Autonomous adaptations to climate change and rice productivity: a case study of the Tanahun district, Nepal

Khanal, Uttam and Wilson, Clevo and Hoang, Vincent and Lee, Boon

Queensland University of Technology, Queensland University of Technology, Queensland University of Technology, Queensland University of Technology

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Abstract

A key issue arising from farmers' climate change adaptation practices in agriculture is whether autonomous adaptations improve crop production and productivity. A comparison of crop productivity between farms employing autonomous adaptations and those not adopting provides an empirical means of resolving this question. This study assesses the climate change adaptation practices used by rice farmers in the Tanahun district of Nepal, their impact on rice productivity, and the factors that affect farmers' decisions to adopt adaptation practices. Adaptation practices used by rice farmers include adjustment in timing of farm operations, selection of varieties, crop rotation, improved irrigation, and fertilizer management. Rice productivity was found to be significantly higher among adopting farmers compared to non-adopting farmers. The findings further suggest that age of the household head, family size, migration of family members outside their village, number of plots under rice cultivation, land holding, and farmers' access to information on climate change all influence farmers' adaptation decisions. This study provides empirical evidence indicating the need for policy makers to take into consideration autonomous adaptations when designing planned adaptations against likely impacts of climate change.

Key words: *adaptation; determinants; endogenous switching; rice productivity*

1. Introduction

Agriculture has been identified as one of the most vulnerable sectors to the impacts of climate change. Changing climate trends have negatively affected food production in many regions of the world (IPCC, 2014). Studies indicate that a small increase in temperature can have adverse impacts on crop production (Morton, 2007; Bandara and Cai, 2014; Sarker et al., 2014). According to Rosenzweig and Parry (1994) and Parry et al. (2013) under the expected scenario of ongoing climate change effects, by 2060 world cereal production will decrease by between 1% and 7%. The largest negative changes of between -9% and -11% are projected to occur in developing countries. While the prospect of climate-induced yield loss in agriculture is becoming a concern, some studies indicate that crop production might in fact benefit from future climate change if suitable adaptations are implemented in agricultural systems (Di Falco et al., 2011; Reid et al., 2007; Tingem & Rivington, 2009).

As agriculture is the main source of livelihood for most people in many least developed countries including Nepal, adaptation of the agricultural sector to the impact of climate change is vital to ensure food security (Bryan et al., 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). Adaptation of agriculture to climate change is broadly defined as the adjustment of agronomic practices, agricultural processes and capital investments in response to observed or expected climate change threats (Easterling et al., 2007).

In many countries, smallholder farmers have been making adjustments in farming systems and their livelihoods in order to adapt to a diversity of changes to their farming environment including climate change. Many proven agricultural practices and policies can reduce climate change impacts without compromising food production (Scholes et al., 2014). Rosenzweig and Parry (1994) and Parry et al. (2013) report that with adaptation (shifts in planting dates, increased fertilizer application, development of new varieties and installation of irrigation systems) the climate change impacts on agricultural yields are projected to be reduced by a third. The literature suggests that, in particular, agricultural management practices such as conservation tillage, cover cropping, agroforestry, development of new crop types, efficient irrigation practices, water harvesting, and enhanced water and nutrient management can reduce the adverse impact of climate change on agricultural production (Bryan et al., 2013; Deressa et al., 2009; Kurukulasuriya & Mendelsohn, 2006; Tingem & Rivington, 2009). Research undertaken shows that it is possible to potentially provide quantitative estimates of impacts and adaptation potentials of effects of climate change (see, for example, Halkos and Tsilika, 2017). However, while assessing the impact of adaptation on crop production, most of the studies take into account only a few adaptation strategies and concentrate their analysis at the macro level, ignoring the impact at farming household and community levels (Challinor et al., 2014; Waha et al., 2013). Our study therefore contributes to the literature by examining the impact of adaptation on specific crops at the household level.

Autonomous adaptations can be defined as those which occur in a system as a matter of course as distinct from planned adaptations which are a product of deliberate policy decisions (Smith et al., 2000). Stage (2010), for example, defines autonomous adaptation as adaptation decisions made by private firms and households as distinct from planned adaptation where decisions are made by government bodies. Small-scale farmers in many less developed countries have been autonomously adjusting their farming management practices to combat the adverse impacts of climate change. However a key issue is whether such autonomous adaptation enhances agriculture production (Leclère et al., 2013). A better understanding of such adaptations, the factors influencing farmers' decision to adapt, and the role of these adaptations in enhancing crop production and productivity is needed to craft effective policies and programs aimed at enhancing farmers adaptive capacity and increasing the resilience of the agricultural sector.

