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Economic impact of climate change on agriculture using Ricardian approach: A case of northwest Vietnam

Nguyen Thi Lan Huong [a,b,1], Yao Shun Bo [a,*], Shah Fahad [a,1]

[a] College of Economics and Management, Northwest A&F University, Yangling, Shaanxi 712100, PR China
[b] HoaBinh Technical and Economics College, Hoa Binh Province 350000, Viet Nam

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ABSTRACT

The impact of climate change on agriculture will help to clarify the perception of the problem and quantify the impact, contributing to the formulation of sustainable livelihoods. This study uses the Ricardian approach to explore the implications of climate change on agriculture in the Northwestern area of Vietnam by taking farmer adaptations into account. The study uses secondary data of 1055 households which selected from Vietnam Household Living Standards Surveys in 2012 dataset and climate. To examine the effect of an infinitesimal change of temperature and rainfall in Northwest farming, marginal impact analysis was conducted. The study then predicts the impact of climate scenarios on net revenue for the years 2050 and 2100. The study found that relationship between household revenue and weather variables are nonlinear significant and inverted U-shaped relationships between the two seasons. Net revenue decreased as temperature and rainfall increase in the dry season. Net revenue projected to decline about 17.7% and 21.28% due to climate change in 2050 and 2100 respectively in without adaptation model. Net revenue would be loss about 0.37% and 0.20% in 2050 and 2100 respectively in with adaptation model.

1. Introduction

Climatic change influences all regions of the world, which causes significant perturbations that can be expected to be natural systems that have inevitable impacts on the economic policies of highland areas (Kohler and Maseli, 2012) through both direct and indirect means (Fahad and Wang, 2017). There has been a focus on various impacted aspects like water resources, agriculture, fisheries, forestry, human health, infrastructures, ecological system and so on, which are considered to be essential to livelihood (Kohler and Maseli, 2012; Huong et al., 2017). The communities most vulnerable to climate change are the poorest, for they are involved in agricultural production, and their livelihoods are considerably dependent on the natural environment (SRD, 2011). Vietnam is one of the countries that are most affected by the impacts of climate change (WB, 2010; ISPONRE, 2009) due to its long coastlines, the high concentration of population, the economic activities heavily relied on agriculture, exploit natural resources and forestry. In Vietnam, climate change does not only affect the coast and the delta but also today affects more of the high mountains in the Northwest (UNDP and IMHEN, 2015; Jamieson et al., 1998). Its climate change is taking place with increasing frequency and tends to increase in hazard. The phenomena such as drought, heavy rain cause erosion, and landslides, and extreme weather like ice and snow, frost, which makes it too cold in winter and too hot in summer (CARE, 2013; MONRE, 2012; SRD, 2011; UNDP and IMHEN, 2015). In Vietnam, impact assessment of climate change and how to improve the ability to cope or to recover were studied in the coastal areas, mangrove areas or delta areas (Dang et al., 2014; Can et al., 2013; Razafindrabe et al., 2012; Vien, 2011; Dung and Phuc, 2012). Though there are some findings on assessing the impact and adaptation of climate change in Northwest area (Schad et al., 2011; Zohova, 2011; Do et al., 2013; SRD, 2011), they only considered qualitative parameters. To our knowledge, up to date, the current findings do not contain any metrics that quantify the specific impact of climate change on agricultural production in

* Corresponding author.
E-mail addresses: huongkthb@gmail.com (N.T.L. Huong), yaoshunbo@163.com (Y.S. Bo), shah.fahad@nwafu.edu.cn (S. Fahad).
[1] The authors contributed equally.

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this region. This is also the area that annually suffers severe consequences of climate change due to the distinct climate characteristics compared to the other areas in the country. Agriculture plays a vital role in economic development and food security in the Northwest mountain area (Zohova, 2011; ILRI, 2014). Agricultural production is the primary source of income for most of the households; production depends on exploitation of natural resources. Also, limited literacy levels, outdated farming techniques, poor infrastructure development, transportation difficulties all aggravate the vulnerability to the climate here. Therefore, the impact study of climate change on agriculture will help clarify the perception of the problem and quantify the impact, contributing to the formulation of plans to respond timely.

This paper used Ricardian approach to analyses the relationship between farm household's net revenue and climate variables (rainfall and temperature); Identify the climate impacts trends and forecast damage to households' net revenue under climate change scenarios in the coming years. It is expected that findings from this research will make a contribution to practical adaptation initiatives in the context of climate change for mountain areas in particular and for Vietnam in general.

The remainder of this paper is structured as follows: The methodology used is defined in the following section (Section 2). Section 3 presents the survey design and data collection. The results and discussion parts are discussed in Section 4 and 5, while Section 6 concludes the study.

