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Impact of Climate Variation in Paddy Production of Nepal

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IMPACTS OF CLIMATE VARIATION ON PADDY PRODUCTION OF NEPAL

Masters Thesis

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Abstract

Climate change and its consequences on various sectors (human health, water availability, agriculture) are important global issues. Agriculture sector is regarded as one of the sensitive sectors under climate change scenarios and the agriculture sector has a vital role in the economy of most developing countries. On this ground this study attempts to find out possible impacts of climate variation in paddy production of Nepal.

Panel data model based on Ricardian approach of climate variation was adopted for the study. I used two different datasets for two different geographical regions of Nepal, Hill and Terai with panel of five development regions. Paddy yield was taken as the dependent variable with maximum temperature, minimum temperature and precipitation as climatic variables and labor, bullock, improved seed, manure and fertilizer as agriculture input explanatory variables. The time period from 1990 to 2013 was incorporated to find out climate variation impacts on paddy yield.

The variation in maximum temperature over the study period has negative impact in paddy yield of both regions and the precipitation experienced during the study period has negative impact in paddy yield of the Terai Region.

The calculation from the test results showed that one-degree increase of maximum temperature will cause 127 kg per hector and 94.99 kg per hector decrease in paddy yield in Hilly and Terai Region respectively. One-millimeter increase in rainfall in Terai Region will cause 1.59 Kg per hector decrease in paddy yield.

My results indicate that future climate change in Nepal, including higher temperature and more rainfall, might have negative impacts in the agriculture sector.

Keywords: Climate Change, Climate Variation, Paddy

Dedication:

Dedicated to all of the earthquake (2015) victims of Nepal and Joint hands combined together to uplift Nepal.

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Ås, May 2015

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Introduction

Agriculture has always been a dominant sector in the developing economies. The sector contributes a major share in GDP, balance of trade, employment and even to sustain daily livelihood of the people of the developing countries. Without development in the agricultural sector it is difficult to achieve the desired development and poverty reduction. As oppose to this, existence of traditional farming system, dependence of the agriculture on climatic condition, involvement of semi-skilled and unskilled farmer in the agriculture along with other bottlenecks like lack of efficient agricultural market, timely availability of improved seed and chemical fertilizer and less incentives of government for commercial farming retards to achieve the desired level of agriculture development. Hence, one of the emerging phenomenon and the most important and serious issue to deal with is the consequences of climate change on agricultural output.

According to Bernstein et al. (2007), Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forces such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. The Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes. (Field & Van Aalst, 2014)

According to the World Meteorological Organization, variation in the mean state and other statistics of the prevailing climate variables on temporal and spatial states beyond normal weather is climate variability. It is used to denote changes in climatic variables over a given period of time as compare to long-term statistics of respective climatic variables. Climate variability is measured by calculated deviation, which are termed as anomalies (WMO, 2015).

Agricultural productivity is subsequently affected due to changes in land and water regimes as a result of changes in temperature and precipitation. Different researches from Sivakumar, Das, and Brunini (2005), Lobell, Bänziger, Magorokosho, and Vivek (2011) and Dinar, Hassan, Mendelsohn, and Benhin (2012) has shown that in tropical regions, with many of the poorest countries, impacts on agricultural productivity are expected to be particularly harmful. Technological, resource and institutional constraints prevail in these countries have additional negative impact. Although estimates suggest that global food production is likely to be robust, experts predict tropical regions will see both a reduction in agricultural yields and a rise in poverty levels as livelihood opportunities for many engaged in the agricultural sector become increasingly susceptible to expected climate pressures (Kurukulasuriya & Rosenthal, 2013) .

Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation, changes in precipitation patterns increase the likelihood of short-run crop failure and long-run product declines. The overall impact of climate change on agriculture are expected to be negative although there will be gains in some crop in some region of the world, threatening global food security (Nelson et al., 2009).

Contribution of agriculture sector to the Nepalese economy has been noteworthy. The agriculture sector contributes to almost one third of Gross Domestic Product (GDP) with about two third of the country's population being dependent on this sector. Contribution of agriculture sector to GDP was 33.87 percent in fiscal year 2012/13, and is expected to remain at 33.10 percent in fiscal year 2013/14. In fiscal year 2013/14, the annual growth rate of agriculture sector is expected to be 4.72 percent at constant prices of 2000/01 (MOF, 2014).

Agriculture is the dominating sector for providing food security for both the rural and urban populations in Nepal. However, rapidly expanding population, rapid urbanization, migration (both internal and international), change in the interest of the people has negative impact in the outcome from the agriculture sector. The agriculture of Nepal is primitive and highly dependent on the weather and monsoon. The agriculture production of the whole year and its contribution to the GDP is significantly determined by the climatic condition of the year. According to the Economic survey of Nepal Agriculture sector is affected by favorable/unfavorable climatic conditions, resulting in the fluctuation of GDP thereby affecting overall economic growth (MOF, 2014). Hence, the influence of the climatic variable on agriculture sector is one of the important topics to study.

Background of the Study

Nepal is a South Asian landlocked country surrounded by India in the east, west and south and China in the north. Total area of Nepal is 147,181 sq. km and located between latitude of 26° 22' to 30° 27' north and longitude of 80° 04' to 88° 12' east. Globally, it falls in the temperate zone north of the Tropic of Cancer. The length of Nepal along east to west is about 800 km against 150 to 250 km width along north to south. It contains 8 of the 10 highest mountain peaks in the world, including Mount Everest (at 8848 m), although some of its low lying areas are only about 80 meters above sea level. There is therefore variation in climate of Nepal from a tropical to artic climate within a span of about 200 kilometers.

Nepal is divided into five development regions along east to west. The five development regions are (i) Eastern Development Region (ii) Central Development Region (iii) Western Development (iv) Mid-western Development Region (v) Far-western Development Region. The map of the Nepal with five development regions is given in the figure below.

Figure 1 Development regions of Nepal

Geographically Nepal is divided into three regions, Terai, Hill and Mountain. Terai region consists of plain terai and siwaliks and Hilly Region consists of Middle Hill and High Hill. Each regions experience diverse climatic variation as per the altitude of these regions. Different features of these regions are given in the table below.

Table 1 Major features of the Geographical Region

Region	Geology and soil	Elevation (masl) [1]	Climate	Average Temp.
Terai	Gently sloping, recently deposited alluvium	200	Humid tropical	> 25^{O}C
Siwaliks	Testing mudstone, siltstone, sandstone. Steep slopes and weakly consolidated bedrock. Tends to promote surface erosion despite thick vegetation	200-1500	Moist subtropical	25^{O}C
Middle Hills	Phyllite, schists, quartzite, granite, limestone. Stony and course textured soil. Conifer forests commonly found associated with quartzite	1000-2500	Temperate	20^{O}C

[1] masl-meters above sea level

Region	Geology and soil	Elevation (masl) [1]	Climate	Average Temp.
High Hills	Phyllite, schists, quartzite. Soil is generally shallow and resistant to weathering	2200-4000	Cool to sub-alpine	10-15^{O}C
Mountain	Limestone and shale. Physical weathering predominates, stony soils	> 4000	Alpine to arctic	< 0 to 5^{O}C

Source: CST Nepal 1997 (Agrawala et al., 2003).

Paddy is the most important and prestigious food crop of Nepal. It is grown in a diverse environment ranging from tropical plains to foot of the mountain at highest elevation (3050 masl). Nepal is considered as one of the origin center of rice. Rice is grown in 1440 thousand hectares and the productivity is 2.56 ton/hector. It contributes nearly 20 percent to the agricultural gross domestic product and provides more than 50 percent of the total calorie requirement of the Nepalese people. In the context of increasing urbanization and use of the agricultural land for non-agriculture use (housing, industries etc.) and necessity of preserving forest against deforestation for agriculture, productivity increment is the only way to increase the production. Nepal has released fifty-five rice varieties with full package of growing practices in the last 40 years. The coverage by improved varieties is 85 percent of the total rice cultivated land (NARC, 2015).

Although being within the subtropical climatic zone globally, Nepal posses huge climatic and ecological diversity with in 130-260 km north-south span. Within this short distance, climatic condition differs considerably. It ranges from sub-tropical Terai to artic high Himalayas. In addition, the east west extension of Himalayas in the northern part, local climate varies during the alternation in wet and dry season (Marahatta, Dangol, & Gurung, 2009).

During monsoon rainfall from June to September, cloudy days with heavy and continuous rainfall are common in Nepal. Although, about 80 percent of annual participation falls within the period, due to tropic variation, this amount declines from east to west. On one hand, timely monsoon helps successful farming; on the other hand, it is also a source of problem such as landslides, debris mow and cutting of land in plains. Conversely, expanded monsoon breaks cause drought resulting severe famine (Marahatta et al., 2009).

Statement of the Problem

Climate change has multidisciplinary impacts on earth and its inhabitants, meteorology, oceanography, environmental science, earth science, geography, agriculture and social science (Burroughs, 2007). Agriculture sector of the developing countries is backbone of the economy and vulnerability in agriculture sector directly affects the economy of the developing countries. The involvement of economists, scientists and researchers worldwide along with the different word international organizations and different departments of universities of the world clearly highlights the importance of the subject matter.

According to the Intergovernmental Panel for Climate Change (IPCC), 2014 report, climate change has different effects on different regions and crops. Negative impacts of climate change on crop yields have been more common than positive impacts (high confidence). There is some evidence of positive impacts mainly in high-latitude regions, though it is not yet clear whether the balance of impacts has been negative or positive in these regions (high confidence). According to same report, effects on rice and soybean yields have been smaller in major production regions and globally, with a median change of zero across all available data.

The observed impacts of climate change on agriculture according to IPCC 2014 report, relate mainly to production aspects of food security rather than access or other components of food security. Several periods of rapid food and cereal price increases following climate extremes in key producing regions indicate a sensitivity of current markets to climate extremes among other factors (medium confidence) (Field & Van Aalst, 2014).

Nepal is one of many developing countries with an agriculture-dominated economy. A major portion of agriculture production and calorie requirement of the people is supplied by rice. On the other hand, Nepal experiences wide range of climatic variation within different regions with different altitude covering the wide range of climatic scenario. Therefore, a study of the effects of climate variation might enlighten the different circumstances of climate and its effect on paddy production.

In the fiscal year 2013/14, the production of paddy (rice) among the major crops rose by 12.0 percent with due credit to favorable climate, use of improved seeds and seedlings and modern technology. As the rice production holds 21 percent share in aggregate agriculture GDP, fluctuations in its production greatly influences aggregate growth of the agriculture sector (MOF, 2014). This shows the importance of the climate on paddy production of Nepal.

Chaudhary and Aryal (2009) found higher rate of temperature rise in high altitude and latitude regions as compared to other regions. The mean annual temperature of Nepal increased by 0.06 degree Celsius during 1977-1994. The present estimates for rise in average temperature in Nepal is 0.5 degree Celsius per decade, which is very high as compared to other developing countries. The pattern of precipitation is not as regular as previous with more droughts and shorter periods of heavy rainfall. Thus, the precipitation pattern has become more unpredictable.

There is different evidence of climate change in Nepal. There is evidence of late or pre-monsoon, unusual precipitation, decreased rainy days or intense rainfall events and these events have impacts on agriculture since the agriculture production depends on timely rainfall. Furthermore, traditional rainfall of mid July has been shifted to Mid August in Kathmandu, which has negative impact on paddy productivity (Malla, 2009). Based on the stated evidences we can say that the climate variation and paddy production is an important and interesting topic to study.

Objective of the Study

The objectives of my study are:

1. To find out the impact of climate variation in paddy production of Hilly Region of Nepal (Temperate and cool sub-alpine climate)
2. To find out the impact of climate variation in paddy production of Terai Region of Nepal (Humid tropical and moist subtropical climate).
3. To compare the impact in two regions (Temperate and cool sub-alpine climate compared with Humid tropical and moist subtropical climate)

I tried my best to incorporate Himalayan Region in this study but due to the unavailability of sufficient data I have to drop this region from my study.

Literature Review

This section includes the theoretical and methodological literature review. The theoretical review contains different studies on impact of climate change on agriculture throughout the world. Methodological review contains different methodologies widely and frequently used to find out the relationship between climate change and its impact on agriculture sector.

Theoretical Review

There are wide ranges of literature available for impact of climate change on agriculture sector.

According to the Climate Change 2007; Synthesis Report of IPCC, warming of climate system is unequivocal, which has been observed by the evidences of increase in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. "Changes in precipitation and temperature lead to changes in runoff and water availability. Runoff is projected with high confidence to increase by 10 to 40% by mid-century at higher latitudes and in some wet tropical areas, including populous areas in East and South-East Asia, and decrease by 10 to 30% over some dry regions at mid-latitudes and dry tropics, due to decreases in rainfall and higher rates of evapotranspiration. There is also high confidence that many semi-arid areas (e.g. the Mediterranean Basin, western United States, southern Africa and north-eastern Brazil) will suffer a decrease in water re- sources due to climate change. Drought-affected areas are projected to increase in extent, with the potential for adverse impacts on multiple sectors, e.g. agriculture, water supply, energy production and health. Regionally, large increases in irrigation water demand as a result of climate changes are projected" (Barker et al., 2007).