This paper contributes to the existing literature by adopting a unique cross-sectional dataset to address the following questions. Do farm level autonomous adaptation practices improve rice productivity? Second, to what extent are farmers' adaptation decisions influenced by farm and household characteristics? To help answer these questions, an empirical study is carried out focussed on the farming households in Tanahun district of Nepal.

2. A brief literature review

The actual impacts of climate change and variability on agricultural production are largely dependent on farming household's adaptive capacity and their decisions to adopt adaptation strategies (Reidsma et al., 2010). A number of factors influence farmers' adaptation decisions which include farming household characteristics such as age, gender and education of the household heads (Deressa et al., 2009; Sarker et al., 2013), household size, income and assets (Bahinipati, 2015; Sarker et al., 2013). Empirical studies find that farm characteristics such as landholding size and farm slope influence farmers' choices of adaptation practices (Piya et al., 2013; Sarker et al., 2013). Access to credit, extension services and climate information are also found to be influential in enabling farming households to move away from traditional coping strategies and adopt suitable practices to adapt to climatic variations (Bryan et al., 2009; Deressa et al., 2009; Piya et al., 2013). Furthermore, a few studies have identified farmers' perception of climate change and their ability to adapt as the important determinants of proactive adaptation decisions (Piya et al., 2013; Zheng and Dallimer, 2016).

Farmers have employed numerous adaptations in response to the impacts of climate change and variability. Major farm level adaptations identified in the literature include use of different crop varieties, tree planting, soil conservation, changing time of farm operations, irrigation improvement and agroforestry (Biggs et al., 2013; Deressa et al., 2009; Piya et al., 2013; Yila and Resurreccion, 2013). For example, in Mali, as the rainy season becomes shorter, farmers are using short cycle varieties of sorghum (Lacy et al., 2006). In the Ashanti region of Ghana, farmers are growing diverse crops and changing planting dates in response to declining precipitation and increasing temperature (Fosu-Mensah et al., 2012). In Switzerland, irrigation has been identified as a useful adaptation practice for maize crops to combat a decrease in summer precipitation due to climate change (Lehmann et al., 2013). It is also apparent that farmers in Africa (Kurukulasuriya & Mendelsohn, 2008), China (Wang et al., 2010) and South America (Seo & Mendelsohn, 2008) are shifting the crops they plant to match the climate they face. Moreover, farmers' choice of adaptation strategies are found to be sensitive to local climatic condition. For instance in Latin America, farmers in cooler temperature regions are more likely to choose crop variation whereas in dryer locations they would choose changes to the composition of their livestock (Mendelsohn & Seo, 2007).

There exists ample literature assessing the impacts of adaptation on agricultural production. However, many of these studies consider only a few adaptation strategies in their analysis (Waha et al., 2013) and are concentrated at a macro level (Challinor et al., 2014). Such studies provide important information in designing adaptation strategies at the global, regional or national level. Nevertheless, for the effective and robust planning of the adaptations at the local level, it is crucial to understand the impacts of farmers' adaptation practices at farming households and community level. Over the recent years, few studies have investigated the impacts of adaptations on farm productivity taking into account the adaptations employed by farmers (Di Falco et al., 2011; Huang et al., 2015). These studies reported the significant impact of adaptations on enhancing crop productivity.

To date, most of the studies on climate change in agriculture have focused on assessing the impacts of climate change on food production. There is, indeed, a large and growing body of literature that has identified a range of agricultural adaptation strategies. However, very little is known on whether autonomous adaptations by smallholders in their farmlands are effective in improving crop productivity.

3. Background and data

Background

The climate of Nepal is extremely diverse due to exceptionally large altitudinal variation. The average temperature in the country is about 15^{0} C with maximum temperatures occurring in May and June (reaching more than 42^{0} C in the southern plain region) and the minimum temperature occurring in December and January (reaching less than -10^{0}C in the northern mountain area). The average annual rainfall is 1800mm, ranging from more than 5,000mm along the southern slopes of the Annapurna range to less than 150mm in the north of the Annapurna range near the Tibetan plateau (PracticalAction, 2009). The distribution of rainfall based on time and space has important implications. About 80% of precipitation comes in the form of monsoon rain between June and September. The high-intensity rainfall events during the monsoon causes floods and landslides, while prolonged dry spells during summer and winter season cause severe drought. Both these events negatively affect agriculture production.