2. Methods

The Ricardian method is a model that uses a cross-sectional approach to studying agricultural production. The model was developed from the studies land values would reflect its net productivity by David Ricardo (1772–1823). And then in 1994, Mendelsohn et al., introduced this method to estimate the impact of climate change on agriculture. Ricardian models completed in many countries and areas over the world, such as in America (Seo and Mendelsohn, 2007; Mendelsohn et al., 1994; Mendelsohn and Reinsborough, 2007), in Africa (Eid et al., 2007; Ouedraogo et al., 2006; Deressa, 2007; Kurukulasuriya and Mendelsohn, 2008), in Asia (Liu et al., 2004; Mishra and Sahu, 2014; Seo et al., 2005) and Europe (Lippert et al., 2009; Chatzopoulos, 2015). All indicate that net agricultural revenue or land value depends upon climate, soils and economic conditions. The method based on land the assumption that land rent would reflect the long-term net productivity of farmland. The principle is captured by the following equations (1) (Mendelsohn et al., 1994; Mendelsohn and Dinar, 2003)

$$V = \sum P_i Q_i(X, C, S, G, H) - \sum P_x X \quad (1)$$

where *Pi* is the market price of crop i, *Qi is* the output of crop i, *X* is a vector of purchased inputs (other than land), *C* is a vector of climate variables, S is a vector of soil variables, *G* is a vector of economic variables, *H* is water flow, and P_x is a vector of input prices.

In theoretical profit function, this study assumes that farm households are always looking to optimize their profits basing on the terms available of the inputs change, and they will select crops, production type or input to maximize net income, which will be a function of just the exogenous variables.

Input demand function of households is a function that relies on the market price of the input, while the market price of the output expected under the impact of weather factors, climate, and other factors. Output and input market prices in Ricardo model are expected values in the markets. This is an important hypothesis of this study. If it is rejected, the study will be invalidated because the estimation of the model is of no significance. The standard Ricardian model relies on a quadratic formulation of climate. Consequently the net value of the land can be expressed as follows Mendelsohn and Dinar (2003):

$$V = \beta_0 + \beta_1 C + \beta_2 C^2 + \beta_3 S + \beta_4 G + \beta_5 H + \mu_i \quad (2)$$

where V is land value, C is a vector of climate variables, S is set of soil variables, G is set of household's socioeconomic variables, H is set of water flow, the β coefficient of the variables and μ is an error term.

The net revenue climate response function (Eq. (2)) is expressed by quadratic term to reflect the nonlinear shape which indicates how that marginal effect will change as one moves away from the mean (Mendelsohn et al., 1994). When the quadratic term is positive, then the net revenue function is U-shaped, and when the quadratic term is contrary, it is hill-shaped. According to previous cross-sectional analyses, farm net value is expected to have a hill-shaped relationship with temperature. Each crop has an ideal temperature that enables itself to grow best in the seasons. However, the relationship of seasonal climate variables may include a mixture of positive and negative coefficients and more complicated.

The Ricardian model was developed to demonstrate the variant of land value per hectare of cropland over climate zones (Seo and Mendelsohn, 2007; Mendelsohn et al., 1994). Accordingly, the Ricardian approach takes adaptation into account by measuring economic losses such as reduction in net income or the value of land due to environmental factors. On the other hand, secondary data can be relatively easy to collect by cross-sectional sites on climatic. Therefore, this method reduces the cost of data collection more than other methods.

There are some drawbacks in applying this model. The first, it does not take price effects into account. With assumed the price to be equilibrium, the Ricardian estimate would be either over- or underestimating the climate change impacts in case of significant climate change the crop, price could change for a prolonged period (Ouedraogo et al., 2006; Mendelsohn and Tiwari, 2000). However, Mendelsohn and Tiwari (2000) argue that keeping prices constant is justified because of the difficulty in predicting the global crop model, the range of warming expected for the next century and the change of aggregate supply lead to it does not pose a severe problem in using the model.

Non-climatic factors as socio-economic conditions, market access and the fertilization effect of carbon dioxide concentrations are limited or not taken into account in the full model (Mendelsohn et al., 1994). Meanwhile, these factors have an inevitable impact on crop yield or the adaptation of the farmers either directly or indirectly. However, in spite of these weaknesses, it can be used to analyze the effects of climate change on agriculture and still widely used in the world recently (Mendelsohn and Dinar, 2009).

The Ricardo model applied to Vietnam in this study was developed from the model (2). In addition to variations in temperature and rainfall (and its non-linear format) analyzed in dry and rainy seasons, this study uses more interaction variables between average temperatures and average precipitations of two seasons to examine their combined impact on net income. This is the difference between Ricardo model applies to Vietnam and Ricardo model of research in other countries (Dung and Phuc, 2012).

$$V_{net} = \beta_0 + \beta_1 Td + \beta_2 Td^2 + \beta_3 Tr + \beta_4 Tr^2 + \beta_5 Rd + \beta_6 Rd^2 + \beta_7 Rr + \beta_8 Rr^2 + \beta_9 TdRd + \beta_{10} TrRr + \sum_{j=1}^{n} c_j G_j + \mu \quad (3)$$

where V_{net} is farmland net revenue, T and Rare respectively the mean temperature and the mean rainfall; while r represents rainy season and d dry season, Gj is a set of socio-economic characteristics of the household, while β_i, a_i and c_j are coefficients of the variables, β_0 is a constant term, and μ is an error term.

