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Assessing the Impacts of Climate Change on Paddy Production in Malaysia

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ABSTRACT

Climate change issues have since the fairly recent past, attracted enormous debate around the globe. Malaysia like other developing countries faces critical issues on global warming which had changed the local climate; threatening agricultural activities. This climatic anomaly is manifested in temperature and rainfall variability. It is envisaged to challenge the sustainability of food production in the future. The purpose of this study is to investigate the economic impact of these indicators of climate change on paddy production in Malaysia. This is in respect of its adverse effect on farmer's productivity. Using annual data spanning from 1980-2010, a time-series regression based on a modified Ricardian model was employed to assess the impact. In addition, the Providing Regional Climates for Impacts Studies (PRECIS), Regional Climate Modeling (RCM) system was applied to estimate the potential impact of long-term changes in climate on paddy net revenue. Result shows that temperature as well as rainfall variability had a negative impact on paddy production. The total marginal increase in temperature and rainfall was found to account for an estimated loss in paddy production to the tune of RM312.20. Besides, projections based on regional climate modeling system (PRECIS) shows that the loss in paddy production due to climate change will reach RM 7608.90 (168.88%) by the year 2099. Hence, this study recommends the need for adaptation and mitigation strategies to minimize these losses.

Key words: Climate change, paddy cultivation, ricardian model, economic impact, net revenue

INTRODUCTION

Climate change which partly caused by the increased atmospheric concentration of greenhouse gases (GHGs) is the most discussed environmental threats of the 21st century. The severe weather that results from it has disastrous implications. Scientists have found that Carbon Dioxide (CO_2), methane (CH_4), Nitrous Oxide (N_2O) and chlorofluorocarbons (CFCs) are the four most important GHGs which can be influenced by human activities. Figure 1 illustrates that the concentration of GHGs had tremendously increased at a fast rate in the last 2000 years. Besides, other human activities such as deforestation, landfills, mining and agriculture also contribute enormously to the emission of greenhouse gases. This rate of emission is expected to continuously increase if constructive initiatives and precautionary measures are not imbibed.

More disturbing is the fact that global temperatures are projected to continue to rise in the course of this century (Fig. 2). The National Climate Data Center of the National Oceanic and

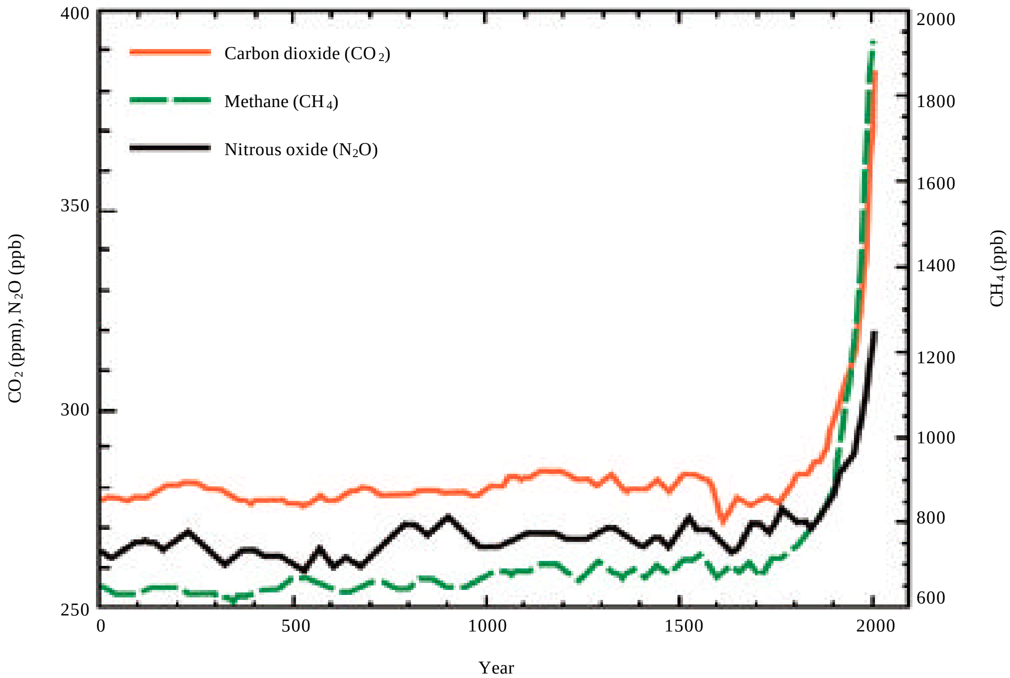

Fig. 1: Concentration of greenhouse gas in the last 2000 years (Source: Climate Change 2007 synthesis report (IPCC, 2007)