The Stern Review; Review by Nicholas Stern on "The Economics of Climate Change" is one of the important literature on climate change. This review contains two chapters: latest evidence on climate change and economic theory that can be used to analyze the relationship between climate change and its consequences. According to Stern (2007), climate change is the event mostly created by human and it is inevitable in the future but the intensity and its impacts depends upon the present precautionary activities made by the human. As explained in his review, agriculture sector in higher-latitude developed countries is likely to benefit from moderate warming (2-3 degree Celsius) whereas even the small amount of climate change in tropical regions will result in declines of agricultural yields. The impact of climate change will be very high across Africa and Western Asia (including the Middle East) resulting in fall in yield of main staple crops by 25-30% (Stern, 2007).

The study by Kurukulasuriya and Mendelsohn (2008) examines the impact of climate change on cropland in Africa. The study is based on an eleven-country survey including over nine thousand farmers from West, South and East African countries. The main finding of the study was that the net revenue from agriculture falls as precipitation falls or temperature warms across the study area. Furthermore, the study highlights that 10% increase in temperature would lead to 13% decline in net revenue and 10% increase in precipitation would lead to 4% increase in net revenue from the agriculture sector. The study reveals that the negative impacts of climate change in dry land areas are more serious than wetland or irrigated land.

As per the study of Bindi and Olesen (2011), response of agriculture in Europe to climate change and as referred from IPCC 2007, there is evidence of climate change in the Europe and there is possibility of increase in temperature, change in precipitation pattern, increase incidents of droughts in different parts of the Europe. The projected increase in temperature created by human activities will impact northern Europe during winter and southern Europe during summer. Similarly the effect of climate change in agriculture is different in various part of the Europe. In northern area, climate change may preliminary have positive effect through increase in productivity whereas there may be negative impact of agriculture on the water quality of surface water. In southern area, there will be lower agricultural yields, variability in yield and reduction in appropriate land area used for growing traditional crops.

Methodological Review

The main objective of this thesis is to study the impact of climate change (climate variation) in paddy production of Nepal. There are different approaches to access the impact of climate change (variation) on agriculture output. In this study I focus on economic impact assessment of climate variation on agriculture production.

Economic Impact Assessment Models

From literature review there are two types of economic impact assessment models, economy wide general equilibrium models and partial equilibrium models. The analytical model that look at the complete system of economy on interdependent components i.e. industries, factors of production, institutions and the rest of the world are economy wide general equilibrium model. Analysis of the part of the overall economy such as single market or single commodity or subsets of markets or sectors are partial equilibrium models (Sadoulet & De Janvry, 1995).

Economy wide computable general equilibrium (CGE) model is an important model used in economic impact assessment analysis. Winter, Muragi, Sadoulet, and DeJanvry (1996) and Yates and Strzepek (1998) adopted CGE model on climate change impact on agriculture. Though different researchers have used CGE model, it has different limitations like difficulties on model selection, specification of parameter and functional forms, data consistency or calibration problems. Another problem of this model is the absence of statistical tests for model specification, the complexity of the CGE model and the high skills needed to develop and use CGE model (Gillig & McCarl, 2002).

Based on different literature (Amiraslany, 2010; Deressa, 2007; Kawuma Menya, 2011), nature and sources of data, time constraint, limitation of the study and simplicity and widely accepted concept of partial equilibrium model, this study is focused on partial equilibrium model. Partial equilibrium models can be divided into following two models: Crop growth simulation models and the Ricardian cross-section model.

Crop Growth Simulation Models

The following two approaches are used to analyze the impact of climate change (variation) on agriculture under this model:

Crop Suitability Approach

This approach is also known as agro-ecological zoning (AEZ) approach. This approach is used to assess the suitability of various land and biophysical attributes for crop production. In this approach, crop characteristics existing technology and soil and climate factors are included as determinant of suitability for crop production (FAO, 1996). This model enables the identification and distribution of potential crop producing land using the combination of the stated variables. In this model one of the determinants of agriculture land suitability for crop production is climate, hence it can be used to predict the impact of changing climate variables on potential agriculture output and cropping pattern (Xiao, 2002).

The Production Function Approach

The production function approach for analyzing the impact of climate change (variation) on agriculture is based on an empirical or experimental production function that measures the relationship between agriculture production and climate change (Mendelsohn, Nordhaus, & Shaw, 1994). In this approach a production function of agriculture production is estimated with independent variables as different inputs of agriculture including environmental variables such as temperature, rainfall, carbon dioxide and other available climatic variables. Change in agriculture production due to change in climatic variables are measured and analyzed at testing sites (Adams, 1989; Kaiser, Riha, Wilks, Rossiter, & Sampath, 1993; Olsen, Bocher, & Jensen, 2000). The estimated changes in yield caused by changes in environmental variables are aggregated to reflect the overall national impact or incorporated into an economic model to simulate the welfare impacts of yield change under various climate change scenario (Adams, 1989; Chang, 2002).

The advantage of this model, is that the model can assess the climate change impact more dependably as the impacts of climate change on crops yield is determined through controlled experiments. The disadvantage of this model is that it does not consider the adaptability response done by the farmer and the model overestimates the negative impact of climate change on crop yield (Deressa & Hassan, 2009). The Ricardian Cross Section Model of climate change addresses the drawback of exclusion of adaptation response by farmers in the production function model.

Ricardian Cross Section Model

The Ricardian approach for estimating the economic impact of climate change (variation) on agriculture has produced an unusual amount of attention and criticism (Polsky, 2004). This approach has been used in different countries including United States, Canada, England, Brazil, Cameroon, India, China and Sri Lanka (Amiraslany, 2010).

The Ricardian model analyzes a cross section of farms under different climatic conditions and examines the relationship between the value of land or net revenue and agro-climatic factors (Mendelsohn et al., 1994). This model has been applied to value the contribution of environmental factors to farm income by regressing land values on a set of environmental inputs thereby measuring the marginal contribution that each input make to farm income. Net revenue or price of land can be used to represent farm income (Mendelsohn et al., 1994).

The advantage of using a Ricardian model in climate change impact studies is that the model incorporates private adaptations carried out by the farmer. Farmers adapt to climate change to maximize profit by changing the crop mix, planting and harvesting dates and a host of agronomic practices. Another advantage of the model is that it is cost effective as the data required for cross section regression analysis of the model can be obtained secondarily without incurring big costs (Molua, 2007)

The Ricardian cross-section model is not without any flaws. One of the weaknesses of the Ricardian model is that it is not based on controlled experiments hence change in agriculture production cannot be only due to the climate change, but also due to other various factors like soil quality, market access, technology changes etc.

Another weakness of the model is that if fails to include price effects. This leads to an under estimation of the climate change impacts when climate change increases productivity and overestimation when agriculture production supply is decreased due to the climate change (Cline, 1996)

Another limitation of the Ricardian approach is that measuring impact in a static spatial model would only be valid if technology, policy or any other temporally varying factor that would affect land use and farmers' production management decisions does not change, or if the value of alternative uses of the land does not change (Antle, 1995). For instance, technological changes would alter the relationship between environmental characteristics and land values and thus the approach would give inaccurate effects of climate change on land values (Antle, 1995).

The Conceptual Perspective of the Ricardian Model

Most studies on impact of climate change (variation) on agriculture employ the Ricardian analysis (Mendelsohn et al., 1994) while traditional studies have used the production function approach (Rosenzweig & Iglesias, 1994). The Ricardian approach is based on the observation by David Ricardo (1772–1823) that land rents reflect the net productivity of farmland and it examines the impact of climate and other variables on land values and farm revenues. This approach has been found attractive because it corrects the bias in the production function approach by using economic data on the value of land. By directly measuring farm prices or revenues, the Ricardian approach accounts for the direct effects of climate on yield of different crops as well as the indirect substitution of different inputs, the introduction of different activities and other potential adaptations to different climates (Mendelsohn et al., 1994). It is also attractive because it includes not only the direct effect of climate on productivity but also the adaptation response by farmers to local climate. To measure the impact of climate variation on paddy production in Nepal, I use the Mendelsohn & Dinar approach (Mendelsohn & Dinar, 2003) with some modification.

The Ricardian model is based on a set of well-behaved production functions of the form:

$$\boldsymbol{Q_i = Q_i\left(K_{ij}, E\right)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. \mathbf{(1)}$$

Where, Q_i is quantity produced of good i, K_{ij} is a vector of production inputs j used to produce Q_i and E defines a vector of exogenous environmental factors such as temperature, precipitation, and soil, characterizing production sites.

Given a set of factor prices w_j, E and Q, cost minimization gives the cost function**:**

$$\boldsymbol{C_i = C_i(Q_i, W, E)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \mathbf{(2)}$$

Where C_i is the cost of production of good i and $W(w_1, w_2, \dots, w_n)$ is the vector of factor prices. Using the cost function C_i at given market prices, profit maximization by farmers on a given site can be specified as:

$$\boldsymbol{Max\, \pi = [P_iQ_i - C_i\,(Q_i, W, E) - P_LL_i]} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \mathbf{(3)}$$

Where, L_i is land at site and P_L is annual cost or rent of land at that site, such that under perfect competition all profits in excess of normal returns to all factors (rents) are driven to zero

$$\boldsymbol{P_iQ_i^* - C_i^*(Q_i^*, W, E) - P_LL_i^* = 0} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. \mathbf{(4)}$$

If the production of good i is the best use of the land given E, the observed market rent on the land will be equal to the annual net profits from the production of the good. Solving for P_L from the above equation gives land rent per hectare to be equal to net revenue per hectare:

$$\boldsymbol{P_L = \frac{P_i Q_i^* - C_i(Q_i^*, W, E)}{L_i}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .\ \mathbf{(5)}$$

The present value of the stream of current and future revenues gives the land value V_L:

$$\boldsymbol{V_L = \int_0^\infty P_L e^{-rt} dt = \int_0^\infty [(P_i Q_i^* - C_i(Q_i^*, W, E))/L_i]\ e^{-rt} dt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(6)}$$

The analyzed issue is the impact of exogenous changes in environmental variables on net economic welfare (ΔW). The net economic welfare is the change in welfare induced or caused by changing environment from a given state to another. Consider an environmental change from the environmental state *A* to *B*, which causes environmental inputs to change from E_A to E_B. The change in annual welfare from this environmental change is given by:

$$\begin{aligned} \boldsymbol{\Delta W} &= \boldsymbol{W(E_B) - W(E_A)} \\ &= \boldsymbol{\int_0^{Q_B} [(P_i Q_i - C_i(Q_i, W, E_B))/L_i] e^{-rt} dQ} \\ &- \boldsymbol{\int_0^{Q_A} [(P_i Q_i - C_i(Q_i, W, E_B))/L_i]\ e^{-rt} dQ} \end{aligned}$$

If market prices do not change as a result of the change in E, then the above equation reduces to:

$$\begin{aligned} \boldsymbol{\Delta W} &= \boldsymbol{W(E_B) - W(E_A)} \\ &= \boldsymbol{[PQ_B - \sum_{i=1}^{n} C_i(\,Q_i, W, E_B)] - [PQ_A} \\ &\boldsymbol{- \sum_{i=1}^{n} C_i(Q_i, W, E_A)]} \ldots\ldots\ldots .\ \mathbf{(7)} \end{aligned}$$

Substituting for $\boldsymbol{P_L L = P_i Q_i - C_i(Q_i^*, W, E)}$ from equation (5)

$$\begin{aligned} \boldsymbol{\Delta W} &= \boldsymbol{W(E_B) - W(E_A)} \\ &= \boldsymbol{\sum_{i=1}^{n} (P_{LB} L_{Bi} - P_{LA} L_{Ai})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots ..\ \mathbf{(8)} \end{aligned}$$

Where P_{LA} and L_A are at E_A and P_{LB} and L_B are at E_B

The present value of the welfare change is thus:

$$\int_{0}^{\infty} \Delta \boldsymbol{W} e^{-rt} \, \boldsymbol{dt} = \sum_{i=1}^{n} (\boldsymbol{V}_{LB} \boldsymbol{L}_{Bi} - \boldsymbol{V}_{LA} \boldsymbol{L}_{Ai}) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (\mathbf{9})$$

The Ricardian model takes either (8) or (9) depending on whether data available on annual net revenues or capitalized net revenues (land values V_L). The model in (8) will be employed for this research, as data on land prices cannot be assessed easily.

Simple graphical explanation of the model

Let us consider a production function reflecting a non-linear relationship between crop production (yield) and temperature as shown in the figure below. Holding other variables constant in this simple model, the yield of one crop (e.g. paddy) increases as temperature increases $\delta Q/\delta E > 0$ up to some point $(T1)$ where further increases in temperature are damaging to the crop such that the yield declines $\delta Q/\delta E < 0$ as temperature rises. Finally, at a higher temperature beyond the coping range of the crop yield drops to zero (Amiraslany, 2010).