The independent variables include the linear and quadratic terms of temperature, rainfall, and characteristics of the household and socio-economic variables. Because the land characteristics of the study area are similar, the soil factor is removed from the model. Some variables such as latitude, altitude, flood-prone, and wetland included in the original model were not taken into account in the present study because those data were unavailable (Kurukulasuriya and Mendelsohn, 2008). Some socioeconomic variables such as household size, education attainment, access to extension services, all of which were not included in the original model now are accounted in the present study to capture farmers' adaptation to climate change. Because the study was conducted in the same region, no significant differences of climatic conditions thus regional variables are not considered.

Household net revenue is taken as dependent variables. Respective net revenue variables are total revenue fewer costs (involving expenses related to cash outlay). During the study, we found that the livelihood majority of households are integrated agricultural production (cultivation, livestock, fishing, forestry) so that it is very difficult to calculate total net revenue per hectare. Therefore, we used revenue per household as the dependent variable.

Definitions, units and other characteristics of the variables in the model are presented in details in Table 1.

From Eq. (3) we can derive the marginal impact of a dry season temperature (T_d) on household revenue evaluated at the mean as follows:

$$MI_{Td} = \left[\frac{dV}{dT_d}\right] = [\beta_1 + 2\beta_2 Td + \beta_9 Rd] \tag{4}$$

The change in welfare measured impact of climate change, ΔMI can be expressed as follows:

$$\Delta MI_{Td} = MI_{Td+1} - MI_{Td} \tag{5}$$

Combining Eqs. (4) and (5) and assuming other factors are constant, ΔMI_{Td} can be measured as follows:

$$\Delta MI_{Td} = [\beta_1 + 2\beta_2(Td_{tb+1}) + \beta_9 Rd] - [\beta_1 + 2\beta_2 Td_{tb} + \beta_9 Rd] \tag{6}$$

If the change increases net income, it will be beneficial, and if it decreases net income, it will be harmful. The marginal impact value for other climatic factors is calculated similarly as above.

3. Study site and data collection

3.1. Study site

The site in this study covers six provinces (Son La, Lai Chau, Dien Bien, Hoa Binh, Yen Bai and Lao Cai) located in Northwest region of Vietnam. While selecting the study area, we considered following adverse effects on that area. At first, due to the typical topography conditions of its high mountains, more and more of the evidence for climate change such as flash floods occur more frequently now and with less time to prepare between the rainstorm and dangerous water levels; Rainfall levels are changing, the rainy season is coming later with is more frequent rain (ISPONRE, 2009; Schad et al., 2011). The dry season is longer than before with dry and hot winds coming earlier. Hence, the weather is warmer than before. Besides, winter is shorter and not so cold (with the exception of some extreme cold bouts killing livestock). Drought happens more often; many water resources are depleted (MONRE, 2012; UNDP and IMHEN, 2015). Landslides are more severe and more continual now (Smyle, 2014). These phenomena are the increasingly severe impact on the livelihoods of the people here.

Secondly, people's livelihoods here are vulnerable to the climate change because of socio-economic characteristics of the region. That is high ethnic diversity (with about 30 ethnic minority and over 70% areas' population) (WB, 2009), the primary source of income is agricultural production, backward farming techniques, poor infrastructure development. Before 1986, Doimoi ethnic minority groups in the Northwest Highlands were mainly engaged in a flash and burn shifting cultivation practice where a section of forest is burned clearly to grow cash crops such as upland rice or maize in the rich soil, which cause soil degradation in the area (Castella et al., 2006). Currently, maize and rice are the two main crops in the Northwest of Vietnam, in terms of production area and income contribution, creating revenues up to VND 1.4 million and VND 1 million per person a year for rice and maize respectively (ILRI, 2014). Raising pigs is the most important source of cash income from livestock. Cattle and buffalo are also raised but only for meat, not a source of draft power as in the past (ILRI, 2014). Livelihoods mainly depend on natural conditions, in addition, local people in these communities do not have a deep understanding of the causes or impacts of climate change so that the level of

Table 1
Descriptive statistics of variables used in regression.

Variables	Description	Unit	Expected sign
NI	Crop Net revenues	1.000 VNĐ	Dependent Variable
Td	Dry season temperature	°C	(+/–)
Td^2	Dry season temperature squared	$(°C)^2$	(+/–)
Tr	Rainy season temperature	°C	(+/–)
Tr^2	Rainy season temperature squared	$(°C)^2$	(+/–)
Rd	Dry season precipitation	mm	(+/–)
Rd^2	Dry season precipitation squared	$(mm)^2$	(+/–)
Rr	Rainy season precipitation	mm	(+/–)
Rr^2	Rainy season precipitation squared	$(mm)^2$	(+/–)
TdRd	Interacting between dry seasonal temperature and rainfall	Interactive variables	(+/–)
TwRw	Interacting between rainy seasonal temperature and rainfall	Interactive variables	(+/–)
Age	Age of household head	Year	+
Edu	Education level of household head (Number of years of formal schooling attained by the household head)	Year	+
Sex	Sex of household head. Male = 1, Female = 0	Dummy	+
Farm area	Cropland area**.** Number of hectares of land cultivated by the farmer	ha	+
Mcrop	Household's cultivated mode. (1: Polyculture; 0:Monoculture)		+
Size	Size of the household.	People	+
Irri	Irrigation water use proactively (1: Active irrigation; 0: Passive irrigation)		+
Es	Access to extension services. (1: The commune has an extension station; 0: The commune has no extension station).		+
Credit	Access to credit (1: Debt; 0: No debt).		+

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vulnerability to the phenomenon of climate change is further increased (Isabel, 2010).

