasing number of weeding Use more pesticides
Precipitation	Change in the timing of rainfall including late start of monsoon	Poor germination Water stress causing less tiller number, delay panicle initiation, reduce grain and panicle	Soil conservation techniques Reduce tillage Seed priming

Decreased availability of surface and ground water Long spell drought Less frequent but heavy rainfall causing flood and landslides	number Delay in transplantation Shortage of irrigation water Loss of crop due to heavy rainfall/ hailstorm Destruction of water resources and irrigation canal Soil erosion Degradation of soil quality Yield reduction	Change planting location of varieties Change sowing/ planting/ harvesting date Cultivation of direct seeded rice Increase seed rate Grow short duration varieties Grow drought tolerant varieties Improve/ increase chemical fertilizer use Improve/ increase farm yard manure use Construction of water ways during heavy rainfall Grow flood tolerant varieties Switch to non-rice crop

Source: Focus group discussion.

Annex 2
Adaptation strategies of the rice farmers in the study area.

Adaptation strategies	Frequency (%) (n = 422)
No adaptation	28.44
Grow drought tolerant varieties	23.46
Grow short duration varieties	22.51
Grow disease/pest resistant varieties	13.98
Grow flood tolerant varieties	15.17
Change planting location of varieties	21.09
Increase seed rate	16.35
Cultivation of direct seeded rice	2.37
Change sowing/planting/harvesting date	17.30
Seed priming	21.80
Improve/increase irrigation	15.64
Construction of water ways during heavy rainfall	24.64
Reduce tillage	8.29
Increasing number of weeding	18.48
Soil conservation techniques	13.27
Improve/increase chemical fertilizer use	22.99
Improve/increase farm yard manure use	33.41
Use more pesticides	15.40

Annex 3
Validity test of selection instruments.

Variable	Coefficients	Std. Err.
Constant	54.514	752.165
Fertilizers	1.605**	0.703
Labour	2.619*	1.967
Seeds	− 2.368	5.760
Other cost	0.552**	0.227
Age	22.078**	9.315
Education	511.478*	296.643
Family size	− 47.934	47.803
Assets	0.039**	0.017
Off farm	− 324.489	255.031
Credit	21.644	257.233
Extension	124.052	224.571
Market	11.567	13.053
Institution	459.604*	288.103
Drought	333.955	294.478
Flood	− 22.700	266.427
Plots	11.904	115.868
Area	− 691.159**	309.162
Terai	2190.618***	457.911
Adaptation belief	103.144	240.340
Climate belief	65.544	295.180
Climate information	249.142	368.279
F-stat	7.81	
Sample size	120	

Note: Dependent variable: Rice yield (kg/ha) produced by non-adapted farming households. Model: Ordinary least squares (R^2 = 0.504).
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

Annex 4
Parameter estimates of rice yield equation on pooled sample.

Variable	Coefficients	Std. Err.
Constant	897.269**	448.014
Adaptation	423.944***	148.102
Fertilizers	1.409***	0.443
Labour	4.305***	1.430
Seeds	6.304*	3.589
Other cost	0.023	0.027
Age	7.052*	4.781
Education	523.011***	125.783
Family size	58.211*	38.879
Assets	0.026***	0.008
Off farm	− 384.071***	129.389
Credit	56.249	120.806
Extension	683.666***	136.825
Market	7.478	7.727
Institution	288.134**	147.916
Drought	− 79.244	139.731
Flood	− 204.796*	117.475
Plots	− 55.620	61.020
Area	− 629.288***	180.831
Terai	1459.725***	250.537
F-stat	25.68	
Sample size	422	

Note: Dependent variable: Rice yield (kg/ha) produced by farming households. Model: Ordinary least squares (R^2 = 0.484).
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

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