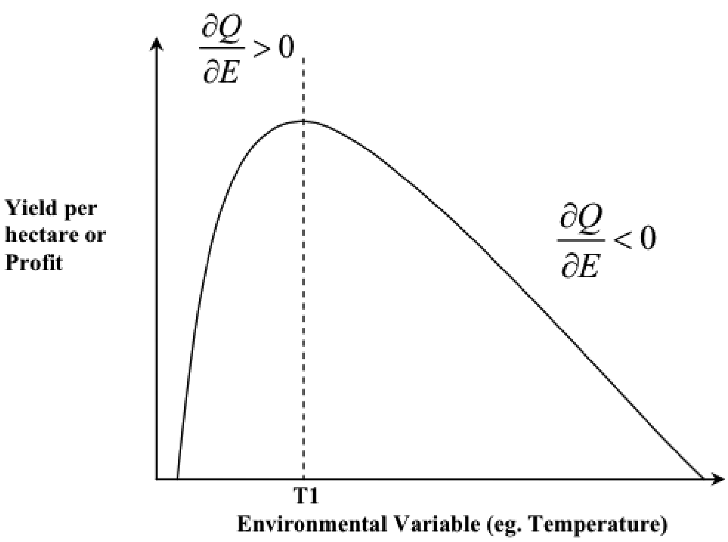

Figure 2 Impact of environmental variable on the production

Source: (Amiraslany, 2010)

Data and Method

This thesis uses the data for agriculture production (paddy yield in Nepal) as dependent variable, temperature and precipitation are climatic explanatory variables and labor days, bullock days, improved seed, manure and fertilizer are agricultural input explanatory variables.

Data

Selection of the study area

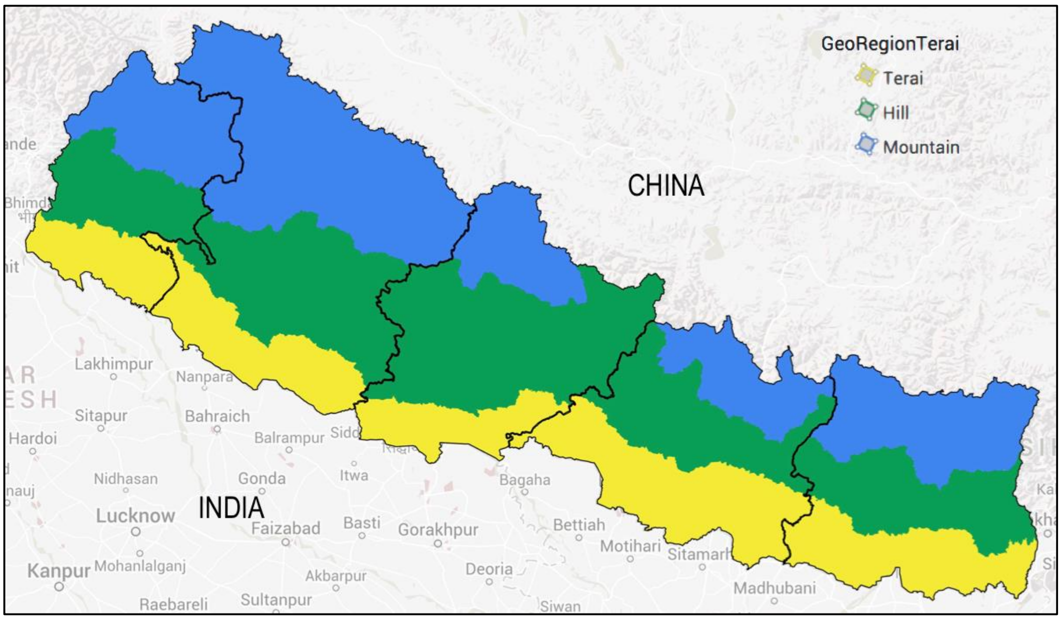

Figure 3 Map of the study area

This thesis attempts to find out the impact of climate variation on paddy production of Nepal. In this aspect, the country Nepal is considered as the study area. Geographically Nepal is divided into three regions as (a) Terai Region in the south (b) Hilly Region in the middle and (c) Himalayan Region in the north. Politically Nepal is divided into five development regions along east to west length as (a) Eastern Development Region (b) Central Development Region (c) Western Development Region (d) Mid Western Development Region (e) Far Western Development region. In this thesis, I tried my best to include all of the geographic regions in the study, but due to unavailability of sufficient data I had to drop the Himalayan region. Furthermore, the data for the Terai and Hilly regions were divided into five regions according to the different development regions, so that the actual climatic data experienced in that particular region can be traced out. The map of the study area is shown in the Figure 3.

Data collection process and sources of data

I collected data from different Governmental ministries, departments and offices depending upon where I could find the data. Paddy production (yield) was obtained from the Statistical Information on Nepalese Agriculture published by Ministry of Agricultural Development in which production, land area and yield of paddy is presented for different geographic region with five development regions. Climatic variables, temperature and precipitation were obtained from the data purchased from the Department of Hydrology and Meteorology, GoN, Ministry of Science, Technology & Environment. The net profit and agriculture input variables labor days, bullock days, improved seed, manure and fertilizer were obtained from Cost of Production & Marketing Margin of Cereal, Cash, Vegetable & Spices Crops report published by GoN, Markets Research & Statistical Management Program. The data set included in this thesis covers 23 years of time span from 1990 to 2013. There are two different panel data sets for Terai region and Hilly region with five development regions as panel.

List and explanation of the variables

Dependent variable

The paddy yield per hectare is used as the dependent variable to estimate the climate response on paddy production of Nepal. It is measured in kilogram (kg) per hector.

Explanatory variables

Climate variables

Mostly paddy is planted in Nepal by the starting time of the monsoon, that is June and it is harvested around October. Hence this study covers the average temperature and precipitation from planting to harvesting period of paddy production i.e. average temperature and precipitation from June to October for each year as the climatic variables.

Temperature

Paddy production requires different temperatures at different stages from planting to harvesting. Temperature requirement differ from one variety to another variety of the paddy. One of the important determining factors of this thesis is temperature, which is measured in degree Celsius and taken as average of five months from June to

October. It is difficult to determine and differentiate the different growing phase of paddy (i.e. vegetative, reproductive and ripening) and different temperature required for different growing phase in the process of paddy farming. Hence for simplicity, viewing the time and resource constraint the average temperature of five months duration of paddy farming is calculated for the study. Temperature data contains both maximum and minimum temperature.

Precipitation

Different level of rainfall is required for different phase of growing stage for the paddy. Generally it requires high level of precipitation in planting phase and very low level of precipitation in harvesting phase. Hence paddy is planted in the peak monsoon season, i.e. in June. Precipitation is measured in millimeter and taken as average of five month from June to October. It is difficult to determine and differentiate the different growing phase of paddy (i.e. vegetative, reproductive and ripening) and different level of precipitation required for different growing phase in the process of paddy farming. Hence for simplicity, viewing the time and resource constraint the average precipitation of five months duration of paddy farming is calculated for the study.

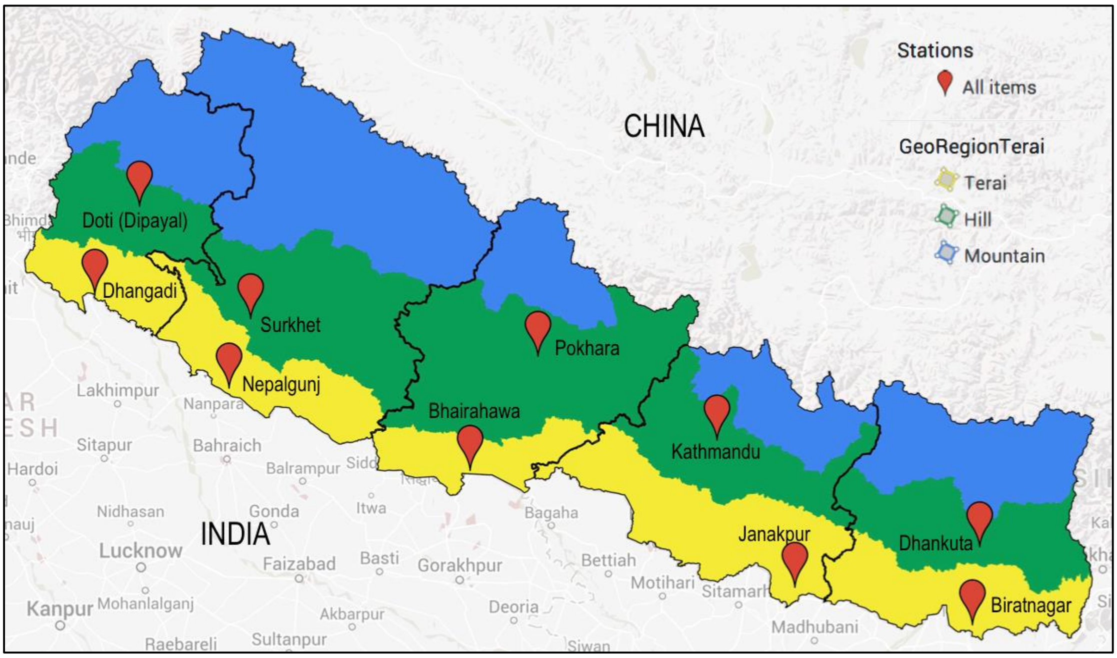

Figure 4 Different climatic stations used to obtain climatic data

For obtaining data for the climate variables, different weather stations were selected that are located in different development regions (panel of our data set). Temperature and precipitation data recorded from the stations located in the respective development region were used. The selected weather station in different development regions to take climatic data is shown in Figure 4.

Economic variables

Economic input variables included in this thesis are labor days, bullock days, improved seeds, manure and fertilizer. It is hard to collect farm-level data regarding socio-economic variables, since farmers usually don't make records of such data. Besides that, there are no strong research organizations performing this type of research in Nepal. But I collected the data from different sources (as mentioned earlier) in different forms and made them available for the purpose of this study. The data has been extrapolated based on available information provided by Ministries and departments. To make extrapolated data genuine and authentic I discussed with the research head and the research division. Some ideas and encouragement has been collected from the research officer of the concerned ministry and department for extrapolation of data. The economic input variables included in this thesis are:

Labor (Labor Days)

Human labor is one of the important factors in agricultural production. As regards to this study, it is measured in terms of adult man-days (eight working hours) in the field. In rural areas, woman workday and child workday is converted in terms of adult man-day, and it is being calculated as it usually practiced. 1.25 woman days is equivalent to One-man day; implying 1 woman day = 0.8 man day and 2 child-days is equivalent to One-man day; implying 1 child day = 0.5 man day.

Further, own family labor implies the labor contribution on farm by own family members. It is the main source of farm labor in case of small and medium sized farms. Hired labor is the non-family labor employed for farm work on payment on wages in cash, kind or both. The labor data included in this study involves both family labor and hired labor. In this study the average labor days involved in paddy production from cultivation to harvesting is taken as labor input.

Bullock Labor

Another explanatory economic input variable used in this thesis is Bullock labor. Bullock labor is used to plough the field in rural areas under traditional techniques. This input is measured in terms of bullock days; one bullock day means the use of a pair of bullock for eight hours. Bullock services costs have been calculated at the current market rate per pair of bullock per day.

Improved Seeds

Improved seed is one of the important economic input variables used in my study. It is measured in kilogram (kg) per hectare. Seed data is obtained from Department of Agriculture, Market Research and Statistical Management Program, Harihar Bhawan, Lalitpur, Nepal. The book calculates average cost of production and marketing margin per hectare.

It is very difficult to calculate the actual amount of seed inputs used in the production of paddy due to the difficulty in calculation of purchase by government sector or self stored or bring from other nation taking advantage of free border of Nepal with India. In discussion with the government researcher, it was enquired that total seeds has been calculated based on total input during cultivation. They told that in case of paddy seeds inputs are generally improved seeds.

Manure

Another economic input variable used in the thesis is manure. Manure is organic matter used as organic fertilizer in agriculture. Manure contributes to the fertility of the soil by adding organic matter and nutrients, such as nitrogen, that are trapped by bacteria in the soil. Generally in Nepal waste of different animals like cow and buffalo are used as manure. The amount of manure used in paddy production throughout the study period was obtained from Department of Agriculture, Market Research and Statistical Management Program, Harihar Bhawan, Lalitpur. Manure is measured in kilogram per hectare.

Fertilizer

Fertilizer is an important input in agriculture production function. While taking account of the fertilizers used in paddy production of Nepal, urea, di-ammonium phosphate (DAP) and murate of potash (potash) are commonly available in the market and applied in the farms. Fertilizer is measured in kilogram per hectare.

The actual quantity of chemical fertilizer required for paddy production and distinguished use of fertilizer in the particular development region required for the dataset cannot be obtained directly. For this I use fertilizer data available from Department of Agriculture, Market Research and Statistical Management Program, Harihar Bhawan, Lalitpur. The book calculates average cost of production and marketing margin per hectare. From this source I got per hectare fertilizer use in district and calculate total fertilizer used for paddy.

All of the economic input variables are obtained from data published by Department of Agriculture, Market Research and Statistical Management Program, Harihar Bhawan, Lalitpur, Nepal. The book contains district wise publication of the variables. In order to prepare the required data set for my research, I used the average value of all the districts available in the book that lay in the concerning development region. Whereas, the district included in that book for different years was not same for all of the year. Hence, I took the average value of the available districts that falls in the concerning development region.