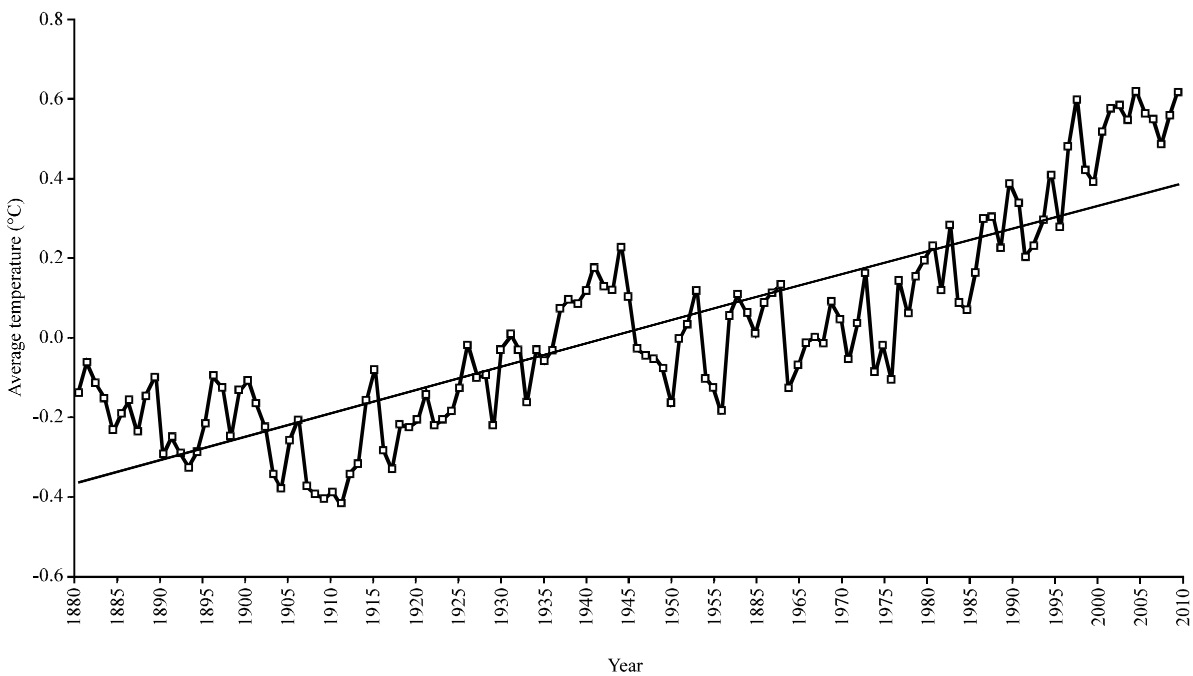

Fig. 2: Global temperature changes (°C), 1980-2010 (Source: National environmental satellite, data and information service (NOAA Satellite and Information Service, 2011)