Third, Northwest region of Viet Nam is ranked the poorest area of the country. Local economic growth has been slow (Vandemoorteleand Bird, 2011) with a human development index ranges from 0.53 to 0.66 in the provinces (UNDP, 2011), and a literacy rate of people is 80.3% (in 2008) (ILRI, 2014). The poverty rate of the highland is the highest in the country stands at around 40 percent (GSO, 2016). Therefore, this study is to identify trends of their impact and forecast damage to agricultural production in the coming years according to climate change scenarios. It is expected that findings from this research will make a contribution to practical adaptation initiatives in the context of climate change for mountain areas in particular and Vietnam in general.

3.2. Data collection

With farming households as research subjects, a total of 1055 farm households from six provinces were randomly selected from Vietnam Household Living Standards Surveys (VHLSS) in 2012 dataset (GSO, 2012). From this database were selected: socioeconomic characteristics of agricultural households, farm characteristics, a factor of production and socio-institutional environment of the farmer. Based on the number of meteorological stations in the area, topographic features of the area and number of samples, we selected sample farm households within a 50 km radius of the nearest meteorological station. This limits the sample reduction for the model.

Identification of climate information for the study site was made by: taking the climatic data of the nearest meteorological station to the study site. If a research site can receive data from more than one station, priority is given to data of the meteorological station located in the same district or province. Climate data were collected by IMHEN from MARD website source (MARD), which includes the monthly mean temperature total monthly precipitation in the 2001–2012 periods of 27 meteorological stations in the region. Average climatic data were calculated according to season based on classification: the rainy season from May to October and a dry season from November to April of next year). The key summary statistics of all the variables used in the estimation are given in Table 2.

To forecasting damage to households' net revenue under climate change, Climate change and sea level rise scenarios B2 for Vietnam was used. This scenario was first published by the Ministry of Vietnam Natural Resources and Environment in 2009 on the basis of a combination of national studies (as Meteorological data of hydro-meteorology; Terrain data of the map; Studies by the Institute of Meteorology Hydrology and Climate Change, Advisory Council of the National Committee on Climate Change, etc) and sea level and international studies (as The Fifth Assessment Report (AR5) of the IPCC) (MONRE, 2012). The information in this scenario is the basis for ministries, agencies, and localities to assess the impact of climate change and develop solutions to respond to climate change today.

4. Results

4.1. Regression models

This study applies two main set of the modified Ricardian model. The first model is defined without adaptation, which relies only on integrated physical factors as climatic variables. In the second model, net revenue is function of two sets of regressors are climate variables and socio-economic variables such as characteristics of the households (age of household head, education level, sex of household head, cropland area, household size), proactive irrigation water use and access to extension service and credit.

These have enabled us to take farmers' adaptations into consideration and to assess their effects on the agricultural income. This second stage will lead us to the model with adaptation options. The coefficients of Ricardo model in two models that are with and without adaptations were respectively estimated. With cross-sectional data, conventional regression (OLS) may encounter problems such as variance, multicollinearity, the effect of extrinsic value, and autocorrelation, which biases the estimation results. In order to limit the above issues, some previous studies (Mano and Nhemachena, 2007; Benhin, 2006) used the quartile regression method. A quartile is interpreted as the value in the sample taking into account the position in the sample after being sorted; a value commonly used in the percentile is median. The extraneous value usually changes the sample meanwhile the median may not change in the sample. These authors argue that the purpose of quantile regression is to estimate the median value of the dependent variable instead of estimating the mean of the dependent variable in the OLS regression, eliminating the problem of external

Table 2
Summary statistics of variables used in the Ricardian model.

Variable	Mean	Std. Dev	Min	Max
Crop Net revenues (1000VND)	16007.09	5416.69	6300	34,000
Dry season temperature (°C)	19.42	1.33	16.72	21.30
Dry season temperature squared ((°C)^2)	378.97	50.84	279.56	453.69
Rainy season temperature(°C)	26.23	2.03	22.53	28.88
Rainy season temperature squared ((°C)^2)	692.19	105.20	507.60	834.05
Dry season precipitation (mm)	49.12	20.84	24.33	107.68
Dry season precipitation squared ((mm)^2)	2846.52	2643.06	591.95	11594.98
Rainy season precipitation (mm)	239.38	65.78	133.52	360.83
Rainy season precipitation squared ((mm)^2)	61624.58	32009.18	17827.59	130198.3
Interacting between dry seasonal temperature and rainfall	938.76	354.76	483.44	1860.71
Interacting between rainy seasonal temperature and rainfall	6262.06	1675.44	3335.33	8270.22
Age of household head (Years)	43.05	8.72	25	64
Education level of household head	2.19	0.89	1	5
Sex of household head. Male = 1, Female = 0	0.70	0.45	0	1
Cropland area**.** Number of hectares of land cultivated by the farmer (ha)	0.757	0.343	0.201	1.588
Household's cultivated mode. (0/1)	0.41	0.49	0	1
Size of household (Person)	4.93	1.06	2	7
Irrigation water use proactively (0/1)	0.53	0.50	0	1
Access to extension services. (0/1)	0.74	0.44	0	1
Access to credit (0/1)				

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Table 3
Regression results.