Studies of temperature data in Nepal reveal a warming trend. One such study by PracticalAction (2009) which analysed maximum temperature data from 45 weather stations for the period 1976 to 2005, revealed the annual temperature had increased by 0.4^0C. Agrawala et al. (2003) using general circulation models shows that the mean annual temperature is likely to increase by an average of 1.2° C and 30° C by 2050 and 2100 respectively compared to a pre-2000 baseline. Similarly, McSweeney et al. (2010) project an annual temperature rise in Nepal of 1.8° C and 2.8° C by 2030 and 2060 respectively. Analysis of rainfall data for 80 stations throughout the country showed decreasing precipitation at the rate of 9.8 mm/decade (MoPE, 2004). Studies also report an increasingly unpredictable rainfall pattern in Nepal (MoE, 2010; Shrestha et al., 2012), and indicate that by 2050 the country will experience annual rainfall decreases of between 20 and 200mm (FAO, 2014).

The existing literature on the effects of climate change on Nepal's agriculture sector focuses on three areas. First, a number of studies have analyzed temperature and rainfall trends (PracticalAction, 2009; Shrestha et al., 2000; Shrestha et al., 1999) and farmers' perception on climate change (Khanal, 2014; Manandhar et al., 2011). The second category of studies has focused on assessing the impact of climate change on the agriculture sector output (Malla, 2009) while the third identifies adaptation practices (Bastakoti et al., 2016; Chhetri et al., 2012; Nayava, 2010). However, an important issue which has been largely ignored in the literature is examination of the impact of climate change adaptation on crop productivity. This is an important gap given Nepal is in the process of planning local and national adaptation programs. This study is, therefore, timely in assisting policy makers in designing and promoting practical and robust adaptation strategies.

In Nepal, agriculture has historically been a dominant sector, contributing about 33% of total gross domestic product and employing 70% of the population. Rice is the most important food crop supplying about 40% of the population's calories (Gauchan & Pandey, 2011). Although rice has special significance and economic importance in Nepal, its production and productivity have not been encouraging and subject to considerable variation (MoF, 2013) (Fig 1). The average rice yield is 3.17 t/ha (MoAD, 2012) which is low compared to other South Asian countries. As rain-fed farming accounts nearly for two-thirds of the cultivated area, prolonged droughts and unseasonal rains has a pronounced effect on rice farming in Nepal. For example, due to unfavourable weather conditions, the area under rice cultivation and the production level fell by 7.2% and 11.3% respectively in 2012/13 compared to the previous year (MoF, 2013). Due to the severe drought in 2006, there was about 13% reduction in the rice area planted (Gumma et al., 2011). Given the importance of rice in Nepal's economy and its sensitiveness to climate change impacts, it is therefore of paramount importance to identify and adopt climate change adaptation strategies that could increase rice productivity.

Data

The study area used for this research is the Tanahun district in the western mid hill region of Nepal which covers an area of 1568.4 sq. km. The majority of the population in the district depends on agriculture for their livelihood and rice is one of the major crops grown. Rice production in the district is mainly rain fed in areas near the river basin and lower hills. For this study, primary data were collected from 150 rice growing households selected by a simple three stage random sampling procedure. First, three village development committees

(VDCs)[1] namely; Ghasikuwa, Jamune Bhanjyang, and Kihun were randomly selected among 46 VDCs in the district. Second, five wards were randomly selected from each VDC. Finally, ten rice growing households from each ward were randomly selected. Data were collected during the January-February 2014 for the cropping year 2012-2013.

To identify the adaptation practices that farmers have adopted in the study sites, focus group discussion (FGD) was conducted with 18 participants. The participants in the FGD include local experts in climate change and rice growing farmers. The identified adaptation practices were then included in the survey questionnaire to assess the actual adaptation by the sample households. The surveyed farm households were asked questions about the adjustment in agricultural practices they had carried out in response to the changing climate. A semi-structured questionnaire was used to interview the sampled farmers to collect information on input, output, adaptation and socio-economic characteristics of farmers. Table 1 presents the descriptive statistics for the surveyed households. On average, a farming household cultivates rice in two parcels of land with a total area of 0.33 hectares. Utilizing 94 days of labour per hectare, on average a farming household produces 3,041 kg rice per hectare.