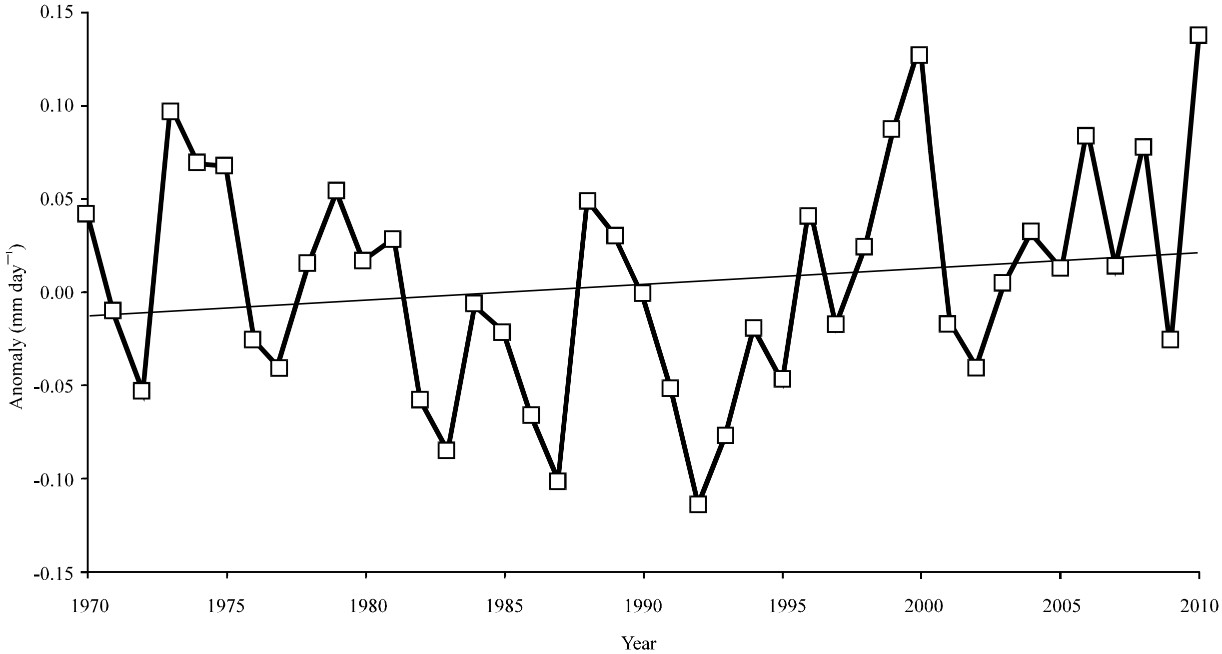

Fig. 3: Global rainfall changes (mm day^{-1}), 1970-2010 (Source: National environmental satellite, data and information service (NOAA Satellite and Information Service, 2011)

Atmospheric Administration in the United States announced that 2010 was the hottest year on record across the entire planet. Furthermore, the period 2001-2010 was the hottest decade. Figure 3 shows that global rainfall had intensely fluctuated between 1970 and 2010. This rainfall trend has slightly increased over the last 40 years, while the year 2010 recorded the driest weather.

It is widely accepted that increased variations in global climate change will impact on agriculture and the environment. These include water resources, fisheries, forests, wildlife and ecosystems. Scientists predicted that enhanced greenhouse effect could intensify climate variability. This variability has implications for climate-sensitive systems such as agriculture and other natural resources (Murad *et al.,* 2010). Findings from recent studies had documented increased frequency of heat stress, droughts and floods, sequel to which agricultural activities had suffered adverse effects as consequences of climate change.

This issue is worthwhile of concern as Eitzinger *et al.* (2010) noted that such variability has undesirable effects on food production. This agronomic impact of climate variability on crop yields could trigger economic impulses reflected through its effects on agricultural prices, production, demand, trade, regional comparative advantage and producers' as well as consumers' welfare (Li *et al.*, 2011). As such, if ignored, climate change would cause serious disruption to the functioning of the society, resulting in widespread human, material, economic or environmental losses (UNEP, 2011).

CLIMATE CHANGE IN MALAYSIA

Malaysia is a country with tropical weather due to its proximity to the equator which stretches from latitudes 0° 60' N to 6° 40' N and from longitudes 99° 35' E to 119° 25' E. Malaysia's climate is categorized as equatorial (tropical rainforest) climate, being hot and humid throughout the year. This climate is characterized by maritime monsoon winds which are subject to interference by mountains in Peninsular Malaysia, Borneo and Sumatra. The average annual rainfall is about