Variables	Model without adaptation	Model with adaptation
Dry season temperature	−43278.2 (−37.51)***	−35220.29 (−11.96)***
Dry season temperature squared	1002.80 (35.61)***	839.64 (11.69)***
Rainy season temperature	61119.82 (39.87)***	49141.13 (3909.50)***
Rainy season temperature squared	−1124.04 (−38.59)***	−910.69 (−2.94)***
Dry season precipitation	−979.61 (−10.55)***	−462.88 (−1.96)*
Dry season precipitation squared	6.06 (13.64)***	2.89 (2.54)**
Rainy season precipitation	−556.17 (−37.05)***	−435.43 (−11.39)***
Rainy season precipitation squared	0.93 (34.25)***	0.73 (10.48)***
Interaction between temperature and rainfall in dry season	32.08 (8.46)***	15.73 (1.63)*
Interaction between temperature and rainfall in rainy season	0.19 (6.75)***	0.16 (2.24)**
Area		0.30 (5.3)***
Age of household head		−32.23 (−1.43)
Education level of household head		921.71 (4.44)***
Sex of household head		767.88 (1.85)*
Household size		382.70 (2.13)**
Mcrop		950.07 (2.53)**
Irri		947.56 (2.46)**
Access to extension services		1398.69 (3.54)***
Access to credit		1078.71 (2.83)***
Cons	−271824.4 (−15.94)***	−225816 (−5.22)***
N	1055	1055
Pseudo R^2	0.1837	0.2146

Values in parenthesis are Robust t-statistic and figures were rounded.
* Significant at 10% level.
** Significant at 5% level.
*** Significant at 1% level.

value. Hybridize and limit estimate bias and overcoming the variability of the variance in OLS regression. Benhin (2006) mentions that multicollinearity is due to the presence of too many explanatory variables in the model and in general this problem is not entirely nullified. Table 3 depicts the regression estimates of two models. The level of interpretation of the model reflected through Pseudo R^2 was 18.37% in the non-adaptation model and 21.46% in adaptation model. This coefficient equivalent that compared to studies by Mano and Nhemachena (2007) as 18.71% and Benhin (2006) as 16.99%. Although that a large part of the variation in the agricultural income remains unexplained by the accounted variables, these two models remain satisfactory compared to the results obtained in the framework of similar studies (Ouedraogo et al., 2006).

The regression results indicate that most of the climatic have significant impacts on the households' net revenue. These results show that the signs of seasonal climatic variables are same for seasonal climatic variables. While the coefficient of dry season temperature in two models are both negative, those of rainy season are positive. The coefficients of precipitation in two models are negative in both seasons.

Besides climatic factors, the results from the model also show characteristics of the households like, education level of household head, household size, household's cultivated and irrigation mode, access to extension services and credit are positive and significantly effect households' revenue as expected a priority.

4.2. Marginal impacts of climate on agricultural revenue and elasticity

The marginal impact analysis was undertaken to observe the effect of an infinitesimal change in temperature and rainfall on households' net revenue. These results are presented in Table 4. The marginal impacts of the temperature were calculated based upon of the average temperatures of the rainy season and the dry season. Similarly the marginal impacts of the rainfall were calculated on the average annual rainfall of the sample in the rainy season and in the dry season. The results show that increasing temperature during dry season significantly reduces the households' net revenue in both models. Per 1 °C increase in temperature in dry season would lead to reducing the net revenue by 43278.2 (1000VND) and 35811.68 (1000VND) in model non-adaptation and model with adaptation respectively. Increasing temperature marginally during the rainy season increases the households' net revenue by 61119.82 (1000 VND) and 51045.72 (1000VND) in both models respectively.

Increasing precipitation levels during the dry and rainy season significantly reduce the net revenue of households in both models. Marginal increasing precipitation during the dry and rainy season decreases households' net revenue by 979.61 (1000VND) and 556.17 (1000VND) in the model without adaptation respectively. It also reduces net revenue in model with adaptation, even though the level of reduction is not significant

The impact trends of climate on net revenue are presented in Figs. 1 and 2. The squared terms of temperature variables are opposite from two seasons implying that impact trend of temperature change on net revenue between the two seasons is opposed.

Based on the sign of their coefficients, dry season temperatures exhibit a U-shaped relationship with net revenue and rainy season temperatures a hill-shaped one. Because the marginal effects of dry

Table 4
Marginal impact of climate on households' net income.

