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Impact of Climate Change on Wheat Production: A Case Study of Pakistan

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1. INTRODUCTION

Atmospheric condition which remains for some days is called weather, whereas, if such condition prevails for a season, decade or a century, it is termed as climate. To keep the pace of growth fossil fuel has been used in order to meet the energy requirement. However, fossil fuel adds some gases in the atmosphere which are altering the climate with the passage of time.

1.1. Climate Change

Climate change refers to "change in climate due to natural or anthropogenic activities and this change remain for a long period of time." [IPCC (2007)]

The gases responsible for the global warming are known as Greenhouse Gases (GHGs), which are comprised of Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and water vapors. These gases are produced by a number of anthropogenic activities (Motha and Baier). CO_2 is mainly produced during the combustion of wastes, carbon, wood and fossil fuels. Methane is produced during the mining of coal, gas and oil and during their transportation, whereas, Nitrous Oxide is produced during agricultural and industrial activities.

Man is responsible for this newly emerging CO_2 enriched world because since the pre industrial time CO_2 concentration has increased from 280ppm[1] to 380ppm due to deforestation, massive use of fossil fuels etc. [Stern (2006)] Concentration of GHGs as a result of anthropogenic activities are increasing at a rate of 23ppm per decade, which is highest rise since the last 6.5 million years. Percentage contribution of different sectors in the atmospheric concentration of GHGs is from energy sector 63 percent, agriculture 13 percent, industry 3 percent, land use and forestry 18 percent and waste 3 percent [Rosegrant, *et al*. (2008)]. Climate change is an externality which is mainly caused by

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[1]PPM means parts per million. It is used to measure the level of pollution in air. It is a ratio between pollutant components and the solution.

particular economic activities, and the geographical position of many developing countries makes them very much vulnerable to climate change. According to the IPCC prediction, in the absence of any policy to abate the GHGs emission, GHGs would increase from 550ppm to 700ppm at the mid of current century and this level of GHGs would cause to accelerate the temperature from 3^{o}C since the pre industrial era to 6^{o}C. (Stern 2006).[2]

Earth gains solar energy from sun in the form of sun light, and the atmosphere, which is composed of different GHGs, holds these energy rays and passes them on to the earth and then let them to go back into the space. So the atmosphere plays a vital role to maintain the earth's average temperature at a level of 15^{o}C [Edwards (1999)].

Global warming is a real issue which is directly caused by the higher level of CO_2 in the atmosphere, whereby GHGs trap the sun rays and do not let them go back to space. Higher level of CO_2, produced by anthropogenic activities, intensifies concentration of GHGs, traps more light and causes to increase earth's overall temperature [Brown (1998)]. Some of the consequences of global warming may appear in the form of more frequent floods and drought, food shortage, non supporting weather conditions, newly born diseases, sea level rise, etc. The concentration of these GHGs are mounting in the atmosphere through number of ways like anthropogenic activities, deforestation etc. It is expected that up to 2100 this concentration would become 3 times as much as the pre-industrial time causing 3 to 10^{o}C hike in temperature [Tisdell (2008)].

1.2. Possible Effects of Climate Change on Agriculture

Agriculture is the most vulnerable sector to climate change. Agriculture productivity is being affected by a number of factors of climate change including rainfall pattern, temperature hike, changes in sowing and harvesting dates, water availability, evapotranspiration[3] and land suitability. All these factors can change yield and agricultural productivity [Harry, *et al*. (1993)]. The impact of climate change on agriculture is many folds including diminishing of agricultural output and shortening of growth period for crops. Countries lying in the tropical and sub tropical regions would face callous results, whereas regions in the temperate zone would be on the beneficial side.

Wheat plant's stalk is normally 2 to 4 feet high and having grass like leaves each of which is normally 8 to 15 inches in length. The top of each stalk is having a spike which is normally 2 to 8 inches in length, it is the grain rich part of wheat plant, each spike contains 20 to 100 kernels (grains) whereas, some spike contains up to 300 kernels depending upon the climate conditions. According to Zadoks scale wheat has ten growth stages which are germination, main stem leaf production, tiller production, stem elongation, booting, heading, anthesis, grain milk stage, grain dough stage and ripening. Winter plants require minimum temperature of 5 to 10^{o}C in order to come out of the dormancy period, and hence wheat, which is a winter crop, also requires long cold season in order to hasten plant development before flowering occurs, so higher temperature delay the vernalisation process in wheat [Chouard (1960)].