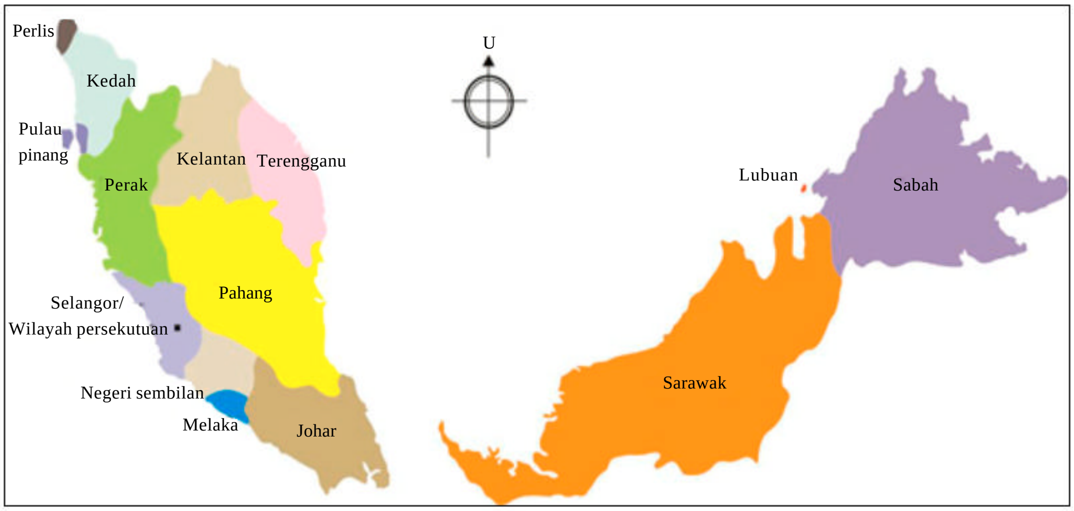

Fig. 4: Map of Malaysia states

2,420 mm in the Peninsular, 2,630 mm in Sabah and 3850 mm in Sarawak. However, the annual average rainfall is more than 4,000 mm in mountainous areas of Sarawak, and more than 3,000 mm in the northern half of Peninsular Malaysia and the coastal areas of Sabah and Sarawak.

The monthly mean air temperature is 25-28°C in the coastal lowlands and monthly relative humidity is between 75 and 90% (MMD, 2009). Climate of Peninsular Malaysia and East Malaysia differ. The climate in the former is directly affected by wind from the mainland, as opposed to the more maritime weather. Meanwhile, the latter faces the Southwest Monsoon from late May to September and the Northeast Monsoon from November to March. The Northeast Monsoon brings more rainfall compared to the Southwest Monsoon, originating from China and northern Pacific. Temperature changes in Malaysia ranges from +0.3°C to +4.5°C and rainfall changes ranges from -30-+30%. The mean temperature in the lowlands ranges from 26-28°C with little variation in different months or across different latitudes (MMD, 2009).

The impact of climate change is of concern in Malaysia. The 2012 Climate Change Performance Index (CCPI) ranks Malaysia among the least in climate protection performances. This constitutes potential threats not only to national food security but also, the country's export earnings from plantation crops. This is because any unfavourable climate negatively affects agricultural productivity (Murad *et al*., 2010). Evidences abound on the fact that Malaysia has been witnessing long-term inconsistent changes in its climate pattern with rapid acceleration in recent decades. It can be seen from Fig. 4, that the annual amount of rainfall during the last 30 years had taken an upward trend despite sharp fluctuations in certain years. Most of such fluctuations are revealed in El Nino disasters of 1982, 1990, 1997, 2002 and 2005, which caused dry hot weather leading to unusually minimal amounts of rainfall in the respective years (MMD, 2009).

EFFECT CLIMATE CHANGE ON PADDY PRODUCTION

A considerable amount of literature has been published on paddy production. These studies show that its cultivation is constrained by factors such as solar radiation, temperature and water. In most part of Peninsular Malaysia, paddy has cropping season planned by a schedule of irrigation or even arbitrary decision by farmers. There is seasonal paddy production which encompasses the growing period, planting, heading and harvesting time. It is also reported that East Malaysia which are Sabah and Sarawak have places which cultivate and harvest paddy at hillside, named hill paddy during the whole year without following any seasonal climate.

Temperature is the most important factor for optimal paddy growth as the crops are found to be more sensitive to temperature changes. Grain yield in paddy production is found to decline steeply as means temperature exceeded 28°C (Jeng *et al.*, 2003). Meanwhile, rainfall variability is not an exception in this context. Decrease in rice yields is attributed to poor amount and distribution of rainfall and soil properties such as water holding capacities and poor fertility (Fukai *et al.*, 1997). This is the reason why paddy is not cultivated during off season because of its low water consumption and average high temperature. Therefore, shifting of cropping season and adoption of a late maturing cultivation may be probable methods to prevent yield reduction caused by high-temperature.