		Model Without Adaptation	Model With Adaptation
Temperature (1000VND/household/°C)	Dry season	−43278.2 (−53.95)***	−35811.68 (43.96)***
	Rainy season	61119.82 (−106.37)***	51045.72 (−87.53)***
Impact of Rainfall (1000VND/household/mm)	Dry season	−979.61 (−2.84)***	−356.63 (−1.03)
	Rainy season	−556.17 (−10.56)***	−453.55 (−8.43)***

Number in bracket represents the elasticity of climate variables.
**Significant at 5% level.
***Significant at 1% level.
*** Significant at 1% level.

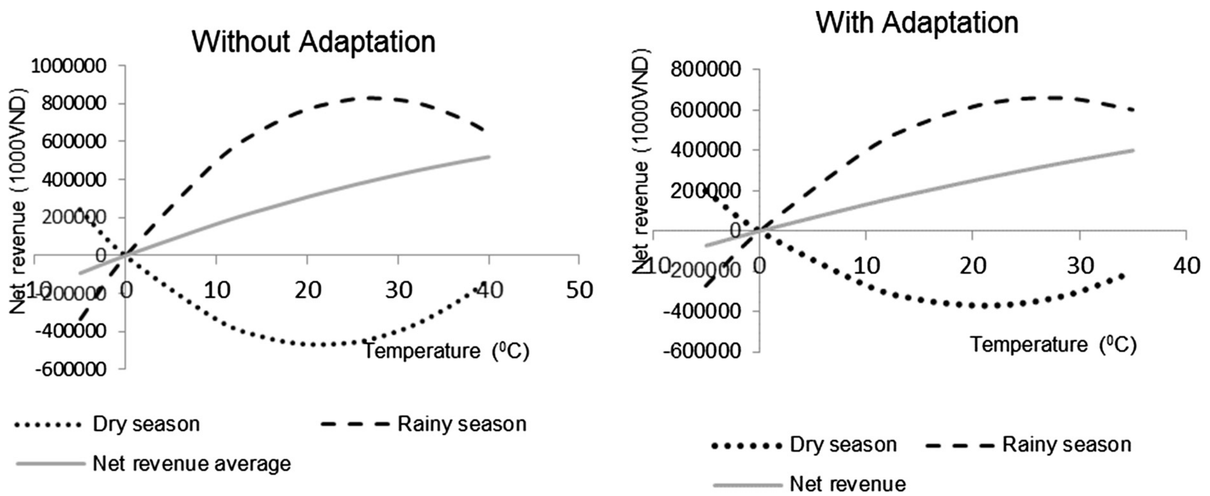

Fig. 1. Impact trend of temperature to household's net revenue.

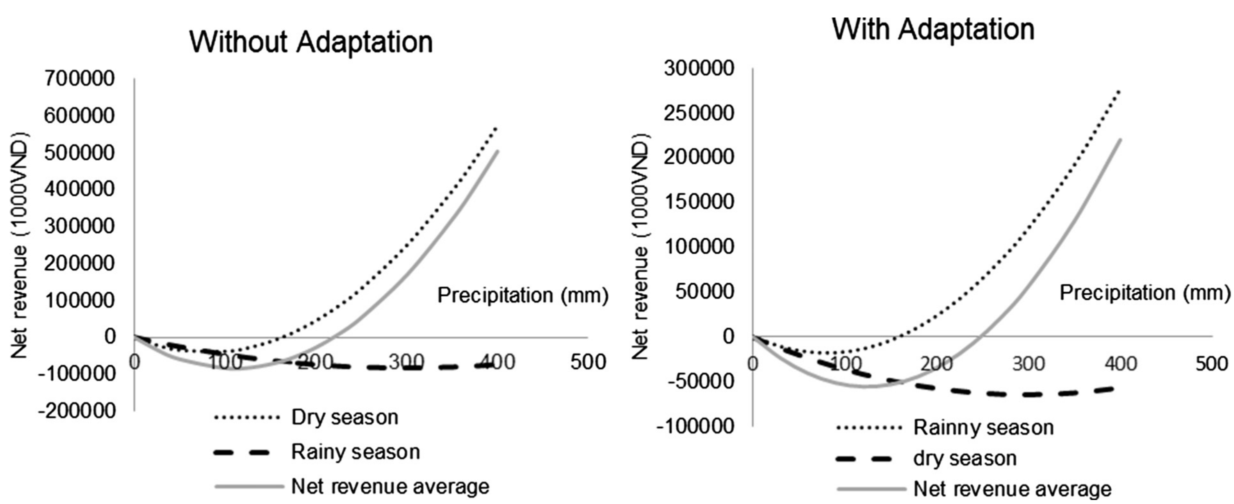

Fig. 2. Impact trend of precipitation to household's net revenue.

Table 5
Impacts from climate scenarios on net revenue.