[2]For international efforts to abate GHGs see Appendix-1.
[3]The sum of evaporation and plant transpiration from the surface of the earth to the atmosphere.

CO_2 is regarded as the driving factor of climate change, however its direct effect on plant is positive [Warrick (1988)] CO_2 enriches atmosphere positively and affects the plants in two ways. First, it increases the photosynthesis process in plants. This effect is termed as carbon dioxide fertilisation effect. This effect is more prominent in C3 plants because higher level of CO_2 increases rate of fixed carbon and also suppresses photorespiration.[4] Second, increased level of CO_2 in atmosphere decreases the transpiration[5] by partially closing of stomata and hence declines the water loss by plants. Both aspects enhance the water use efficiency of plants causing increased growth.

The crops which exhibit positive responses to enhanced CO_2 are characterised as C3 crops including wheat, rice, soybean, cotton, oats, barley and alfalfa whereas, the plants which show low response to enhanced CO_2 are called C4 crops including maize, sugarcane, sorghum, millet and other crops.

Warrick study for USA, UK and Western Europe regarding the impact of increase in temperature on the wheat productivity indicates that impact of increase in temperature is catastrophic in terms of yield losses because higher temperature accelerates the evapotranspiration process creating moisture stress [Warrick (1988)]. It also shorten the growth period duration of wheat crop and this becomes more severe regarding yield losses if it occurs during the canopy formation because less time will be available for vernalisation process and the formation of kernels. Wetter conditions are beneficial for wheat yield whereas drier are harmful and cause to decrease the productivity.

In Pakistan wheat is sown in winter season, preferably in November. Estimated land, on which wheat is cultivated in Pakistan, is 9045 thousand hectare and per hectare wheat yield is 2657 kg. [Khan, *et al*.]. Per head consumption of wheat in Pakistan is about 120 kg which makes the importance of this food crop. The water available for the cultivation of wheat in Pakistan is 26 MAF (million acre feet) which is still 28.6 percent lower than the normal requirement of water [Rosegrant, *et al*. (2008)]. Almost all the models predict that climate change will stress the wheat yield in South Asian region. According to the 4th IPCC report cereal yield could decrease up to 30 percent by 2050 in South Asia along with the decline of gross per capita water availability for South Asia from 1820m^3 in 2001 to 1140m^3 in 2050. Water supply is scarce in many part of the country. In near future a dramatic decline in the water availability would cast a sharp decline towards the production of agricultural productivity.

1.3. Objectives of Study

The primary purpose of this study is whether the global warming negatively affects the wheat production in Pakistan. More specifically, what has been the impact of change in temperature and precipitation on the wheat production in Pakistan? How far possible future changes in temperature and precipitation may affect the level of wheat production in Pakistan? Moreover, along with core variables of temperature, precipitation, carbon dioxide, area under wheat cultivation and water, the study also aims to investigate the role of a number of other variables on the wheat production of Pakistan.

[4]A process that displaces newly fixed carbon.
[5]Loss of water by plant during exchange of gases.

1.4. Scope and Limitation of Study

This study assumes Pakistan as a homogenous region.[6] It considers two basic variables of climatic change, namely temperature and precipitation. It does not consider the impact of climatic change on wheat production through humidity due to non-availability of wide range of time series data about the level of humidity in Pakistan. In context of dependent variable, scientists sometimes consider yield (per unit output) in place of total output to investigate the impact of various independent variables. However, this study does not consider yield due to non-availability of data on various factors (including different features of soil, etc.) that may influence yield.

2. LITERATURE REVIEW

Warrick (1988) investigated that at higher level of CO_2 in the atmosphere, C3 crops specially wheat would show improvement in water use efficiency through less transpiration, in such case at $2\times CO_2$ concentration level (680ppm) wheat production would be increased 10 percent to 50 percent for mid and high latitude region of Europe and America. However, 2^oC increase in temperature would decrease the production by 3 percent to 17 percent which might be offset by higher level of precipitation. He analysed that for each ^oC increase in temperature would cause to shift the geographical location for crops production to several hundred kilometers towards mid and high latitude.

Lobell, *et al*. (2005) used CERES-Wheat simulation model for the climate trend effect on wheat production in the Mexico region. They studied the climate trend and wheat yield for the last two decades from 1988 to 2002. They found that the climate had favoured during the two decades and resulted in 25 percent increase in wheat production. It means climate was having positive effect on the wheat yield for this region. However 25 percent increase is less as compared to the previous studies which predicted higher increase in wheat productivity for this region.