METHODOLOGY

Model specification: The Ricardian model was used to assess the impact of climate variability on paddy farmers' net revenue. The application of this model in estimating climate change impact had been employed in similar studies (Mendelsohn *et al.*, 2010; Mendelsohn, 2007; Gbetibouo and Hassan, 2005; Confalonieri *et al.*, 2005; Adger *et al.*, 2007; Zainal *et al.*, 2012). This model estimates the total net revenue farms earn per hectare of cultivated land predicted by relevant climatic and non-climatic explanatory variables. While the climatic variables include precipitation and temperature, the non-climatic variables could include price and area of cultivated land (Confalonieri *et al.*, 2005; Zainal *et al.*, 2012). The general formulation to calculate the net revenue based on Recardian model (Mendelsohn *et al.*, 1994; Eid *et al.*, 2006) is given:

$$NR = \Sigma P_i Q_i(X, Y, Z) - \Sigma P_x X \tag{1}$$

where, NR denotes net revenue per hectare, P_i is the market price of crop, Q_i is output, X is a vector of purchased input, Z is a vector of economic variables and P_x is a vector of input prices. Meanwhile, Y is a vector of climate variables. The net revenue applied in this study is defined as the gross revenue less per hectare production cost. The dependent variable is regressed on climate and other control variables. The standard Recardian model specifies the linear and quadratic climate variables as the determinants of net revenue (Mendelsohn, 2007). This study extends such specification by adding "labor"; which is conceptualized as the number of labor committed to the planting of paddy as a predictor. Besides, to capture seasonal variability, the variables considered were disaggregated into their main and off-season values. Finally, both the standard specification as well as its extended version was estimated. Thus we model both the basic model (Model 1) and an extended model (Model 2):

- **Model 1:**

$$\begin{aligned} NRp_1 = {} & \beta_0+\beta_1 ms\_rain+\beta_2 ms\_rain^2+\beta_3 ms\_temp+\beta_4 ms\_temp^2 \\ & +\beta_5 os\_rain+\beta_6 os\_rain^2+\beta_7 os\_temp+\beta_8 os\_temp^2+\varepsilon \end{aligned} \tag{2}$$

- **Model 2:**

$$\begin{aligned} NRp_2 = {} & \beta_0+\beta_1 ms\_rain+\beta_2 ms\_rain^2+\beta_3 ms\_temp+\beta_4 ms\_temp^2 \\ & +\beta_5 os\_rain+\beta_6 os\_rain^2+\beta_7 os\_temp+\beta_8 os\_temp^2+labor+\varepsilon \end{aligned} \tag{3}$$

where, ms and os denote main season and off-season, respectively. Main season denotes the period between Augusts in a particular year and February in the succeeding year while the remaining months are dubbed off-season. Rainfall is denoted by rain while temp is abbreviated for temperature. The symbol ε refers to the stochastic error term, included to capture the impact of unobserved factors. Both the linear and quadratic terms are specified for temperature and rainfall to capture their linear and quadratic effects of on the dependent variable. The introduction of quadratic terms reflects the non-linear shape of the response function between net revenues and climate. The expected marginal impact of a single climate variable on the land value and farm net revenue evaluated at mean is:

$$E[d(NR)/d(f_i)] = b_{1,i} + 2\times b_{2,i}\times E[f_i] \quad (4)$$

where, f_i refers to climate variables, measured by both temperature and rainfall. The marginal impact of both rainfall and temperature was estimated for both models. Marginal impact calculations determine how paddy production will be affected by 1°C rise in temperature and 1mm increase in rainfall.

Control variable: The extended Recardian model is adopted to control for unwanted variation in order to increase the accuracy of the climate coefficients. This is necessary to capture some of the non-climate features that influence the land use decision making and land value (Mendelsohn and Nordhaus, 1996). Number of labor employed has been included based on its ability to as a proxy to account for house hold or non-hired labor (Sanghi and Mendelsohn, 2008). This is considered reasonable since Onyemauwa *et al.* (2006) found a statistically significant relationship between labor and net revenue. However, increase in the employment of labor will directly increase production cost. Drawing from production theory, an increase in cost beyond certain output level will decrease the profit. Hence, a negative relationship is expected between labor employment and the net revenue.