Period	Temperature (°C/month)		Rainfall (mm/month)		Change in net revenue (1000.VND/household)	
	Dry season	Rainy season	Dry season	Rainy season	Model Without Adaptation	Model With Adaptation
2050	+1.5				−5887.02 (−0.464)	−4132.48 (−0.341)
		+1.1			+3201.17 (+0.253)	+2179.77 (+0.180)
			+0.7		+57.53 (+0.005)	+31.08 (+0.003)
				+3.0	−195.86 (−0.015)	−404.11 (−0.033)
Scenarios B2 in 2050 for Northwest Vietnam					−2824.18 (−17.70)	−2325.74 (−0.192)
2100	+3.0				−7262.52 (−45.499)	−4487.57 (−0.370)
		+2.2			+3682.08 (+23.071)	+2156.67 (+0.1778)
			+5.0		+438.44 (2.747)	+235.22 (+0.019)
				+7.6	−255.50 (−1.601)	−433.71 (−0.036)
Scenarios B2 in 2100 for Northwest Vietnam					−3396.50 (−21.282)	−2529.38 (−0.209)

Number in bracket represents the percentage changes.

season temperature are greater than rainy season temperature, thus marginal effects over the years will have a similar trend of the dry season.

The effect trends of rainfall on net revenue are not different for two seasons and for both models.

4.3. Forecasts of climate impacts on agriculture in Northwest Vietnam

Some simulations based on scenarios specific to Vietnam were made to estimate the impact of climate change on the agricultural income. We then examined the consequences of these climate

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change scenarios in 2050 and 2100 which using the estimated model in Table 5. This is because the prediction relates mainly to climate variables but not to other variables in the model as they stand for the interest ones. Based on the results of the models run for the specific scenarios B2 of Northwest Vietnam, we considered an increased temperatures of 1.1 °C and 1.5 °C in 2050, 2.2 °C and 3.0 °C in 2100; a fall in rainfall of 0.7% and 3.0% in 2050, of 5.0% and 7.6% in 2100 (MONRE, 2012). The results of this analysis are shown in Table 5. In the mid of the century, an increase in temperature of 1.5 °C in dry season will decrease net agricultural revenue by 5887.02 (1000VND) for the non-adaptation model and 4132.48 (1000VND) for the model with adaptation, respectively. Similarly, a decrease of 195.86 (1000VND) and 404.11 (1000VND) in net revenue respectively in the non-adaptation model and model with adaptation will be expected with a 3.0% increase in precipitation. As a whole, households' net revenue would be losing of 2824.18 (1000VND) and 2325.74 (1000 VND) for both models in 2050 due to changes in climate.

5. Discussion

The effect of the climate variables on net revenue is also nonlinear. The negative quadratic coefficient implies that there is an optimal level of a climatic variable from which the value function decreases in both directions (Seo and Mendelsohn, 2007). The squared terms are positive specifying that there is a minimum productive level of a climatic variable and that the change of temperature or rainy will increase net revenue (Mendelsohn et al., 1994; Seo and Mendelsohn, 2007). This means that temperature or precipitation affects the net revenue positively up to a certain level, above which it causes damage to the crops. Some crops type can grow faster in warmer climates leading to higher yields and incomes. But temperature is too high or too low and prolonged, would be harmful to crop productivity (Mendelsohn et al., 1994). The regressions show that low dry season temperatures are detrimental to crop production while low rainy season temperatures are beneficial to it. This is because, in the dry season, temperatures in the high mountain areas go down to extremely low, even minus temperatures appeared, the lowest of which recorded was minus 3.7 °C (UNDP and IMHEN, 2015; ISPONRE, 2009). Ice and snow have even occurred in some areas affecting both production and living standards of farmers (SRD, 2010b; Vien, 2011; Yu et al., 2010). So, dry season low temperatures would slow down or even destroy crop growth that will decrease crop production (Mendelsohn, 2014; Mahendra, 2011). It also harms animals (Ngondjeb, 2013; Lam and Vien, 2010) as well as affects the growth of aquatic species (Mishra and Sahu, 2014; Hanh, 2011).

The trend of change in temperature and rainfall was found in this study are also similar trend which found in other areas over the world by research as Seo et al. (2005), Ouedraogo et al. (2006), Deressa (2007), Kurukulasuriya and Mendelsohn (2008), and Dung and Phuc (2012). The impact trend of the average annual temperature to the net income is depended on seasons; the marginal could be either negative (if cool) or positive (if hot) (Chen et al., 2016). The interpretations of the signs and magnitudes of impacts are further explained under the marginal analysis. During spring, a slightly higher temperature with the available level of precipitation enhances germination, as this is the planting season. Winter is a dry season, so increasing temperature and precipitation slightly with the already dry season may encourage diseases and insect pests (Deressa, 2007; Mendelsohn et al., 1994). The reduction in net revenue per household during the summer is due to the already high level of rainfall during this season, an increasing precipitation any further results in extreme weather phenomena such as heavy rainfall, floods and landslides (Ho et al., 2011; UNDP and IMHEN, 2015), damage to field crops and infrastructure. When floods occurred, the rice yields were reduced by 5% for the same crops during the spring season (Schad et al., 2011). Not only that, it affects to the fishery industry due to the loss of fish, damage to irrigation canals and infrastructures (Schad et al., 2011). The reduction in net revenue with increasing precipitation during the autumn is due to this is the harvesting season. More precipitation damages crops and may reinitiate growth during this season. All of these impacts affect directly or indirectly to the household's net income. That means, whether there is an adaptation or not to the rainy season, precipitation has an important role in the impact to net revenue of households.