Xiao, *et al*. (2005) carried out the investigation in order to check the effect of climate variability on high altitude crop production and to check whether the wheat yield at high altitude could be affected by the climate variability. For this purpose they selected two sites, Tonguei Metrological station 1798m above the sea level and Peak of Lulu Mountains 2351m above the sea level. They investigated the effect for the time period from 1981 to 2005. Their results showed that yield of both the sites increased during this period bearing positive change in temperature and precipitation. Initially up to 1998 yield of two altitudes was high but after that yield of high altitude showed an increasing trend as compared to loss at low altitude. The simulated results up to 2030 also showed that the agriculture production of wheat for low altitude would increase by 3.1 percent and that of high altitude would increased by 4.0 percent.

Hussain and Mudasser (2006) used Ordinary Least Square (OLS) method to assess the impact of climate change on two regions of Pakistan, Swat and Chitral 960m and 1500m above the sea level, respectively. They investigated whether increase in temperature up to 3^oC would decrease the growing season length (GSL) of the wheat yield of this county. Their result showed that increase in temperature would create

[6]Most of the area under wheat cultivation lies in the plain regions of Indus valley having similar climatic conditions.

positive impact on Chitral district due to its location on high altitude and negative impact on Swat because of its low altitude position. An increase in temperature up to 1.5^{o}C would create positive impact on Chitral and would enhance the yield by 14 percent and negative effect on Swat by decreasing its yield by 7 percent. A further increase in temperature up to 3^{o}C would decrease the wheat yield in Swat by 24 percent and increase in Chitral district by 23 percent. They suggested adaptation strategies of cultivating high yielding varieties for warmer areas of northern region of Pakistan because of expected increasing temperature in the future.

Tobey, *et al*. (1992) used SWOPSIM statistical world policy simulation based on General Circulation Model (GCM). The model used by them is static in nature in the sense that it presents only on spot effect of doubling of CO_2 on global agriculture. The model used 20 agriculture commodities. According to their result the negative impact of climate change on some region would not sabotage the world agriculture market rather this negative impact would be counterbalanced by agriculture yield of some other region which would experience positive impact of the global warming of climate change.

Zhang and Nearing (2005) used Hardley Centre Model (HadCM3) for their study about the wheat productivity in Central Oklahoma. They used three scenarios A2a, B2a and GGal for the current time period (1950–1999) and future time period (2070–2099). The simulations model projected that annual future precipitation would decrease by 13.6 percent, 7.2 percent and 6.2 percent for the three said scenarios respectively, whereas temperature would increase by 5.7^{o}C, 4^{o}C and 4.7^{o}C respectively. They concluded that the short of rainfall in summer and not in winter will affect the yield whereas effect of increased temperature will be offset by the carbon fertilisation.

Winters, *et al*. (1996) analysed the impact of global warming on the archetype structure for Africa, Asia and Latin America. They used Comparable General Equilibrium (CGE) model for their study. They concluded that these entire three regions will face agriculture loss in cereal and export crops and hence income losses. They said that Africa would be the most negatively affected by this climate change because its economy is relying very heavily on agriculture output. They investigated that higher substitution possibility for increase in import cereal could do more to reduce income losses and development efforts regarding production of export crops in order to generate foreign exchange.

Gbetibouo and Hassan (2004) employed Ricardian model on wheat, sorghum, maize, sugarcane, ground nut, sunflower and soybean for the South African region. They found that temperature increase would be having positive impact on the agriculture production of maize, sorghum, sunflower, soybean whereas it would be having negative impact on sugarcane and wheat productivity. They concluded that this region is already having high temperature and any further increase in temperature in future due to climate change would havoc the wheat productivity. They suggested replacing wheat by maize and sorghum or other heat adapted crops in order to avoid possible loss of yield due to increased temperature.

Wolf, *et al*. (1996) compared five wheat models designed for Europe at different levels of agronomic conditions.[7] They concluded that almost all the models predicted the

[7]The models AFRCWHEAT2, CERES-Wheat, N-WHEAT, SIRIUS-WHEAT, and SOILN-wheat were designed for Rothamsted, UK and Sevelle, Spain.

same results. Their results showed that temperature increase would result in yield reduction whereas increased level of precipitation and CO_2 fertilisation would have positive impact on the production of wheat for Europe.