Data collection: The paddy production data analyzed in this study was obtained from the Ministry of Agriculture and Agro-based Industry Malaysia (MOA). Meanwhile, information on the annual number of labor employed was collected from the Department of Statistics. Temperature and rainfall data was obtained from Malaysian Meteorological Department (MMD). The temperature and rainfall data was arranged according to the main seasons (August to February) and off seasons (March to July) following the period of paddy cultivation and harvesting. All the data collected spans 31 years (1980~2010).

All 13 meteorological houses place was selected in every state and temperature and precipitation readings taken in particular states (Fig. 4) including Kluang (Johor), Alor Star (Kedah), Georgetown (Penang), Bintulu (Sarawak), Chuping (Perak), Jelebu (Negeri Sembilan), Ipoh (Perak), Kuala Terengganu (Terengganu), Kota Bharu (Kelantan), Kota Kinabalu (Sabah), Malacca, Kuantan (Pahang), Subang (Selangor). All meteorological stations are valid and recognized under the supervision of Malaysian Meteorological Department (MMD) provides the official data of temperature and rainfall.

Global Circulation Model (GCM): An important post-estimation analysis conducted in this study was the simulation of potential loss in paddy net revenue arising from future variability forecast of climatic conditions. The forecast is based on PRECIS model developed at the Hadley Centre of the United Kingdom Meteorology Office which is used by the Malaysian Meteorological Department. The PRECIS is essentially a regional climatic modeling system. It is based on the third generation of the Hadley Centre regional climate model (HadRM3) with a user-friendly data processing and a visualization interface. Its flexible design allows its application in any region of the world. Like any other regional climate model, PRECIS is driven by boundary conditions simulated by General Circulation Models (GCMs). The GCMs describe important physical elements and processes in the atmosphere such as oceans and surfaces that make up the climate system. This system also provides climate information with useful local details including realistic extreme events.

RESULTS AND DISCUSSION

Estimated model: The regression result (Table 1) shows that both the linear and quadratic terms of the climate variables (temperature and rainfall) have statistically significant impact on paddy farmers' net revenue across seasons. This is also true for the number of labor employed in paddy farms. Temperature was found to affect net revenue both in the main season and off-season periods. Yet, the nature of the relationship differs across seasons. While we found a U-shaped relationship during the main season, a contrary relationship (bell-shaped) was found during the off-season period. This implies that at relatively low temperature levels paddy yields fall with increase in temperature. Whereas, at a comparatively higher temperature levels during the main season, paddy yields and consequently net revenue increases with additional increase in temperature. Meanwhile, during off-season periods, average temperature levels are already relatively high. As such, additional unit increase in temperature will only increase yield and thus net revenue to certain level beyond which additional increase in temperature will reduce paddy yields and hence, net revenue per hectare.

Moreover, rainfall was also found to have a U-shaped relationship with per hectare net revenue. This denotes that when relatively lower volume of rainfall is recorded, paddy yields fall with increase in additional volume. However, higher volumes of rain during main season period increases paddy yields and consequently net revenue per hectare. This is unlike the off-season period where the volume of rain was not found to significantly affect paddy yield. An expected result was found for the impact of the number of labor committed to paddy production. The result

Table 1: Determinants of net revenue per hectare paddy production

	Model 1		Model 2	
Independent variables	Coefficient	t-stat	Coefficient	t-stat
Constant	482415.300	2.820***	351975.300	2.060**
ms_rain	-87.641	-2.923***	-58.654	-3.045***
ms_rain_sq	0.201	2.860***	0.135	3.104***
ms_temp	-99377.430	-6.177***	-72421.690	-4.187***
ms_temp_sq	1858.790	6.226***	1351.903	4.186***
os_rain	-76.681	-1.535	-25.121	-0.609
os_rain_sq	0.228	1.660	0.082	0.712
os_temp	63819.000	5.787***	46234.400	3.532***
os_temp_sq	-1181.137	-5.768***	-852.353	-3.515***
Labor			-2.645	-2.659***
Adjusted R^2	0.643		0.738	

,*Significance at 5 and 1% level, respectively from the extended model shows that labor employment has a statistically significant negative relationship with net revenue per hectare. This is expected as increase in the number of labor increases production cost per hectare and hence, reduces farmers' net revenue.