4. Modelling adaptation and rice productivity

Rice productivity was simply calculated as the ratio of rice production of a household expressed in kilograms to the rice cultivated area of the household expressed in hectares. For analytical purposes, the sampled households were placed into two groups; adopters and non-adopters. Households which adopted at least one adaptation practice are grouped as adopters, and the households that do not adopt any practices are grouped as non-adopters. To ensure that the adaptation practices adopted by farmers were designed to combat climate change

[1]A VDC is the administrative unit in Nepal. Each district has several VDCs, and each VDC is further divided into several wards.

instead of other pressures, farmers were asked to mention only the practices that they adopted to minimize the adverse impacts of climate change.

A number of approaches can be employed to examine the impact of technology adoption on agriculture production. The difference-in-difference approach has been widely used (Yorobe et al., 2011). However, this approach requires a before and after analysis to be used. In our case, farmers have been adopting various adaptation practices at the different points of time and therefore no common time period is available. Another approach is the application of propensity score matching to a cross-sectional dataset. However, this approach does not take into account unobserved effects (Mendola, 2007). A more suitable method is the endogenous switching regression model, which accounts for both observed and unobserved factors when estimating the impact of adaptation on rice productivity (Di Falco et al., 2011).

The endogenous switching regression model accounts for both endogeneity and sample selection. This approach first models adoption decisions (e.g., adaptation) by binary dependent variable methods, and subsequently the equations for the outcome variable (e.g., productivity) are modelled for both groups - in this case adopters and non-adopters - conditional on the adoption decision.[2] We model the climate change adaptation and rice productivity under the assumption that farmers choose to adopt adaptation practice if it generates net benefits. 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 & Huffman, 2014): that is $Y_{Ai} > Y_{Ni}$.

[2] The first stage uses a probit model to determine the relationship between adoption of adaptation and household and farm characteristics. In the second stage, separate regression equations are used to model rice productivity conditional on a specified criterion function.

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.

$A_i^* = Z_i\alpha + \eta_i$ with $A_i = 1$ if $A_i^* > 0$ and 0 otherwise (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 household and farm characteristics which influence the farmer's decision to adopt climate change adaptation practices. We included household characteristics such as age, gender, education, family size, income, migration status, livestock holding and household members' involvement in agricultural institutions. As different farm types adapt differently (Reidsma et al., 2010), farm characteristics such as land holding size and number of parcels under rice cultivation are included in the model. Furthermore, we assume that farmers must have information on climate change before they can consider adopting climate change adaptation strategies in their farmlands. The explanatory variables used in this study and their definition are presented in Table 2.

It is expected that the farmer's choice of an adaptation practice affects rice productivity. Based on this assumption, separate outcome equations are specified for adopters and non-adopters.

$Y_{Ai} = X_{Ai}\beta_A + \varepsilon_{Ai}$ if $Ai = 1$ (2a)

$Y_{Ni} = X_{Ni}\beta_N + \varepsilon_{Ni}$ if $Ai = 0$ (2b) where Y_{Ai} and Y_{Ni} are the rice quantity produced per hectare specified in a log form for adopters and non-adopters respectively. X is a set of explanatory variables that include production inputs specified in log (e.g., fertilizers, labour) and household and farm characteristics included in Z. The vectors β_A and β_N are the parameters to be estimated. For the model to be identified, it is required that there is at least one variable in the adoption equation that does not appear in the outcome equation. The variable representing access to climate information is used as the instrument variable. While access to climate information is expected to affect adoption decisions, it is assumed that it does not affect rice productivity directly.