Anwar, *et al*. (2007) used the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO's) global atmospheric model under three climate change scenarios which were Low, Mid and High for the time period of 2000-2070 for South-East Australian location. Their results showed that for all the three scenarios the medium wheat yield declined by about 29 percent, however positive affect of CO_2 reduced this decline in production from 29 percent to 25 percent. CO_2 fertilisation affect offset a very small level of low rain fall and higher temperature. They suggested that higher yield productivity could be made through better agronomic strategies and breeds of wheat.

Cerri, *et al*. (2007) used simulation model for Central South region of Brazil up to 2050. They revealed that 3^oC to 5^oC increase in temperature and 11 percent increase in precipitation would cause to decrease the productivity of wheat to the level equal to one million ton of wheat. They ascertained that in Brazil wheat was being cultivated at the threshold level of temperature and any further addition to this level of temperature would cause to decline agricultural production specially wheat. They further concluded that most of the developing countries lying on the tropical belt and relying on agriculture would face losses in agricultural yield.

Zhai, *et al*. (2009) used comparable general equilibrium (CGE) model in order to examine the impact of climate change on agriculture sector of China in 2080. Their results showed 1.3 percent decline of agricultural share in GDP. The CGE simulation results showed that in 2080 agricultural output would become slow which ultimately leads to output losses except wheat which showed enhancement in output because of increase in global wheat demand. The simulation results also showed that as compared to world average agricultural production the agricultural productivity in China would decline less.

Zhai and Zhuang (2009) made a study on Southeast Asian region to investigate the economic impact of climate change on the said region by suing CGE model. According to them impact is not consistent throughout the world and developing countries would face large losses. According to the simulation results made by them up to 2080 Southeast Asia would face 1.4 percent decline in GDP. Crop productivity would fall up to 17.3 percent, whereas, the agriculture productivity of paddy rice would fall 16.5 percent and that of wheat up to 36.3 percent. In future, the Southeast Asian countries' dependency on import of these agricultural products would increase creating more welfare losses and hence weakening the term of trade of this region.

3. METHODOLOGY

3.1. Vector Auto Regression (VAR) Model

Vector autoregressive model (VAR) was developed by Sims (1980). Christopher Sim and Litterman urged that it is better to use VAR model for forecasting instead of structural equation model. VAR model superficially resembles simultaneous equation modeling in that we consider several endogenous variables together. But each endogenous variable is explained by its lagged or past values and the lagged values of all other endogenous variables in the model. Usually there is no exogenous variable in the model. Sim developed VAR model on the basis of true simultaneity among the exogenous and endogenous variables. All variables used in this model are endogenous and believed to interact with each others.[8]

3.2. General From of VAR Model

The general form of VAR model in the matrix form is as follows:

$$\begin{bmatrix} y_t \\ y_{t-1} \\ --- \\ y_{t-p+1} \end{bmatrix} = \begin{bmatrix} \mu \\ 0 \\ --- \\ 0 \end{bmatrix} + \begin{bmatrix} \Gamma_1 & \Gamma_2 & --- & \Gamma_p \\ I & 0 & & 0 \\ --- & --- & --- & 0 \\ 0 & --- & I & 0 \end{bmatrix} + \begin{bmatrix} y_{t-1} \\ y_{t-2} \\ --- \\ y_{t-p} \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ 0 \\ --- \\ 0 \end{bmatrix}$$

However, in the equation form the model can be expressed as follows:

$$y_t = \mu + \Gamma_1 y_{t-1} + \text{-------} + \Gamma_p \; y_{t-p} + \varepsilon_t$$

Or

$$\Gamma(L)\, y_t = \mu + \varepsilon_t$$

Where $\Gamma(L)$ is matrix of polynomial in lag operator.