Table 2 Variables used in the thesis with descriptions

Variable	Description
Dependent Variable	
Yield	Production per hectare of land of paddy in kilogram per hectare
Independent Variables	
Climate Variables	
TempMax	Average maximum temperature from June to October measured in degree Celsius
TempMaxSq	Squared value of average maximum temperature
TempMin	Average minimum temperature from June to October measured in degree Celsius
TempMinSq	Squared value of average minimum temperature
Prcpt	Average precipitation (rainfall) from June to October measured in millimeter.
PrcptSq	Squared value of average precipitation (rainfall)
Economic Input Variables	
Labor	Labor days (8 hours per day) involved in paddy production from plantation to harvesting (per hectare)
Bullock	Bullock labor days used in paddy production from plantation to harvesting (per hectare)
ImpvSeed	Improved seed used for production of paddy measured in kilogram per hectare
Manure	Manure used for paddy production measured in kilogram per hectare

Variable	Description
Fertilizer	Chemical fertilizer used for paddy production measured in kilogram per hectare

Note : The variables TempMaxSq, TempMinSq and PrcptSq and squared value of the average of the respective variables.

Expected Sign of the Variables

Based on nature of the used variables and prediction there are different expected signs of the included variables of this study. The table below shows the expected signs of the variables included in the model for paddy production in Nepal in the analysis.

Table 3 Expected sign of explanatory variables

Variables	Expected Sign
TempMax	±
TempMaxSq	-
TempMin	±
TempMinSq	-
Prcpt	±
PrcptSq	-
Human Labor	+
Bullock Labor	+
ImpvdSeed	+
manure	+
fertilizer	+

Methodology

This section describes the econometric framework that has been used to assess the effects of climate variation on paddy production of Nepal. The econometric model specification involves regressing yield per hector against climate variables with other agricultural input variables that are used in paddy production for the years 1990 to 2013. The data is pooled over the 23 years with development region of Nepal taken as the panel of the data. Generally in Ricardian analysis based on the equation 8, land value or net revenue is taken as the dependent variable. In my study as well I tried my best to involve net revenue of paddy production as the dependent variable. Whereas, the net profit data over the period 2007-2012 have unexpectedly higher values affecting the whole analysis (effects of extreme values in analysis) The trend line of net-profit is given in Appendix B. Further considering the net profit in analysis will have direct influence of different price level of the same agriculture output in the rural economy of developing country like Nepal. As there exist significant differences in the price of agriculture output at the time of harvesting (production) and off-season. To cope with this problem and make the analysis more reliable I used paddy yield as the dependent variable.

Cross Section Approach

The following cross sectional approach has been widely used in studies of impact of climate variation on agriculture production.

$$\boldsymbol{Y} = \boldsymbol{\alpha N} + \boldsymbol{\beta N^2} + \boldsymbol{\delta Z} + \boldsymbol{\gamma P} + \boldsymbol{\varphi D} + \epsilon_i \dots\dots\dots(10)$$

In the above equation, Y is paddy yield kilogram per hectare, N represent the climate variables N^2 is climate variables in quadratic form), Z are the socioeconomic variables, P are agricultural market price variables, D are the dummy variables and ε_i is a stochastic error term. The coefficient vectors ($\alpha, \beta, \delta, \gamma$ and φ) will be estimated by OLS and Panel econometrics methods and the results reflect the effects of climate, non-climate, price and dummy factors on agricultural land value.

Practically the basic model used for climate variation and its impact on agriculture production analysis is given below:

$$\textbf{Yield} = \boldsymbol{\beta_1} + \boldsymbol{\beta_2}(\textbf{Climate}) + \boldsymbol{\beta_3}(\textbf{Climate}^2) + \boldsymbol{\beta_4}(\textbf{ Control}) + \boldsymbol{\beta_5}(\textbf{Price}) + \boldsymbol{\beta_6}(\textbf{Dummies}) \dots\dots\dots(11)$$

Equation 11 shows that the functional form for climate variables in quadratic form. Quadratic forms are designed to take into account any possibilities of nonlinearities in the climate sensitivities. If the agricultural yield expressed as a quadratic function of climate variables then the partial derivative with respect to climate of the general equation would be: ($\beta_2 + 2\beta_3$CLIMATE) (Polsky, 2004). The linear terms represent the marginal value of the climate on paddy yield mean value, while the squared terms represents the shape of the relationship between climate and paddy yield. A positive coefficient indicates a U shape and the negative coefficient reflects the hill shape relationships (Mendelsohn, 2001). A hill shape relationship between a climate variable and paddy yield indicates that as the climate variable increases the paddy yield increase to the certain point (maximum) then increasing climate variable beyond this point reduces the paddy yield. On the other hand, a U shape relationship shows that paddy yield will decrease as climate variables rise to reach a certain point

(Minimum) then both paddy yield and climate variables will increase (Amiraslany, 2010).

Panel Fixed Effects Approach

As this study considers periods of 23 years and five different development regions, the analysis must include a mechanism to represent regional and temporal scale variation in this study. Econometrically, these time and spatial effects can be tested by running the model as a two way fixed effects method. The model can be estimated as a panel considering time and place fixed effects on the Ricardian analysis as follow:

$$\boldsymbol{Y = \eta + \lambda_t + \alpha N_t + \beta {N_t}^2 + \delta Z_t + \gamma P_t + \varphi D_t + \epsilon_{it}} \ldots\ldots\ldots (12)$$

In above equation Y is agricultural land value from 1990 to 2013, λ_t is year fixed effects and this equation includes η as a development region indicator. There are two reasons to include time-place fixed effects in the model. The first reason is that the development region wise fixed effects can absorb unobserved time invariant determinants of the dependent variable. Second, the year indicator λ_t control for time differences in the dependent variable, which are common across development region.

Adopted model for the study

Based on the theoretical model described above and nature of the data set and the available climatic and other agriculture input control variables of the study, the following models has been adopted to find out the impact of climate variation on paddy production of Nepal.

Model A: Ricardian Cross-section model with only Climate Variables.

$$Yield = \beta_0 + \beta_1 TempMax + \beta_2 TempMaxSq + \beta_3 TempMin + \beta_4 TempMinSq + \beta_5 Prcpt + \beta_6 PrcptSq$$

Model B: Ricardian Cross-section model with Climate Variables and other agriculture input control variables.

$$Yield = \beta_0 + \beta_1 TempMax + \beta_2 TempMaxSq + \beta_3 TempMin + \beta_4 TempMinSq + \beta_5 Prcpt + \beta_6 PrcptSq + \beta_7 Labor + \beta_8 Bullock + \beta_9 ImpvdSeed + \beta_{10} Manure + \beta_{11} fertilizer$$

Model C: Panel Data model with only Climate Variables.

$$Yield_{it} = \beta_0 + \lambda_t + \beta_1 TempMax_{it} + \beta_2 TempMaxSq_{it} + \beta_3 TempMin_{it} + \beta_4 TempMinSq_{it} + \beta_5 Prcpt_{it} + \beta_6 PrcptSq_{it}$$

Model D: Panel Data model with Climate Variables and other agriculture input control variables.

$$Yield_{it} = \beta_0 + \lambda_t + \beta_1 TempMax_{it} + \beta_2 TempMaxSq_{it} + \beta_3 TempMin_{it} + \beta_4 TempMinSq_{it} + \beta_5 Prcpt_{it} + \beta_6 PrcptSq_{it} + \beta_7 Labor_{it} + \beta_8 Bullock_{it} + \beta_9 ImpvdSeed_{it} + \beta_{10} Manure_{it} + \beta_{11} fertilizer_{it}$$

In panel model i represents the five development regions (i = 5). 1 = Eastern Development Region, 2 = Central Development Region, 3 = Western Development Region, 4 = Mid-western Development Region, 5 = Far-western Development Region. t represents the time period from 1990 to 2013.

Results and Discussion

This section includes descriptive statistics for both Terai Region and Hilly Region and their comparison, impact of climate variation on paddy production of Hilly Region and impact of climate variation on paddy production of Terai Region. Finally I will compare the results of both regions. The analytical four models stated above are adopted for the study.

Descriptive Statistics

This section consists of the descriptive statistics of Hilly Region, Terai Region and comparison between them. The descriptive statistics tables presented below shows the number of observations, mean, standard deviation, minimum value and maximum value of the dependent and independent variables obtained from the Stata for the Hilly region (Table 4) and the Terai region (Table 5). The data consists of 23 years of span for five different development regions of Nepal; hence we have 120 different observations if there are no missing values.

Table 4 Descriptive Statistics, Hilly Region

Variable	Obs	Mean	Std. Dev.	Min	Max
Yield	120	2418.925	509.8479	1623	4041
TempMax	120	29.99467	2.486802	23.84	35
TempMin	120	20.343	1.460359	17.38	22.84
Prcpt	120	294.1838	192.7412	102.24	853.34
Labor	120	176.5833	32.19415	100	237
Bullock	120	27.9	10.0364	4	42
ImpvdSeed	120	51.11667	8.229056	29	64
manure	120	2309.567	1077.111	450	5902
fertilizer	120	97.81667	34.16347	22	191

Table 5 Descriptive Statistics, Terai Region

Variable	Obs	Mean	Std. Dev.	Min	Max
Yield	120	2681.567	403.3343	1638	3907
TempMax	119	33.05664	.6371191	31.6	35.04
TempMin	119	24.59859	.6415676	22.62	26.24
Prcpt	113	297.8138	91.83106	134.8	811

Variable	Obs	Mean	Std. Dev.	Min	Max
Labor	120	149.5333	15.63606	117	187
Bullock	120	23.425	15.39544	4	45
ImpvdSeed	120	52.69167	10.79511	30	74
manure	120	1690	819.0253	400	4833
fertilizer	120	104.6917	36.4728	15	240

Table 6 Comparisons of the Descriptive Statistics of Two Regions

Variable	Hill	Terai	T-value	P-value
Yield	2418.92	2681.54	-4.43	0.00
TempMax	29.99	33.06	-13.06	0.00
TempMin	20.34	24.60	-29.21	0.00
Prcpt	294.18	297.81	-0.19	0.85
Labor	176.58	149.53	8.28	0.00
Bullock	27.90	23.43	2.67	0.01
ImpvdSeed	51.12	52.69	-1.27	0.21
Manure	2309.57	1690.00	5.02	0.00
Fertilizer	97.82	104.69	-1.51	0.13

Table 6 shows a comparison of the average values of the variables for each region included in this study. The important factors to consider in this comparison are that the yield, climate variables and modern agriculture input (improved seed and chemical fertilizer) use in Terai Region is higher than that of the Hilly Region. Labor, bullock and manure use in Hilly Region is higher than that of the Terai Region. Statistically there found to be difference in yield, maximum temperature, minimum temperature, labor, bullock and manure and there is no difference in mean precipitation improved seed and fertilizer of two regions. Terai Region consists of plain farm land and it has easy access to the open boarder market of India whereas the Hilly Region consists of sloping terrace land and primitive agriculture are adopted in the rural areas of the Hilly Region. Furthermore, Terai Region is plain land with lower altitude from the sea level and Hilly Region is located in higher altitude than that of the Terai Region. These may be the possible reason for differences in the average value of variables between two regions.

In this study, the climate factors are represented by the variables maximum temperature and minimum temperature. The trend lines of these variables are presented in the figure below. The figures show that there are fluctuations in both maximum and minimum temperature in all regions representing the existence of climate variation.