The three error terms η, ε_A and ε_N in equations (1), (2a) and (2b) are assumed to have a trivariate normal distribution, with zero mean and the following covariance matrix:

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

where Var (ε_A) = σ_A^2, Var (ε_N) = σ_N^2 and Var (η) = σ_η^2 , Cov ($\varepsilon_{A,}$ ε_N) = $\sigma_{AN,}$ and Cov ($\varepsilon_{A,}$ η) = $\sigma_{A\eta}$, and Cov ($\varepsilon_{N,}$ η) = $\sigma_{N\eta.}$ 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 equation (1) η_i is correlated with the error terms of the outcome equations (2a) and (2b), hence the expected values of ε_{Ai} and $\varepsilon_{Ni,}$ conditional on the sample selection, are non-zero (Lee & Trost, 1978), and given as:

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

and,

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

where φ(.) is the standard normal probability density function, and ϕ(.) is the standard normal cumulative density function. The terms λA and λN 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 equations (2a) and (2b) 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 farming household that adopted with respected to the household that did not adopt, which is defined as:

$$E[Y_{Ai}|A_i = 1] = X_{Ai}\beta_A + \sigma_{A\eta}\lambda_{Ai} \quad (3)$$

$$E[Y_{Ni}|A_i = 0] = X_{Ni}\beta_N + \sigma_{N\eta}\lambda_{Ni} \quad (4)$$

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, is given respectively as:

$$E[Y_{Ni}|A_i = 1] = X_{Ai}\beta_N + \sigma_{N\eta}\lambda_{Ai} \quad (5)$$

and

$$E[Y_{Ai}|A_i = 0] = X_{Ni}\beta_A + \sigma_{A\eta}\lambda_{Ni} \quad (6)$$

The change in the rice yield due to adoption of climate change adaptation strategies can be calculated as the difference between (3) and (5), which is termed the average treatment effect (TT):

$$TT = E[Y_{Ai}|A_i = 1] - E[Y_{Ni}|A_i = 1] = X_{Ai}(\beta_A - \beta_N) + (\sigma_{A\eta} - \sigma_{N\eta})\lambda_{Ai} \quad (7)$$

Similarly, we can calculate the effect of the treatment (adoption) on the untreated (non-adopted) (TU) for the household that did not adopt as the difference between (4) and (6):

$$TU = E[Y_{Ni}|A_i = 0] - E[Y_{Ai}|A_i = 0] = X_{Ni}(\beta_N - \beta_A) + (\sigma_{N\eta} - \sigma_{A\eta})\lambda_{Ni} \qquad (8)$$

5. Results and discussions

5.1 Rice farmers' adaptation strategies

The findings of the study show that about 77 % of the household adopt at least one adaptation practices in their rice farms in response the adverse impact of climate change. The climate change adaptation practices include an adjustment in timing of farm operations, selection of varieties, crop rotation, improved irrigation and fertilizer management (Table 2). Among the adopted adaptations, the adjustment in timing of farm operations is the most common whereas fertilizer management is the least common (Fig 2). The reason behind the higher level of adoption of adjustment in timing of farm operation in response to the impact of climate change may be due to the lower cost associated with this adaptation and less effort required in its implementation. The main reason behind not taking up adaptation practices is the lack of information about the practices (Fig 3).

5.2 Adaptation determinants

The second column of Table 3 presents the results of the adoption equation and represents the determinants of adaptation. Age of the household head has a significantly negative impact on adoption which indicates that younger farmers are more likely to employ adaptation practices than older ones. The existing literature shows a mixed assessment of the impact of age of household on adaptation (Deressa et al., 2009; Hassan & Nhemachena, 2008; Piya et al., 2013). The coefficient of family size is positive and significant suggesting that households with larger family size are more likely to adopt adaptation practices in response to climate change impacts. Migration of any member of a household outside the village has a negative and significant impact on adaptation. This may be explained by participation in non-farm activities impeding the involvement in farm production activities (Abdulai & Huffman, 2014). Land holding has a positive and significant impact on adaptation. A similar finding is reported by Piya et al. (2013). The variable rice parcel is also positive and significant, indicating that households cultivating rice in multiple plots are more likely to adopt adaptation strategies. The positive and significant coefficient of climate information indicates that farmers who obtain information on climate change are more likely to adapt to climate change - a finding consistent with the Bryan et al. (2009) Ethiopian and South African studies. The literature shows the varying relationship of household characteristics such as gender, education, income, livestock holding, and membership in agriculture-related institution with adaptations (Deressa et al., 2009; Hassan & Nhemachena, 2008; Kurukulasuriya & Mendelsohn, 2008; Piya et al., 2013). However, our findings did not show any significant impact of these variables on the adoption of climate change adaptation practices in the study region.