For other areas of the country, marginal effect trends in the rainy season temperature are greater than the dry season temperature. So the marginal effects of whole year will be the same pace with marginal effects in the rainy season (Dung and Phuc, 2012). This means increasingly asserted that the temperature change is the main factor that explains the spatial variation of revenue in Northwest Vietnam. This can be explained by climatic features of the region; there is a large difference in temperature and rainfall between two seasons (Do et al., 2013). Dry season-low temperature, accompanied by declining rainfall (IMHEN, 2010). Excessive low rainfall in the dry season leads to a shortage of water for life and production. Land with no access to irrigation (usually further from a water source) can only produce one crop a year and production is therefore highly dependent on the timing of the rains (CARE, 2013; Clement et al., 2006). Although adaptation has been partially limiting the negative impact of the rainy season precipitation on net revenue, it has not solved the problem of drought in the dry season. Droughts with increasing seriousness levels make the poor growth of crops then leading to low crop yields or crop failure (SRD, 2010a; WB, 2010). So that transformation of the crop structure and agricultural diversification are considered an appropriate suggestion to adapt to changing rainfall in the dry season to secure crop income as well as food security this season (Minot et al., 2006). Controlling the number of rice crops, limiting the second crop but replacing hedgerows to improve soil quality and support flood control measures (Fischer and Hager (2005)). Marginal impact in a model with adaptation is greater than in model non-adaptation. This means that the farmers taking adaptation measures are less vulnerable to the effects of climatic changes because they integrate the climatic risks better and take enough precautions.

The education level of the household head has positive significant with net revenue (Agossou, 2014; Mishra and Sahu, 2014). If households head has higher education level, they have easier adopted adaptive measures that require knowledge and skill of new science or technologies, thus opportunity to increase revenue more. Access to services and credit have also positive and significant indicating that strengthening the presence of commune extension stations to provide information on new varieties, farming techniques, pest control monitoring, market information, and weather information is an important measure to mitigate the negative impact of climate change on household incomes. In addition to extending access to incentives credit for households, controlling the purpose and effectiveness of loan is also a necessity problem. Some studies show that the loan does not bring benefits to increase income for farmers (Dung and Phuc, 2012). Household's cultivation mode and of irrigation water are both positively and significantly correlated with net revenues. Mixed cropping farming practice not only reduces risks due to fluctuations in weather, but it also makes effective use of the land than the monoculture farming practice. These households with proactive irrigation water use will reduce the negative impacts of the drought in the dry season, thus increasing productivity and incomes. This result is similar to Seo and Mathieu findings (2007) findings and confirmed by Agossou (2014). At present, the agriculture extension sector in Vietnam is experimenting with cropping patterns, reducing the amount of irrigation water and irrigation. Reducing irrigation water is often accompanied by efficient water management technology. That is very expensive if done in the mountains. Therefore, in order to limit the negative impact of drought, it should utilize and store water in rainy season and flood season for mountainous irrigation. In addition, the method of cultivation should be the development of crops on upland fields.

The elasticity shows that agriculture in Northwestern is more sensitive to temperature changes than to precipitation changes in both to models. Moreover, the dry season suffers more yield reduction than the rain season. These results are confirming once again in the report of Worldbank (2010), IMHEN (2010). This suggests that Vietnam Government should develop contingency plans for climate contingencies in Northwest Vietnam. Farmers should be helping in adapt to these new circumstances.

6. Conclusions

This paper describes a Ricardian analysis of farm households' net revenue in Northwestern, Vietnam. The above analysis more or less shows the magnitude and direction of climate change impact on Northwest region of Vietnam. In general, a decrease in rainfall or temperature is expected to be harmful to net revenue. This has a policy implication worth thinking about and planning before damage occurs. Vietnam government must consider designing and implementing adaptation policies to counteract the harmful impacts of climate change. Adaptation options should focus on structural change of crops, development of new plant varieties suitable to the region's climatic conditions, planting drought tolerant, implementing agricultural diversification, educating farmers, opening more extension stations, and strengthen the financial services. This paper also reconfirms that tropical developing countries are sensitive to the predicted climate changes over the next century.

There are a number of caveats that readers should keep in mind when interpreting these results. That is the analysis did not incorporate the potential of future increase of crop productivity; impacts due to the application of farmer's adaptation measures to net revenue are not taken into account; the change in price is not mentioned, and the analysis did not take future technological change into account. Limitations in terms of climate data such as access to climate data are not long enough for 30 years, and there is a lack of climate data for some stations when the statue, the farmer is located not entirely sure. There are the limitations of the study. In addition, the importance of those additional climatic variables other than temperature and precipitation was omitted which lead to bias the predicted impacts of climate change on crop yields (Zhang et al., 2017). There is still a great deal to learn. Although that, significant information for policy-making can be extracted.

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