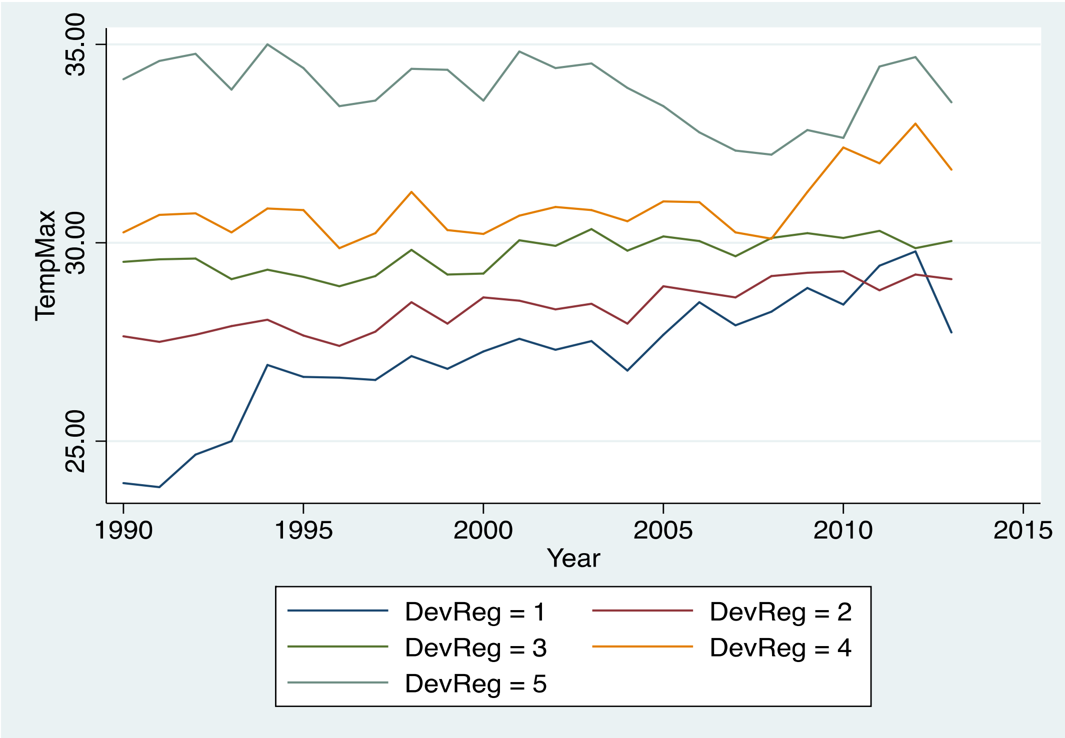

Figure 5 Trends of Maximum Temperature in Hilly Region

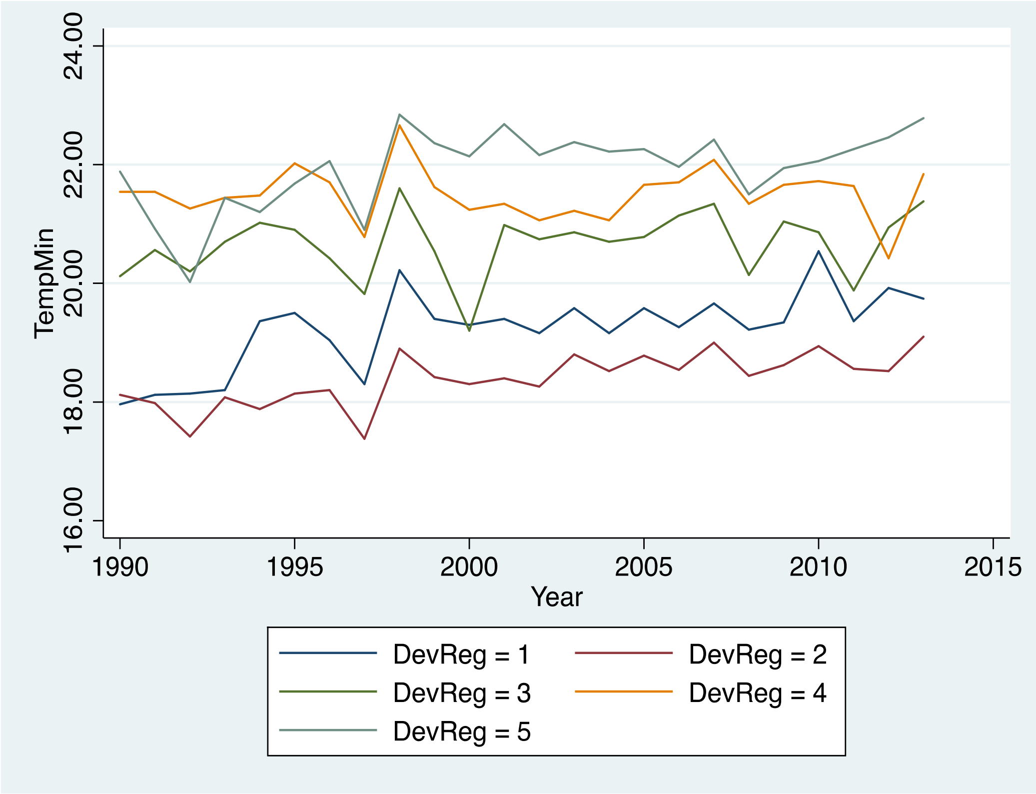

Figure 6 Trends of Minimum Temperature in Hilly Region

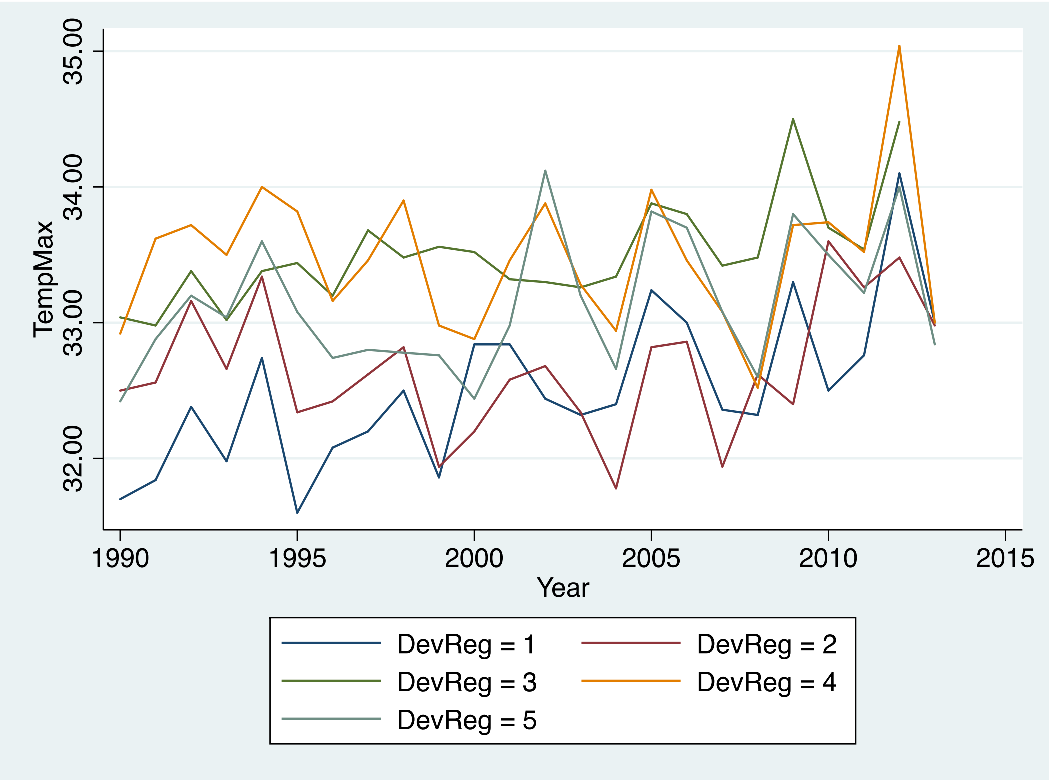

Figure 7 Trends of Maximum Temperature in Terai Region

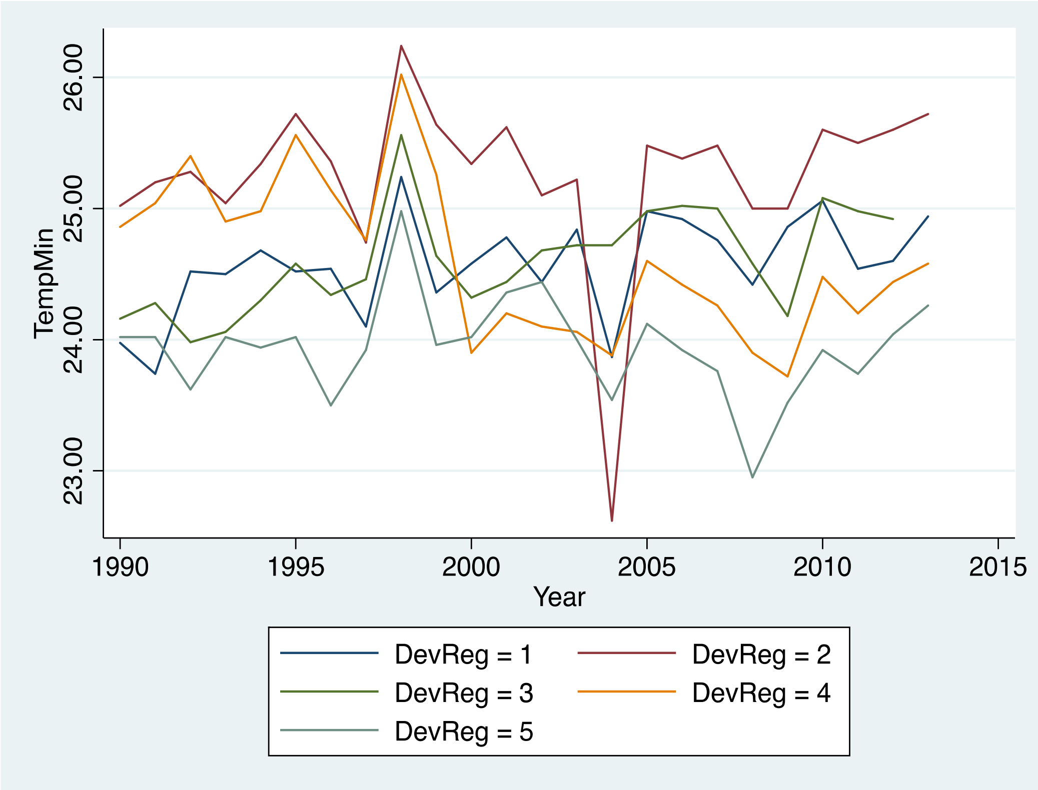

Figure 8 Trends of Minimum Temperature in Terai Region

Note: 1-Eastern Development Region, 2-Central Development Region, 3-Western Development Region, 4-Mid-western Development Region, 5-Far-western Development Region

Econometric Results

This section contains the econometric results of the four models adopted in the study to find out the impact of climate variation on paddy production of Nepal. Model A is a Ricardian Cross Section model with only climate variables and Model B is the same model including both climate and other economic input control variables which pools all five development region panel in one OLS regression. Model C is a Panel Data Model with only climate variables and Model D is a Panel Data Model including both climate and other economic input control variables. The models with only climate variables incorporates effects of all other factors used in paddy production in climate variables which gives overestimated impacts. Similarly, the Pooled OLS model cannot incorporate the time invariant factors for different development regions on the yield of paddy. Panel data analysis provide superior estimates since it contains multiple observations on each unit as compared to cross-section models. Hence Panel Data model is more appropriate compared to pooled regressions for the study.

I had to decide whether to use a fixed effect model or a random effect model under Panel Data Model. I ran a Hausman specification test (Hausman test for both regions are attached in Appendix C). Fixed Effect Model was found to be more appropriate than the random effect model. Similarly, the fixed effect model can explain the time invariant model across different development regions on paddy yield. Hence this study uses the fixed-effect model for explaining the impact of climate variation on paddy production.

Impact of Climate Variation in Paddy Production of Hilly Region

The statistical results obtained under four adopted model of Hilly Reason are presented and discussed in this section. The statistical results of econometric tests under four models are presented in the table below:

Table 7 Statistical Results of Different Models for Hilly Region

Variable	ModelA	ModelB	ModelC	ModelD
TempMax	1631.3063	621.96097	-292.44411	-870.33427
	0.0000	0.0094	0.4716	0.0035
TempMaxSq	-25.611586	-9.1209355	7.3852389	15.589902
	0.0000	0.0195	0.2785	0.0018
TempMin	-2436.6252	-1596.136	172.17365	632.15278
	0.0145	0.0306	0.8665	0.3863
TempMinSq	53.617869	34.221418	-.59108231	-14.700291
	0.0282	0.0554	0.9809	0.4044
Prcpt	1.8762043	2.4515721	-.50132734	-1.070535
	0.0399	0.0035	0.7312	0.3026
PrcptSq	-.0021019	-.00234927	-.00050813	.00054256
	0.0324	0.0081	0.6924	0.5467
Labor		-5.1795819		-5.6505243
		0.0013		0.0000
Bullock		-16.155931		-15.106065
		0.0181		0.0059
ImpvdSeed		2.2890092		3.2836638
		0.7159		0.5779
manure		.00341509		.03559068

Variable	ModelA	ModelB	ModelC	ModelD
		0.8988		0.1773
fertilizer		3.0304445		1.3593275
		0.0078		0.1326
_cons	3660.9064	10773.687	1454.5567	8941.7451
	0.6758	0.0987	0.8727	0.1958
				legend: b/p

The results of the Model A, Ricardian Cross Section Model with only climate variables shows that the maximum temperature has significant positive impact on paddy yield. And minimum temperature across time of paddy production has significant negative impact on paddy yield. Similarly the precipitation has significant positive impact on paddy yield. In this model only climate variables are used as explanatory variables due to which the impact of other varibles influencing paddy yield are aslo incorporated in the coefficient of climate.

The results of the Model B shows same direction and relationship between climate variables and paddy yield in the Hilly Region but the intensity of effect is lower than that of the model B. It is due to the inclusion of agriculture input control variables and incorporation of their contribution in the regression. Unexpectedly labor and bullock work days invovled in paddy production have significant negative impact on paddy yield. Agriculture inputs such as improved seed, manure and fertilizer have positive impacts on paddy production, but only the test result for fertilizer is statistically significant.

The results of Model C, the Panel data model with only climate variables found the opposite relationship between climate variables and the paddy yield than that of the OLS models with only climate variables. The reason may be due to the use of panel fixed model and impact of time invariant effect of each development region in the paddy yield. Whereas, test results for these variables are found to be statistically insignificant.

Theoretically, statistically and econometrically Model D is the most appropriate model to explain the objective of the study. Hence the study is focused on the results of the Model D to discuss the impact of climate variation on Paddy production of Hilly Region.

The result of the Model D shows significant negative impact of the maximum temperature on paddy yield of the Hilly Region, while minimum temperature and precipitation has positive impact on paddy yield but the test results are statistically insignificant. The significant coefficient of squared maximum temperature indicates non-linear relationship between maximum temperature and paddy yield and insignificant coeffecient of minimum temperature and precipitation indicates linear relationship between these variables with paddy yield. The economic input variables labor and bullock working days have negative impacts on paddy yield with significant test statistics and other agriculuture input variables improved seed, manure and fertilizer have positive impact on paddy production whereas the test results are statistically insignificant.