5.3 Rice productivity

The overall average rice productivity in the study site is 3,041 Kg/ha which is lower compared to average rice productivity in Nepal of 3,312 Kg/ha (MoAD, 2012). Most of the area under rice production in the study site is rain fed and which may therefore be the reason behind lower productivity. Furthermore, the rice productivity of adopters (3,328.61 kg/ha) is found to be significantly higher (P value < 0.001) than that of non-adopters (2,061.50 kg/ha). This finding is in line with other studies (Di Falco et al., 2012; Zhou & Turvey, 2014) which find the implementation of adaptation strategies improves farm productivity. However, this approach does not take into account the sample selection bias.

The estimates presented in the last two columns of Table 3 account for the endogenous switching in the rice productivity function. The estimated coefficients of the correlation terms ρ are not significantly different from zero, indicating the hypothesis of absence of sample selectivity bias in adaptation may not be rejected (Di Falco et al., 2011). However, the differences in the coefficients of the rice productivity equation between adopters and non-adopters shows the presence of heterogeneity in the sample. Table 4 presents the expected rice productivity for the adopters and non-adopters under adopted and not adopted conditions. Cells (a) and (b) represent the expected rice productivity observed in the sample. The expected rice productivity for the adopters is about 2,726 kg, and 2,050 kg for the non-adopters. This indicates that on average the adopters produced about 32% (676 kg/ha) more than the non-adopters. The last column of Table 4 presents the average treatment effects, which show the impact of adaptation on rice productivity. These treatment effects account for the selection bias arising from the probability that adopters and non-adopters are systematically different (Abdulai & Huffman, 2014). Cell (c) represents the expected rice production per hectare by the adopters if they had decided not to adopt and cell (d) represents the expected rice production per hectare by the non-adopters if they decided to adopt. Farming households who actually adopted would have produced about 648 kg/ha less if they had not adopted. Similarly, Farming household who actually did not adopted would have produced about 241 kg/ha more if they had adopted. These results suggest that adoption of climate change adaptation practices significantly increases rice productivity.

6. Conclusion and implications

This study compares the rice productivity between farms adopting climate change adaptation practices and those not adopting based on cross-sectional survey data collected in the Tanahun district of Nepal. The average rice productivity of adopting farms is found to be significantly higher than that of non-adopting farms. This means the adaptation practices which farmers have been autonomously adopting in rice farms is playing an important role in maintaining or increasing rice productivity in the context of climate change. The findings of the study show that about 22% of the households did not employ any adaptation practices. Thus, it is clear that agricultural development policy should focus, not only on the planning and implementation of long term planned adaptation strategies, but also on the improvement, promotion and wider extension of autonomous adaptation strategies.

The study also reveals that households with a greater number of plots under rice cultivation and households with larger land holdings are more likely to employ adaptation strategies. This may be because of easier adoption of adaptation practices in larger plots. It may also be because households having a greater number of plots are more likely to take the risk of adopting innovations in at least one of their many plots. Consequently, policies aiming at promoting adaptation to climate change could first demonstrate the benefits of adaptation strategies with households with a greater number of farm plots and subsequently promote adaptation on a wider scale. The study shows that age of the household head and migration of family members out of the village have a negative impact on adaptation. Specifically, younger farmers are more likely to employ adaptation practices. Policy interventions should therefore focus on young people in villages who are involved in agriculture by providing necessary training and building their capacity for further enhanced adaptation to climate change. We find that access to climate information plays an important role in determining farming households' decision to adapt. This indicates the importance of awareness raising and capacity building activities in rural areas of Nepal which are designed to enhance farmers' awareness on climate change issues.

The study found that 77% of farmers have adopted at least one adaptation strategy to combat climate change impacts and which have a positive and significant contribution to rice productivity. This indicates that farmers are aware, to some extent, of climate change impacts. Also, they clearly have the knowledge of, and skills relating to, different agricultural management practices that contribute to maintaining and increasing productivity in the context of climate change. Policy makers could therefore more fully recognise the contribution of these adapting farmers, learn from them and focus on further identification, improvement, and promotion of such strategies.

This study does however have some limitations. Its methodology involves making adaptation a binary variable. However future studies could provide further valuable insights into how to improve adaptation systems by examining the effect of different types of adaptation strategies on crop yields. Furthermore, consideration of profitability and the environmental impact of adaptation practices is equally important.