This implies that temperature is the most prominent factor in the growth of paddy across both seasons. The adjusted coefficient of determination (adjusted R^2) of model 1 (without labor) is 64.30%. The integration of labor improved the model (model 2), yielding a relatively higher adjusted R^2 value of 73.80%. This evidences the relevance of labor in Malaysia's paddy production. Even though paddy production is fairly mechanized to achieve production efficiency, some part of Malaysia still use manual cultivation practices. The negative sign obtained in this study would imply less revenue due to labor employment. Meanwhile, since non-mechanized farms would require large number of workers, less and less net revenue will be obtained from such practice. This constraint is one of reasons why the young generations are not much interested in the agricultural sector. This is likely to cause low paddy productivity mainly due to shortage of manpower.

Marginal impact analysis for net revenue model: Estimated regression output for paddy shows that on average, increase in temperature and rainfall is harmful to annual production. The result for model 1 as depicted in Table 2, shows that the marginal effect of 1 mm and 1°C increase in rainfall and temperature will reduce net revenue per hectare annually (both main and off season) by RM 6.99 and RM 114.03, respectively. These results are consistent with the simulation results obtained by Vaghefi *et al.* (2011) which predicted a rice yield decrease of 0.18 t ha^{-1} (RM 106.27) under the scenario of an increase in temperature by 1°C at the current CO_2 level of 383 ppm. However, after the inclusion of an additional control variable (labor), the effect of climate variability shows less negative impact on net revenue. This is depicted by annual marginal effect of RM 2.63 and RM 46.57 per hectare for rainfall and temperature respectively. This implies while labor increases production cost on one hand, more employment would mean more harvest. This would help mitigate the reduction in yield that would result from climate variability.

In addition, the marginal analysis result in Table 2 shows that loss in net revenue (RM ha^{-1}) caused by temperature anomaly is greater than rainfall impact. This is because rice is very sensitive to high temperature; affecting photosynthesis activity. Previous studies noted that the optimum temperature of 26°C is averaged over the years. It further asserted that high temperature causes intense surface evaporation which results in parched fields. That creates a situation where cultivated plants will be in desperate need of continuous water supply whereas excessive rains also cause flooding on the paddy fields. It also causes paddy area damage which reduces the yield particularly at the flowering and ripening stage. Moreover, flooding also encourage the establishment of disease due to biotic and a biotic factors. Diseases usually occur in a region which has experienced a lot of rain and high humidity. Diseases such as bacterial leaf blight and rice blast (caused by fungus) are usually common.

Future climate impacts: Using the net revenue function obtained earlier, future impact was projected based on climate forecast data. We projected the impact of climate change on net revenue

Table 2: Marginal effect of temperature and rainfall on paddy production (RM ha^{-1})

	Model 1			Model 2		
Parameters	MS	OS	Annual	MS	OS	Annual
Rainfall	-8.12	1.13	-6.99	-5.34	2.72	-2.63
Temperature	-46.55	-67.47	-114.03	-178.08	131.50	-46.57

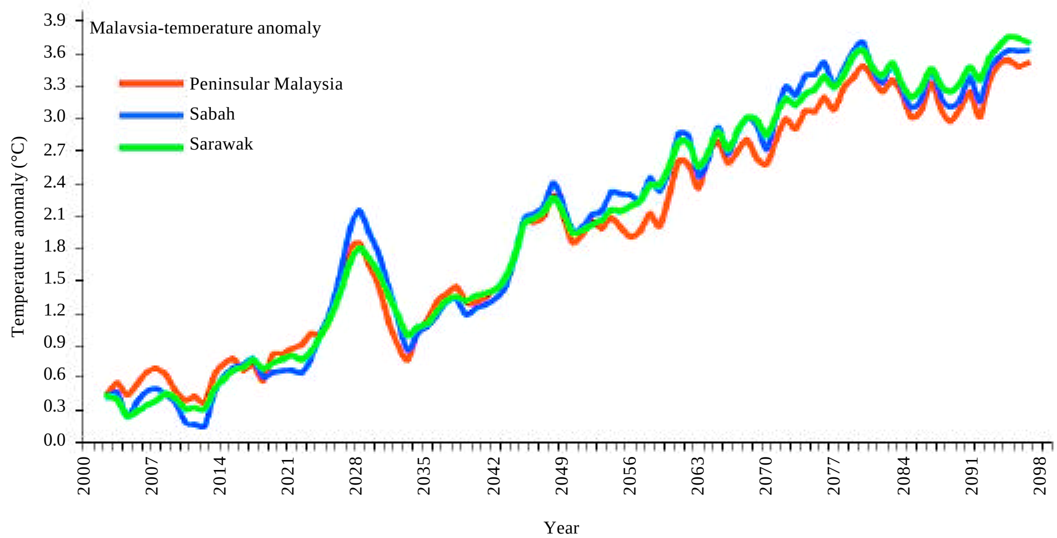

Fig. 5: PRECIS simulation (2001-2099) annual temperature anomaly (Source: Malaysian Meteorology Department, MMD, 2009)