The negeaive impact of labor and bullock working days on paddy yield is outside of understanding. I have tried to figure out the reason behind this but I could not trace out any logical reason. Although overuse of these factors may have decreasing marginal productivity but the negative effect of these factors is out of my understanding.

Marginal Impact Analysis: Hilly Region

This section is based on the test results of ModelD (focused model). The significant negative value of maximum temperature indicates that the maximum temperature experience in hilly region during the period of study has negative impact on paddy yield. The marginal impact of maximum temperature on yield given by the equation: $\beta_2 + 2\beta_3\, CLIMATE$ (Calculation is presented in Annex D) is -127. This indicates that the one-degree Celsius increase in maximum temperature results in 127 kg per hectare decrease in paddy yield. Therefore the result shows that the variation in maximum temperature over the study period 1990 to 2013 has negative impact on paddy yield of Hilly Region.

Impact of Climate Variation in Paddy Production of Terai Region

The statistical results obtained under four adopted model for Terai Region are presented and discussed in this section. The statistical results of econometric tests under four models are presented in the table below:

Table 8 Statistical Results of Different Models for Terai Region

Variable	ModelA	ModelB	ModelC	ModelD
TempMax	-8961.0519	-7276.5299	-4221.7707	-5407.943
	0.0181	0.0316	0.2581	0.0840
TempMaxSq	138.15183	111.40242	69.105785	84.065797
	0.0160	0.0297	0.2188	0.0742
TempMin	-752.26185	402.75181	-3.1691135	593.01004
	0.7886	0.8205	0.9992	0.8174
TempMinSq	15.793153	-7.9484847	-1.8066879	-12.663213
	0.7820	0.8255	0.9768	0.8094
Prcpt	-3.1393405	-3.1840004	-1.2878268	-2.2461878
	0.0171	0.0001	0.3611	0.0671
PrcptSq	.00390148	.00331896	.00210202	.00246169
	0.0176	0.0000	0.2136	0.0895
Labor		-3.9862769		-4.09138
		0.1698		0.1626
Bullock		-5.4933367		-6.1849245
		0.0913		0.1251
ImpvdSeed		-9.4784845		-6.0458262
		0.0275		0.2995
manure		.12153029		.08528263
		0.0049		0.0543
fertilizer		-1.4387738		-1.0842709
		0.1016		0.2894
_cons	157403.18	118148.77	68071.91	84119.527
	0.0245	0.0356	0.3288	0.1517
				legend: b/p

The results of the Model A, Ricardian Cross Section model with only climate variables shows that all the climate variables maximum temperature, minimum temperature and precipitation have negative impact on paddy yield whereas the test result for minimum temperature is not found to be statistically significant.

The results of Model B shows significant negative impact of maximum temperature and precipitation on paddy yield and positive impact of minimum temperatue on paddy yield whereas this test result is not found to be statistically significant. Due to the inclusion of other economic input control variables more distributed effect of other variables in the paddy yield is obtained. This is why the result of Model B is quite different than that of the Model A.

Unexpectedly Labor and bullock work days, improved seed and fertilizer implemented in paddy production have negative impact on paddy yield. Manure has a significant positive impact on paddy yield.

The results of the Model C, Panel data model with only climate variables found negative impacts of maximum temperature and precipitation on paddy yield. As oppose to this minimum temperature has postive impact on paddy yield. Whereas, test results for these variables are not found to be statistically significant.

Theoretically, statistically and econometrically Model D is the most appropriate model to explain the objective of the study. Hence the study is focused on the results of the Model D to discuss the impact of climate varaition on Paddy production of Terai Region.

The result of the Model D shows significant negative impact of the maximum temperature and precipitation on paddy yield of the Terai Region. As opposite to this, minimum temperature has positive impact on paddy yield whereas the test result is not statistically significant. The significant coefficient of squared maximum temperature and precipitaton indicates non-linear relationship between these variables and paddy yield. And insignificant coefficient of squared minimum temperature indicates linear relationship between minimum temperature and paddy yield. The economic input variables labor and bullock working days, improved seed and fertilizer have negative impacts on paddy yield, whereas the test results are statistically insignificant. And the use of manure has significant postive impact on paddy production.

The reason behind negative impact of labor and bullock working days on paddy yield is outside of my understanding. Furthermore lack of the technical knowhow to use improved seed and fertilizer, disproportional and untimely use of these factors and unedequate use of the fertilizer may have caused negative impacts in paddy yield by these variables. But for Terai the test results for these variables are insignificant, statisticaly this indicates that there doesn’t exist impact of these variables on paddy yield.

Marginal Impact Analysis: Terai Region

This section is based on the test results of ModelD (focused model). The significant negative value of maximum temperature indicates that the maximum temperature experienced during the study period in terai region has negative impact on paddy yield. The marginal impact of maximum temperature on yield given by the equation: $\beta 2 + 2\beta 3\, CLIMATE$ (Calculation is presented in Annex D) is -94.99. This indicates that a one-degree increase in maximum temperature results in 94.99 kg per hectare decrease in paddy yield. Similarly the marginal impact of precipitation on paddy yield is -1.59, which shows that one-millimeter increase in precipitation results in 1.59 kg per hectare decrease in paddy yield. Therefore the result shows that the variation in maximum temperature and precipitation over the study period 1990 to 2013 has negative impact on paddy yield of Terai Region.

Comparison of the Impact of Climate Variation on Paddy Production in two regions

This result gives the overall impact of climate variation on paddy production of Nepal as only about 2% of Paddy Production of Nepal is cultivated in Himalayan Region which has dropped in this study. The comparision of concerned climatic variables as per the topic are presented in the table below:

Table 9 Comparison of climate variables impacts on Hilly Region and Terai Region

Variable	Hill	Terai
TempMax	-870.33	-5407.94
	(0.035)	(0.0840)
TempMin	632.15	593.01
	(0.3863)	(0.8174)
Prcpt	-1.07	-2.25
	(0.3026)	(0.0671)
Marginal Effect of TempMax	-127.00	-94.99
Marginal Effect of TempMin	121.18	20.27
Marginal Effect of Prcpt	-0.97	-1.59

legend: b/p

Note: marginal effect of maximum temperature of both regions and precipitation of terai region are siginificant as they are derived from the significant test coefficients and marginal effect of minimum temperature of both region and precipieation of hilly region are insignificant as they are derived from the insignificant test coefficent.

From the table above it is clearly seen that the maximum temperature on the production period of paddy has negative impact on both Hilly Region and Terai Region but the negative impact of maximum temperature on Hilly region is found to be more than the Terai Region. Similarly precipitation on Terai Region has negative impact on paddy yield. Minimum temperature of both regions and precipitation of hilly region are statistically insignificant.

Based on overall significant test results of both regions, we can say that maximum temperature variation over the study period of 1990 to 2013 have negative impact on paddy yield in both regions and precipitation experienced in Terai Region have negative impact on paddy yield. These results indicate that future climate change in Nepal, including higher temperature and more rainfall, might have negative impact in the agriculture sector.

Conclusion

The study attempts to find out the impact of climate variation on paddy production of Nepal. Geographically Nepal is divided from south to north into Terai, Hilly and Himalayan regions, but due to the low share of paddy production and scarcity of necessary data Himalayan Region was drop out from the study. Furthermore, politically Nepal is divided into five development regions from east to west. Based on this, I prepared two different datasets, one for Hilly Region and one for Terai Region using the five development regions as panel for the study. The time period from 1990 to 2013 was taken into consideration to study the impact of climate variation on paddy production.

Paddy yield was taken as the dependent variable; maximum temperature, minimum temperature and precipitation was taken as the climatic variables and labor, bullock, improved seed, manure and fertilizer was taken as the agricultural input control variables. The study was based on Ricardian theory of climate change, which focuses on land value or net return from the land represented, by net profit as the dependent variable. Due to the higher price effect in agriculture output prevailed in market of Nepal and extreme value of collected net profit data, paddy yield was taken as the dependent variable for the study. Four models were derived based on the Ricardian model and the nature and availability of the dataset of the study.

The four models used for the study were; i) Ricardian cross section OLS model (pooled data) with only climate variables; ii) Ricardian cross section OLS model (pooled data) with climatic and agricultural input control variables; iii)panel data fixed effect model with only climate variables, and; iv) panel data fixed effect model with both climate and agriculture input control variables. The study mainly focused on the fourth model, panel data with both climatic and agriculture input control variables.

On analyzing the results of four different models, coefficients of same variables were found different for different models. Theoreticaly and practically, the fourth model is the most appropriate model which addresses the nature and range of available variables for the study. Other variables like irrigation, tractor, farm size, soil quality, humidity etc. that can have significant impact on paddy yield could not be incorporated in the model due to unavailability, incomplete record of these data or time and financial limitation of the study. Hence the result obtained from the selected model with available variables cannot be considered as the complete model.

The results show that the marginal impact of maximum temperature is negative for paddy yields in both Hilly and Terai Region. Hence, an increase in temperature, which has been proved as inevitable phenomenon by the IPCC report, would result in decreased paddy yields. Similarly, the marginal impact of precipitation in the Terai region during the study period is negative for paddy yield, which shows that increases in precipitation in the Terai region might decrease the paddy yield. Based on this finding of the negetive impact on paddy yield by the expereinced variation in maximum temperature in both regions and precipitation patterns in Terai Region. It can be predicted that climate change with increasing maximum temperature and changing patterns of precipitation might have negative impact on paddy production of Nepal.

References

Adams, R. M. (1989). Global climate change and agriculture: an economic perspective. *American Journal of Agricultural Economics, 71*(5), 1272-1279.

Agrawala, S., Raksakulthai, V., van Aalst, M., Larsen, P., Smith, J., & Reynolds, J. (2003). Development and climate change in Nepal: Focus on water resources and hydropower. *Environment Directorate and Development Cooperation Directorate, Organisation for Economic Cooperation and Development (OECD), Paris*.

Amiraslany, A. (2010). *The impact of climate change on Canadian agriculture: a Ricardian approach*. University of Saskatchewan Saskatoon.

Antle, J. M. (1995). Choice and Efficiency in Food Safety Policy. *AEI Press*.

Barker, T., Davidson, O., Davidson, W., Huq, S., Karoly, D., Kattsov, V., . . . Matsuno, T. (2007). Climate change 2007: Synthesis report. *Valencia; IPPC*.

Bernstein, L., Bosch, P., Canziani, O., Chen, Z., Christ, R., & Davidson, O. (2007). Climate change 2007: synthesis report. Summary for policymakers *Climate change 2007: synthesis report*. *Summary for policymakers*: IPCC.

Bindi, M., & Olesen, J. E. (2011). The responses of agriculture in Europe to climate change. *Regional Environmental Change, 11*(1), 151-158.

Burroughs, W. J. (2007). *Climate change: a multidisciplinary approach*: Cambridge University Press.

Chang, C. C. (2002). The potential impact of climate change on Taiwan's agriculture. *Agricultural Economics, 27*(1), 51-64.

Chaudhary, P., & Aryal, K. P. (2009). Global warming in Nepal: challenges and policy imperatives. *Journal of Forest and livelihood, 8*(1), 5-14.

Cline, W. R. (1996). The impact of global warming of agriculture: comment. *The American economic review*, 1309-1311.

Deressa, T. T. (2007). *Measuring the economic impact of climate change on Ethiopian agriculture* (Vol. 4342): World Bank Publications.

Deressa, T. T., & Hassan, R. M. (2009). Economic impact of climate change on crop production in Ethiopia: evidence from cross-section measures. *Journal of African Economies*, ejp002.

Dinar, A., Hassan, R., Mendelsohn, R., & Benhin, J. (2012). *Climate change and agriculture in Africa: impact assessment and adaptation strategies*: Routledge.

FAO. (1996). Agro-ecological zoning: Guidelines, FAO Soils Bulletin 73. . Rome, Italy.: Food and Agriculture Organization.

Field, C., & Van Aalst, M. (2014). *Climate change 2014: impacts, adaptation, and vulnerability* (Vol. 1): IPCC.

Gillig, D., & McCarl, B. (2002). Introduction to Computable General Equilibrium Models (CGE). *Department of Agricultural Economics, Texas A & M University*.

Kaiser, H., Riha, S., Wilks, D., Rossiter, D., & Sampath, R. (1993). A farm-level analysis of economic and agronomic impacts of gradual warming. *American Journal of Agricultural Economics 75*, 387–398.

Kawuma Menya, C. (2011). Rainfall variation due to climate change: an intertemporal investigation into its impact on susbsistence crop net revenue.

Kurukulasuriya, P., & Mendelsohn, R. (2008). A Ricardian analysis of the impact of climate change on African cropland. *African Journal of Agricultural and Resource Economics, 2*(1), 1-23.

Kurukulasuriya, P., & Rosenthal, S. (2013). Climate change and agriculture: A review of impacts and adaptations.

Lobell, D. B., Bänziger, M., Magorokosho, C., & Vivek, B. (2011). Nonlinear heat effects on African maize as evidenced by historical yield trials. *Nature Climate Change, 1*(1), 42-45.

Malla, G. (2009). Climate change and its impact on Nepalese agriculture. *Journal of agriculture and environment, 9*, 62-71.

Marahatta, S., Dangol, B. S., & Gurung, G. B. (2009). TEMPORAL AND SPATIAL VARIABILITY OF
CLIMATE CHANGE OVER NEPAL (1976 - 2005) (pp. 67).