The specific form of the model which we used for our study is as follows;

Wheat Production = f (Temperature, Carbon dioxide, Precipitation, Agricultural Credit, Wheat Procurement Price, Fertilisers takeoff, Technology, Land under wheat cultivation, Water availability) + Ui

$$W_p = \beta_0 - \beta_1 CO_2 + \beta_2 T_{emp} + \beta_3 Precip + \beta_4 A_{crdt} + \beta_5 W_{pp} + \beta_6 F_{ert} + \beta_7 T_{ech} + \beta_8 Lw + \beta_9 Wa + Ui$$

$$Wp = \alpha_1 - \alpha_2 Temp_{t-1} + \alpha_3 Prepcip_{t-1} + \alpha_4 Wp_{t-1} + \varepsilon_1 \qquad \varepsilon_1 \sim N(0,\delta 2)$$

$$Temp = \beta_1 + \beta_2 Wp_{t-1} + \beta_3 Prepcip_{t-1} + \beta_4 Temp_{t-1} + \varepsilon_2 \qquad \varepsilon_2 \sim N(0, \delta 2)$$

$$Prepcip = \gamma_1 - \gamma_2 Temp_{t-1} + \gamma_3 Prepcip_{t-1} + \gamma_4 Temp_{t-1} + \varepsilon_3 \qquad \varepsilon_3 \sim N(0, \delta 2)$$

Data and Variables

Wheat production data is collected from different editions of Economic Survey of Pakistan. We consider the amount of wheat in thousand tons. The direct impact of carbon dioxide on the production of wheat is positive, as it enhances the water use efficiency of plants. The data regarding the CO_2 is collected data source from the website of Carbon Dioxide Information Analysis Centre and all emission estimates are expressed in thousand metric tons of carbon. Temperature assumed to be having negative impact on wheat productivity for the regions which lie on the tropical or near to the tropical regions. We consider temperature in Celsius degree centigrade. Data source is Metrological Department of Pakistan. Precipitation assumed to be having positive impact on the production of wheat. Our source of data for precipitation is Metrological Department of Pakistan. The gauge of precipitation is millimetre. Similarly, data source for other variables like agricultural credit, wheat procurement price, fertilisers offtake and technology, is Economic Survey of Pakistan.

[8]There might be certain indirect effect of wheat production on climate; however, our analysis is limited to the impact of climate change on wheat production.

4. RESULTS AND INTERPERTATION[9]

4.1. Unit Root and Cointegration Test

Before going to incorporate the Vector Autoregression (VAR) model we have to check the unit root of all the variables of our study. For this we apply Augmented Dicky-Fuller (ADF) test to our variables. The results of the ADF test are shown in the Table 1.

Table 1

Results of the Unit Root Test Statistics

Variables	Level	First Difference	Conclusion
Wheat	4.21966	–7.875017	I(1)
CO2	4.325126	–4.922875	I(1)
Temp	1.701159	–12.00938	I(1)
Precip	–0.435624	–13.86419	I(1)
Water	3.803203	–9.966595	I(1)
Area	1.760045	–11.79492	I(1)

The results in the Table 1 show that all the variables are non-stationary at conventional level as the observed values are greater than 5 percent critical values. However, all the variables of our study are stationary at first difference, because observed values of variables are less than the 5 percent critical values. From the results it is concluded that all the variables are integrated of order one.

We apply Johansen's cointegration technique which is multivariate generalisation of the Dickey-Fuller test. Johansen's technique uses Trace test and Max-Eigen test statistics. The results are obtained by using Eviews 5, AIC is used for choice of lag length and the optimal lag length is 1 (at first difference). Table 2 gives the results of the cointegration relationship.

Table 2

Johansen's Test for the Number of Cointegration Relationship

No. of CE(s)	Trace Statistics	5% CV	Max-Eigen Statistics	5% CV
None	79.46599	95.75366	29.9226	40.07757
At most 1	49.54339	69.81889	21.03386	33.87687
At most 2	28.50953	47.85613	17.70915	27.58434
At most 3	10.80038	29.79707	6.655616	21.13162
At most 4	4.14476	15.49471	3.158354	14.2646
At most 5	0.986407	3.841466	0.986407	3.841466

Results in Table 2 express that t-stat values are less than 5 percent critical values which exhibit that the null hypothesis of no co-integrating relationship is accepted at the conventional significance level. This is also confirmed by max-eigen statistics of no co-integrating relationship. And the absence of no co-integrating association necessitates application of VAR in first difference.

[9]PC application Eviews5 has been used for the purpose of estimation.