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Table 1. Definition and descriptive statistics of the variables

Variables	**Definition**	Mean	SD
Rice productivity	Rice production in Kg per hectare	3041.33	1299.79
Adaptation	Dummy = 1 if the farming household adapted to climate change, 0 otherwise	0.77	0.42
Labour	Labour use per hectare (days)	94.23	29.46
Gender	Gender of the household head (takes the value of 1 if female)	0.46	0.50
Age	Age of the household head in years	48.14	14.48
Education	Education of the household head in number of years of schooling	5.19	4.16
Family size	Family size in number	4.34	2.39
Migration	Out-migration of family members (takes the value of 1 if any member of the household is living outside the village for more than 6 months during 2012-13)	0.63	0.48
Rice Area	Area under rice in hectare	0.33	0.26
Rice parcel	Total number of plots under rice cultivation	2.08	1.17
Land holding	Total land holding of the household in hectare	0.46	0.22
Livestock holding	Total livestock holding of the household in livestock standard unit (LSU)[†]	2.37	1.23
Household income	Total income of the household in Nepalese Rupees	158,566.67	61,216.24
Membership	Membership of family members in agricultural institutions (takes the value of 1 if any member of the household is member in institutions)	0.65	0.43
Climate information	Dummy = 1 if the household received information on climate change, 0 otherwise	0.32	0.47

[†]LSU is aggregates of different types of livestock in standard unit. 1 LSU = 1 buffalo = 1 cattle = 3 sheep or goats = 10 poultry (CBS, 2003)

Table 2. Description of adaptation strategies

Adaptation Strategies	Description
No Adaptation	No adjustment in agricultural practices in response to climate change
Adjustment in time of farm operation	Shifting on sowing/transplanting/weeding/harvesting time
Selection of varieties	Selection of varieties with higher tolerance capacity to drought, higher temperature and frost, and early maturing varieties to escape extreme weather events
Crop rotation	Growing different crop species before or after rice cultivation in the same piece of land
Improved irrigation	Improvement in irrigation method, changing number and intensity of irrigation
Fertilizer management	Changing fertilizer application method, fertilizer types and quantity

Table 3. Endogenous switching regression results for adaptation and impact of adaptation in rice productivity

Variables	**Adaptation**	**Rice Yield (log)**	
		Adapters	**Non-adapters**
Area (log)	0.341	0.644***	0.602**
	(0.632)	(0.106)	(0.266)
Fertilizer (log)	-0.419**	0.016	0.234***
	(0.181)	(0.027)	(0.082)
Labour (log)	-0.605	0.139*	0.456*
	(0.544)	(0.085)	(0.250)
Female	-0.393	0.090*	0.126
	(0.351)	(0.055)	(0.159)
Age	-0.036***	-0.003	-0.013
	(0.013)	(0.002)	(0.008)
Education	-0.069	0.009	0.015
	(0.052)	(0.007)	(0.023)
Family size	0.118*	0.022*	0.009
	(0.075)	(0.012)	(0.028)
Migration	-1.183***	-0.202***	0.187
	(0.437)	(0.058)	(0.237)
Land holding	0.143***	0.006	0.018
	(0.055)	(0.004)	(0.029)
Livestock holding	-0.061	0.059**	0.161**
	(0.173)	(0.025)	(0.077)
Household income	0.023	0.005***	0.004*
	(0.074)	(0.001)	(0.002)
Membership	-0.098	0.201***	0.389***
	(0.321)	(0.061)	(0.149)
Rice parcel	0.538*	0.019	-0.128
	(0.289)	(0.029)	(0.186)
Information on climate change	0.681** (0.324)		
Constant	5.208***	4.483***	2.876***
	(1.751)	(0.249)	(1.042)
σ		0.268(0.018)***	0.331(0.045)***
ρ		0.287(0.304)	-0.145(0.731)

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

Table 4. Impact of adaptation on expected rice productivity

Sub-samples	Decision stage		Treatment effects
	To adopt	Not to adopt	
Households that adopted	(a) 2726.314 (53.127)	(c) 2078.101 (64.512)	TT=648.213*** (106.132)
Households that did not adopt	(d) 2291.803 (95.764)	(b) 2050.428 (134.523)	TU=241.375*** (96.472)

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