Mendelsohn, R. (2001). Global Warming and the American Economy. *Edward Elgar Publishing Inc., Massachusetts*.

Mendelsohn, R., & Dinar, A. (2003). Climate, water, and agriculture. *Land economics, 79*(3), 328-341.

Mendelsohn, R., Nordhaus, W. D., & Shaw, D. (1994). The impact of global warming on agriculture: a Ricardian analysis. *The American economic review*, 753-771.

MOF. (2014). Economic Survey (M. o. Finance, Trans.) *Economic Survey* (Vol. 2013/14, pp. 321): Government of Nepal, Ministry of Finance.

Molua, E. L. (2007). The economic impact of climate change on agriculture in Cameroon. *World Bank Policy Research Working Paper Series, Vol*.

NARC. (2015). Nepal Rice Knowledge Bank. 2015, from http://www.narc.org.np/rice_knowledge_bank/

Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., Zhu, T., . . . Batka, M. (2009). *Climate change: Impact on agriculture and costs of adaptation* (Vol. 21): Intl Food Policy Res Inst.

Olsen, J., Bocher, P., & Jensen, Y. (2000). Comparison of scales of climate and soil data for aggregating simulated yields in winter wheat in Denmark. *Agriculture, Ecosystem and Environment, 82*(3), 213-228.

Polsky, C. (2004). Putting Space and Time in Ricardian Climate Change Impact Studies: Agriculture in the U.S. Great Plains, 1969–1992. *Annals of the Association of American Geographers, 94*(3), 549-564.

Rosenzweig, C., & Iglesias, A. (1994). Implications of climate change for international agriculture.

Sadoulet, E., & De Janvry, A. (1995). *Quantitative development policy analysis*: Johns Hopkins University Press Baltimore.

Sivakumar, M. V. K., Das, H. P., & Brunini, O. (2005). Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics. *Climatic Change, 70*(1-2), 31-72.

Stern, N. H. (2007). *The economics of climate change: the Stern review*: cambridge University press.

Winter, P., Muragi, R., Sadoulet, E., & DeJanvry, A. (1996). Climate change, agriculture, and developing economies. Department of Agricultural and Resource economics, Division of Agriculture and Resource Economics. University of California at Berkley: Working paper.

WMO. (2015). Frequently Asked Questions (FAQs). Retrieved 2015/05/13, 2015, from http://www.wmo.int/pages/prog/wcp/ccl/faqs.php

Xiao, X. (2002). Transient climate change and potential croplands of the world in the 21st century.: Massachusetts Institute of Technology, Joint program on the Science and Policy of Global Change.

Yates, D. N., & Strzepek, K. M. (1998). Modeling the Nile Basin under climatic change. *Journal of Hydrologic Engineering, 3*(2), 98-108.

Appendix A: Code Used

Code Used

```
sum Yield TempMax TempMin Prcpt Labor Bullock ImpvdSeed manure
fertilizer

* Richardian Cross Section Model Analysis
gen TempMaxSq = TempMax*TempMax
gen TempMinSq  = TempMin*TempMin
gen PrcptSq = Prcpt*Prcp

** Model A: Ricardian Cross-section model with only Climate
Variables.

reg Yield TempMax TempMaxSq Prcpt PrcptSq
hettest
reg Yield TempMax TempMaxSq TempMin TempMinSq Prcpt PrcptSq, r
estimates store ModelA

** Model B: Ricardian Cross-section model with Climate Variables and
other agriculture input control variables.

reg Yield TempMax TempMaxSq TempMin TempMinSq Prcpt PrcptSq Labor
Bullock ImpvdSeed manure fertilizer
hettest

reg Yield TempMax TempMaxSq TempMin TempMinSq Prcpt PrcptSq Labor
Bullock ImpvdSeed manure fertilizer, r
estimates store ModelB


* Panel Data Model Analysis

xtset DevReg Year

xtline TempMax, t(Year) i(DevReg) overlay
xtline TempMin, t(Year) i(DevReg) overlay

**Model C: Panel Data model with only Climate Variables.

xtreg Yield TempMax TempMaxSq TempMin TempMinSq Prcpt PrcptSq, fe
estimate store fe

xtreg Yield TempMax TempMaxSq TempMin TempMinSq Prcpt PrcptSq, re
estimate store re

hausman fe re
xtreg Yield TempMax TempMaxSq TempMin TempMinSq Prcpt PrcptSq, fe
estimates store ModelC
```

```
** Model D: Panel Data model with Climate Variables and other
agriculture input control variables.

xtreg Yield TempMax TempMaxSq TempMin TempMinSq Prcpt PrcptSq Labor
Bullock ImpvdSeed manure fertilizer, fe
estimate store fe

xtreg Yield TempMax TempMaxSq TempMin TempMinSq Prcpt PrcptSq Labor
Bullock ImpvdSeed manure fertilizer, re
estimates store re

hausman fe re

xtreg Yield TempMax TempMaxSq TempMin TempMinSq Prcpt PrcptSq Labor
Bullock ImpvdSeed manure fertilizer, fe
estimates store ModelD

estimates tab ModelA ModelB ModelC ModelD, b p
```

Appendix B: Some Relevant Plots

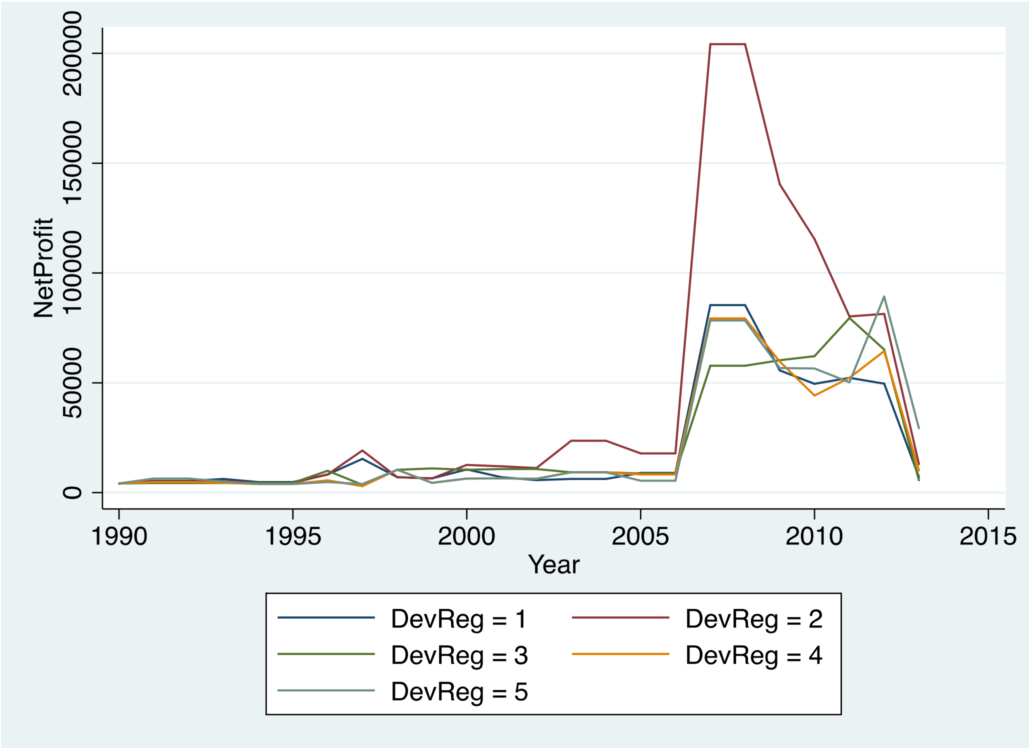

Figure 9 Fluctuation in net profit data with extreme values: Hilly Region

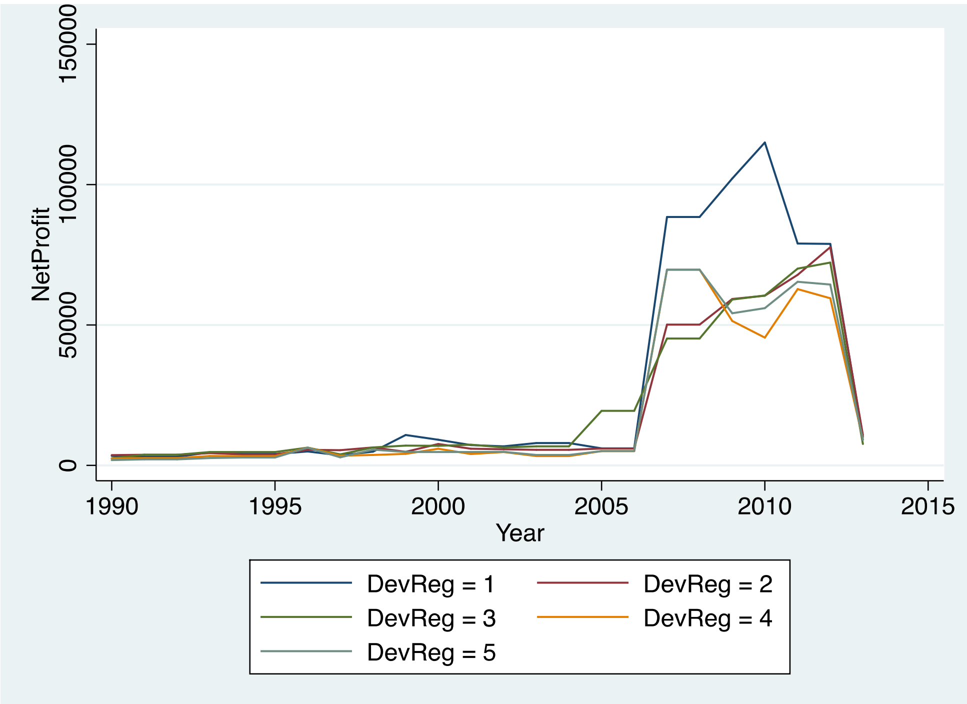

Figure 10 Fluctuation in net profit data with extreme values: Terai Region

Appendix C: Stata Results

Hilly Region

Ricardian Cross Section (OLS) results only with climate variables

```
Linear regression                               Number of obs =      120
                                                F(  6,    113) =    10.39
                                                Prob > F       =   0.0000
                                                R-squared      =   0.4298
                                                Root MSE       =   395.08
```

Yield	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
TempMax	1631.306	327.8486	4.98	0.000	981.7791	2280.833
TempMaxSq	-25.61159	5.402279	-4.74	0.000	-36.31448	-14.9087
TempMin	-2436.625	980.8642	-2.48	0.014	-4379.894	-493.3563
TempMinSq	53.61787	24.11578	2.22	0.028	5.840165	101.3956
Prcpt	1.876204	.902549	2.08	0.040	.088092	3.664317
PrcptSq	-.0021019	.0009702	-2.17	0.032	-.004024	-.0001798
_cons	3660.906	8731.807	0.42	0.676	-13638.38	20960.19

```
. estimates store ModelA
```

Ricardian Cross Section (OLS) results with both climate and agriculture input variables

```
Linear regression                               Number of obs =      120
                                                F( 11,    108) =    24.93
                                                Prob > F       =   0.0000
                                                R-squared      =   0.7380
                                                Root MSE       =   273.95
```

Yield	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
TempMax	621.961	235.16	2.64	0.009	155.833	1088.089
TempMaxSq	-9.120935	3.848089	-2.37	0.020	-16.74852	-1.493356
TempMin	-1596.136	728.3336	-2.19	0.031	-3039.82	-152.4525
TempMinSq	34.22142	17.671	1.94	0.055	-.8055713	69.24841
Prcpt	2.451572	.8221991	2.98	0.004	.8218308	4.081313
PrcptSq	-.0023493	.0008711	-2.70	0.008	-.004076	-.0006226
Labor	-5.179582	1.563578	-3.31	0.001	-8.278866	-2.080298
Bullock	-16.15593	6.731286	-2.40	0.018	-29.49851	-2.813354
ImpvdSeed	2.289009	6.272354	0.36	0.716	-10.14388	14.7219
manure	.0034151	.0267851	0.13	0.899	-.0496777	.0565079
fertilizer	3.030444	1.117616	2.71	0.008	.8151361	5.245753
_cons	10773.69	6469.428	1.67	0.099	-2049.841	23597.22

```
. estimates store ModelB
```

Hausman's test for fixed vs. random effect model for panel data with only climate variables

```
Note: the rank of the differenced variance matrix (5) does not equal the number of
        coefficients being tested (6); be sure this is what you expect, or there may be
        problems computing the test.  Examine the output of your estimators for
        anything unexpected and possibly consider scaling your variables so that the
        coefficients are on a similar scale.
```

	Coefficients (b) fe	Coefficients (B) re	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
TempMax	-292.4441	1631.306	-1923.75	184.8962
TempMaxSq	7.385239	-25.61159	32.99682	3.249568
TempMin	172.1736	-2436.625	2608.799	456.8836
TempMinSq	-.5910823	53.61787	-54.20895	9.549245
Prcpt	-.5013273	1.876204	-2.377532	.9418167
PrcptSq	-.0005081	-.0021019	.0015938	.0003555

```
                      b = consistent under Ho and Ha; obtained from xtreg
        B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(5) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =       68.46
                Prob>chi2 =      0.0000
                (V_b-V_B is not positive definite)
```