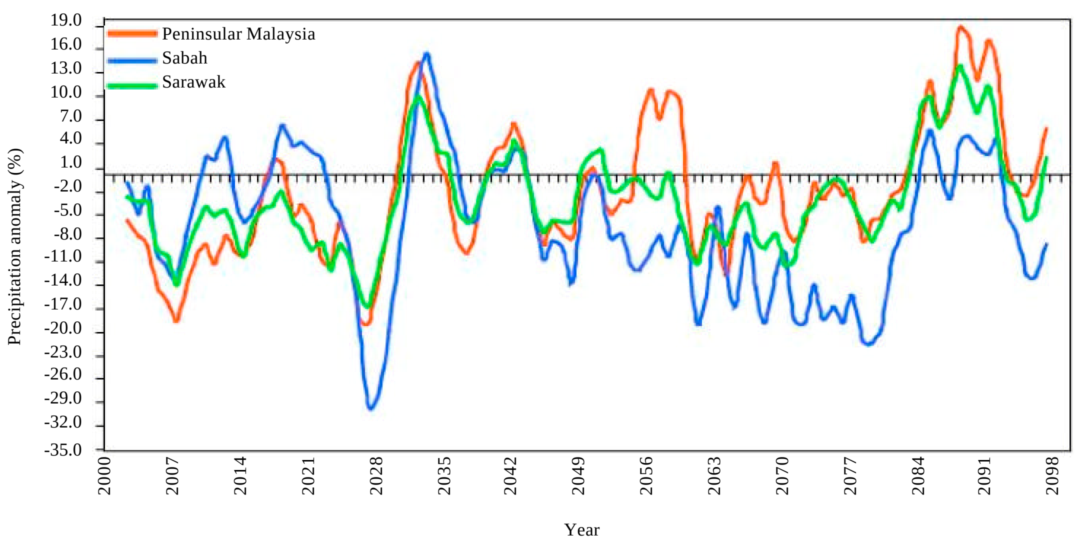

Fig. 6: PRECIS simulation (2001-2099) annual rainfall anomaly (Source: Malaysian Meteorology Department, MMD, 2009)

(RM ha^{-1}) and percentage impact of changing climate by applying PRECIS regional climate modeling system on paddy production. We estimated the consequences of climate change scenarios for the years 2029, 2059 and 2099 (Fig. 5 and 6). The climate scenario projection by PRECIS provided a future predicted estimates of climate variability in Malaysia. Table 3 shows that average estimated net revenue under PRECIS climate scenarios for paddy production for years 2029, 2059 and 2099. The respective impacts obtained are RM 3124.10 (-97.28%), RM 4583.10 (-129.11%) and

Table 3: Average estimated net revenue (RM ha^{-1}) and percentage impact of changing climate on paddy production under PRECIS climate scenario

Year	Average estimated net revenue (RM ha^{-1})	Impact of changing climate (%)
2029	-3124.10	-97.28
2059	-4583.10	-129.11
2099	-7608.90	-168.88

RM 7608.90 (-168.88%). This evidences that net revenue loss is predicted to increase into the future if no adaptation and mitigation strategies are implemented.

CONCLUSION

This study's contribution is three-fold. Firstly, we assessed the relationship between paddy net revenue in response to climate change. Secondly, we estimated the marginal effect of changes in rainfall and temperature on paddy productivity under baseline climate condition. Finally, we forecast the potential impact of climate change on paddy net revenue arising from long-term changes in climate by applying PRECIS climate scenario model. The results of our study also unveiled the importance of temperature relative to rainfall for paddy production in Malaysia. Our findings based on marginal effect, reveals that climate change impacts negatively on paddy net revenue. This is true both for the baseline scenario and forecasted scenarios. Hence, we suggest the implementation of adaptation and mitigation strategies to reduce these losses.

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