Fixed Effect model for panel data with only climate variables

```
Fixed-effects (within) regression               Number of obs      =       120
Group variable: DevReg                          Number of groups   =         5

R-sq:  within  = 0.2545                         Obs per group: min =        24
       between = 0.3506                                        avg =      24.0
       overall = 0.0928                                        max =        24

                                                F(6,109)           =      6.20
corr(u_i, Xb)  = -0.8964                        Prob > F           =    0.0000
```

Yield	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
TempMax	-292.4441	404.8272	-0.72	0.472	-1094.798	509.9102
TempMaxSq	7.385239	6.781562	1.09	0.279	-6.055596	20.82607
TempMin	172.1736	1021.949	0.17	0.867	-1853.296	2197.644
TempMinSq	-.5910823	24.63922	-0.02	0.981	-49.42521	48.24304
Prcpt	-.5013273	1.455846	-0.34	0.731	-3.386767	2.384112
PrcptSq	-.0005081	.001281	-0.40	0.692	-.003047	.0020307
_cons	1454.557	9055.608	0.16	0.873	-16493.36	19402.48
sigma_u	947.8608					
sigma_e	319.28673					
rho	.89809513	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(4, 109) =     16.01             Prob > F = 0.0000

. estimate store fe
```

Hausman's test for fixed vs. random effect for panel data with both climate and agriculture input variables

```
Note: the rank of the differenced variance matrix (9) does not equal the number of
        coefficients being tested (11); be sure this is what you expect, or there may
        be problems computing the test.  Examine the output of your estimators for
        anything unexpected and possibly consider scaling your variables so that the
        coefficients are on a similar scale.
```

	Coefficients (b) fe	(B) re	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
TempMax	-870.3343	621.961	-1492.295	100.911
TempMaxSq	15.5899	-9.120935	24.71084	1.845404
TempMin	632.1528	-1596.136	2228.289	172.0998
TempMinSq	-14.70029	34.22142	-48.92171	2.459359
Prcpt	-1.070535	2.451572	-3.522107	.6588539
PrcptSq	.0005426	-.0023493	.0028918	.0002177
Labor	-5.650524	-5.179582	-.4709423	.
Bullock	-15.10606	-16.15593	1.049867	.
ImpvdSeed	3.283664	2.289009	.9946546	.
manure	.0355907	.0034151	.0321756	.
fertilizer	1.359328	3.030444	-1.671117	.

```
                           b = consistent under Ho and Ha; obtained from xtreg
            B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(9) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =       57.08
                Prob>chi2 =      0.0000
                (V_b-V_B is not positive definite)
```

Fixed Effect model for panel data with both climate and agriculture input variables:

```
Fixed-effects (within) regression               Number of obs      =       120
Group variable: DevReg                          Number of groups   =         5

R-sq:  within  = 0.6656                         Obs per group: min =        24
       between = 0.1930                                        avg =      24.0
       overall = 0.0437                                        max =        24

                                                F(11,104)          =     18.82
corr(u_i, Xb)  = -0.5271                        Prob > F           =    0.0000
```

Yield	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
TempMax	-870.3343	290.9756	-2.99	0.003	-1447.35	-293.3188
TempMaxSq	15.5899	4.861314	3.21	0.002	5.949735	25.23007
TempMin	632.1528	726.6717	0.87	0.386	-808.8644	2073.17
TempMinSq	-14.70029	17.55876	-0.84	0.404	-49.51997	20.11939
Prcpt	-1.070535	1.033402	-1.04	0.303	-3.119809	.9787392
PrcptSq	.0005426	.0008973	0.60	0.547	-.0012369	.002322
Labor	-5.650524	1.276806	-4.43	0.000	-8.182478	-3.118571
Bullock	-15.10606	5.373071	-2.81	0.006	-25.76107	-4.451064
ImpvdSeed	3.283664	5.88298	0.56	0.578	-8.382507	14.94983
manure	.0355907	.0262046	1.36	0.177	-.0163739	.0875553
fertilizer	1.359328	.896858	1.52	0.133	-.4191756	3.137831
_cons	8941.745	6867.74	1.30	0.196	-4677.241	22560.73
sigma_u	595.6536					
sigma_e	218.91268					
rho	.88100405	(fraction of variance due to u_i)				

```
F test that all u_i=0:      F(4, 104) =     16.28            Prob > F = 0.0000

. estimate store fe
```

Terai Region

Ricardian Cross Section (OLS) results only with climate variables:

Source	SS	df	MS
Model	3183108.55	6	530518.092
Residual	12568395.4	105	119699.004
Total	15751504	111	141905.441

Number of obs	=	112
F(6, 105)	=	4.43
Prob > F	=	0.0005
R-squared	=	0.2021
Adj R-squared	=	0.1565
Root MSE	=	345.98

Yield	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
TempMax	-8961.052	3732.667	-2.40	0.018	-16362.24	-1559.863
TempMaxSq	138.1518	56.40779	2.45	0.016	26.3056	249.9981
TempMin	-752.2618	2798.182	-0.27	0.789	-6300.54	4796.016
TempMinSq	15.79315	56.92271	0.28	0.782	-97.07406	128.6604
Prcpt	-3.13934	1.296132	-2.42	0.017	-5.70933	-.5693507
PrcptSq	.0039015	.001617	2.41	0.018	.0006953	.0071077
_cons	157403.2	68974.64	2.28	0.025	20639.22	294167.1

```
. estimates store ModelA
```

Ricardian Cross Section (OLS) results with both climate and agriculture input variables:

Linear regression

Number of obs	=	112
F(11, 100)	=	15.19
Prob > F	=	0.0000
R-squared	=	0.5342
Root MSE	=	270.88

Yield	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
TempMax	-7276.53	3336.975	-2.18	0.032	-13896.99	-656.066
TempMaxSq	111.4024	50.51159	2.21	0.030	11.18886	211.616
TempMin	402.7518	1770.271	0.23	0.820	-3109.415	3914.919
TempMinSq	-7.948485	35.95161	-0.22	0.825	-79.27545	63.37848
Prcpt	-3.184	.7607118	-4.19	0.000	-4.693231	-1.67477
PrcptSq	.003319	.0007784	4.26	0.000	.0017746	.0048633
Labor	-3.986277	2.882947	-1.38	0.170	-9.705962	1.733408
Bullock	-5.493337	3.222281	-1.70	0.091	-11.88625	.8995777
ImpvdSeed	-9.478484	4.236351	-2.24	0.027	-17.88328	-1.073685
manure	.1215303	.042214	2.88	0.005	.0377788	.2052818
fertilizer	-1.438774	.8707476	-1.65	0.102	-3.166312	.2887646
_cons	118148.8	55447.93	2.13	0.036	8141.654	228155.9

```
. estimates store ModelB
```

Hasuman's test for fixed vs. random effect for panel data with only climate variables

Note: the rank of the differenced variance matrix (**5**) does not equal the number of coefficients being tested (**6**); be sure this is what you expect, or there may be problems computing the test. Examine the output of your estimators for anything unexpected and possibly consider scaling your variables so that the coefficients are on a similar scale.

	Coefficients (b) fe	Coefficients (B) re	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
TempMax	**-4221.771**	**-8961.052**	**4739.281**	**.**
TempMaxSq	**69.10579**	**138.1518**	**-69.04605**	**.**
TempMin	**-3.169113**	**-752.2618**	**749.0927**	**1166.839**
TempMinSq	**-1.806688**	**15.79315**	**-17.59984**	**24.48964**
Prcpt	**-1.287827**	**-3.13934**	**1.851514**	**.5390476**
PrcptSq	**.002102**	**.0039015**	**-.0017995**	**.0004533**

b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic

```
     chi2(5) = (b-B)'[(V_b-V_B)^(-1)](b-B)
             =        13.09
   Prob>chi2 =       0.0225
   (V_b-V_B is not positive definite)
```

Fixed effect model for panel data with only climate variables

```
Fixed-effects (within) regression               Number of obs     =        112
Group variable: DevReg                          Number of groups  =          5

R-sq:  within  = 0.2646                         Obs per group: min =        18
       between = 0.0000                                        avg =      22.4
       overall = 0.1263                                        max =        24

                                                F(6,101)          =       6.06
corr(u_i, Xb)  = -0.5016                        Prob > F          =     0.0000
```

Yield	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
TempMax	**-4221.771**	**3711.964**	**-1.14**	**0.258**	**-11585.31**	**3141.768**
TempMaxSq	**69.10579**	**55.84087**	**1.24**	**0.219**	**-41.66747**	**179.879**
TempMin	**-3.169113**	**3031.722**	**-0.00**	**0.999**	**-6017.289**	**6010.951**
TempMinSq	**-1.806688**	**61.96723**	**-0.03**	**0.977**	**-124.733**	**121.1196**
Prcpt	**-1.287827**	**1.403756**	**-0.92**	**0.361**	**-4.0725**	**1.496847**
PrcptSq	**.002102**	**.0016793**	**1.25**	**0.214**	**-.0012293**	**.0054333**
_cons	**68071.91**	**69370.6**	**0.98**	**0.329**	**-69540.69**	**205684.5**
sigma_u	**224.6221**					
sigma_e	**319.15639**					
rho	**.33125295**	(fraction of variance due to u_i)				

F test that all u_i=0:   F(**4**, **101**) =   **5.60**   Prob > F = **0.0004**

. estimates store ModelC

Hausman's test for fixed vs. random effect model for panel data with both climate and agriculture variables:

```
Note: the rank of the differenced variance matrix (9) does not equal the number
        coefficients being tested (11); be sure this is what you expect, or the
        may be problems computing the test.  Examine the output of your estimat
        for anything unexpected and possibly consider scaling your variables so
        the coefficients are on a similar scale.
```

	Coefficients (b) fe	(B) re	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
TempMax	-5407.943	-7276.53	1868.587	841.5109
TempMaxSq	84.0658	111.4024	-27.33663	11.77312
TempMin	593.01	402.7518	190.2582	1151.596
TempMinSq	-12.66321	-7.948484	-4.714729	23.96609
Prcpt	-2.246188	-3.184	.9378126	.6149429
PrcptSq	.0024617	.003319	-.0008573	.0006041
Labor	-4.09138	-3.986277	-.1051031	.
Bullock	-6.184925	-5.493337	-.6915878	.9400747
ImpvdSeed	-6.045826	-9.478484	3.432658	2.17901
manure	.0852826	.1215303	-.0362477	.0051277
fertilizer	-1.084271	-1.438774	.3545029	.3153408

```
                     b = consistent under Ho and Ha; obtained from xtreg
       B = inconsistent under Ha, efficient under Ho; obtained from xtreg

  Test:  Ho:  difference in coefficients not systematic

               chi2(9) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                       =       26.85
             Prob>chi2 =      0.0015
             (V_b-V_B is not positive definite)
```

Fixed effect model for panel data with both climate and agriculture input variables:

```
Fixed-effects (within) regression               Number of obs      =       112
Group variable: DevReg                          Number of groups   =         5

R-sq:  within  = 0.5259                         Obs per group: min =        18
       between = 0.4480                                        avg =      22.4
       overall = 0.5064                                        max =        24

                                                F(11,96)           =      9.68
corr(u_i, Xb)  = 0.0403                         Prob > F           =    0.0000
```

Yield	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
TempMax	-5407.943	3097.705	-1.75	0.084	-11556.84	740.952
TempMaxSq	84.0658	46.57302	1.81	0.074	-8.380917	176.5125
TempMin	593.01	2560.812	0.23	0.817	-4490.162	5676.182
TempMinSq	-12.66321	52.35748	-0.24	0.809	-116.592	91.26557
Prcpt	-2.246188	1.212826	-1.85	0.067	-4.653628	.1612526
PrcptSq	.0024617	.001435	1.72	0.089	-.0003867	.0053101
Labor	-4.09138	2.907788	-1.41	0.163	-9.863293	1.680533
Bullock	-6.184925	3.997164	-1.55	0.125	-14.11923	1.749383
ImpvdSeed	-6.045826	5.795663	-1.04	0.299	-17.55013	5.458473
manure	.0852826	.0437749	1.95	0.054	-.0016098	.1721751
fertilizer	-1.084271	1.01769	-1.07	0.289	-3.104369	.9358276
_cons	84119.53	58210.22	1.45	0.152	-31426.84	199665.9
sigma_u	114.77979					
sigma_e	262.8478					
rho	.16014904	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(4, 96) =      2.55              Prob > F = 0.0440

. estimates store ModelD
```

Appendix D: Marginal impacts

Calculation of the marginal impacts of the climate variables

Marginal impacts of climate variables is given by the equation: $\beta_2 + 2\beta_3 \text{CLIMATE}$

Hilly Region

Variable	β 2	β 3	Climate	Marginal Impact
TempMax	-870.33	15.5899	23.84	-127.00
TempMin	632.152	-14.7	17.38	121.18
Prcpt	-1.07	0.0005	102.24	-0.97

Terai Region

Variable	β 2	β 3	Climate	Marginal Impact
TempMax	-5407.943	84.0657	31.6	-94.99
TempMin	593.01	-12.66	22.62	20.27
Prcpt	-2.24	0.0024	134.8	-1.59

Where β_2 and β_3 are the coefficient of climatic and squared term of respective climate variables taken from the test result of Model D and climate is the minimum value of the respective climatic variables taken from the dataset.

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