4.2. Results from Vector Autoregression (VAR) Model

The results of VAR model estimation to our core variables, namely wheat production (Wheat), carbon dioxide (CO_2), average temperature (Temp), average precipitation (Precip), agricultural land under wheat cultivation (Area) and water availability (Water) are shown in the following Table 3.[10]

Table 3

Estimation through VAR Model

Vector Autoregression Estimates
Sample (Adjusted): 1961 2009
Included Observations: 49 after Adjustments
Standard errors in ( ) and t-statistics in [ ]

	Area	CO2	Precip	Temp	Water	Wheat
Area(–1)	0.124842	–0.52507	0.004539	–0.001234	0.004142	0.028147
	–0.17774	–0.42893	–0.00326	–0.00043	–0.00128	–0.41724
	[0.70239]	[–1.22413]	[1.39243]	[–2.88007]	[3.24645]	[0.06746]
CO2(–1)	–0.038178	0.823331	–0.000274	–0.000108	5.52E-05	0.131691
	–0.02392	–0.05773	–0.00044	–5.80E-05	–0.00017	–0.05616
	[–1.59586]	[14.2610]	[–0.62529]	[–1.87557]	[0.32148]	[2.34497]
Precip(1)	14.38281	–81.90536	0.16735	–0.002084	0.007075	16.29369
	–8.89935	–21.4766	–0.16323	–0.02145	–0.06389	–20.891
	[1.61616]	[–3.81370]	[1.02522]	[–0.09714]	[0.11074]	[0.77994]
Temp(1)	40.76017	75.97065	–0.62428	0.61034	0.132138	265.6333
	–47.1042	–113.675	–0.86399	–0.11353	–0.33817	–110.576
	[0.86532]	[0.66831]	[–0.72256]	[5.37595]	[0.39075]	[2.40227]
Water(1)	10.96782	98.01159	0.164828	–0.003554	0.661926	95.77185
	–12.3892	–29.8987	–0.22724	–0.02986	–0.08894	–29.0834
	[0.88527]	[3.27812]	[0.72534]	[–0.11903]	[7.44210]	[3.29301]
Wheat(1)	0.181938	0.02629	–0.000935	0.000643	0.000564	0.186449
	–0.07976	–0.19249	–0.00146	–0.00019	–0.00057	–0.18724
	[2.28103]	[0.13658]	[–0.63915]	[3.34487]	[0.98579]	[0.99579]
C	2193.293	–1654.546	8.441518	10.23913	–3.072556	–7210.404
	–963.863	–2326.07	–17.6792	–2.32312	–6.91966	–2262.64
	[2.27552]	[–0.71131]	[0.47748]	[4.40749]	[–0.44403]	[–3.18672]
R-squared	0.900537	0.994282	0.187826	0.893184	0.989251	0.976617
Adj. R-squared	0.886327	0.993465	0.071801	0.877924	0.987716	0.973277
Sum sq. Resides	7034773	40969940	2366.709	40.86617	362.5677	38766060
S.E. Equation	409.261	987.6613	7.506678	0.98641	2.938123	960.7296
F-statistic	63.37758	1217.136	1.618842	58.53312	644.2508	292.3638
Log Likelihood	–360.4546	–403.6229	–164.5252	–65.0808	–118.5621	–402.2683
Akaike AIC	14.99815	16.76012	7.001027	2.942074	5.124982	16.70483
Schwarz SC	15.26841	17.03038	7.271287	3.212334	5.395242	16.97509
Mean Dependent	7049.531	16314.98	35.9642	18.41485	103.8781	12514.45
S.D. Dependent	1213.871	12217.37	7.791611	2.823207	26.50935	5877.001

[10]VAR model estimation results to other variables, namely agricultural credit (Ac), fertilisers offtake (Fr), technology (Te) and wheat procurement price (Wpp), are given in Appendix-2.

The statistical values of t-statistics for some of our variables are significant whereas for some of them is insignificant, but the higher value of F-statistics makes all the lag terms of our model statistically significant. The coefficient of determination R-squared values of our variables is lying between 0 and 1 which shows the goodness of fit of our model. We consider VAR model with lag 1 because the values of Akaike AIC and Schwarz Sc for the data using lag 1 is smaller than that of lag 2, lag 3 and lag 4, so the lower values Akaike AIC 16.70483 and Schwarz Sc 16.97509 for lag 1 make the model more parsimonious. Therefore, VAR model for lag 1 for the study is more preferable as compared to other lag values.

4.3. Prediction of Wheat for 2010

In order to estimate the predicted value for wheat production in 2010 using VAR technique for 1 lag values, the calculation is follows;

$$
\begin{aligned}
E\ (\text{Wheat } 2010) &= -7210.404 + 0.186449\ (\text{wheat } 2009) + 0.131691\ (CO_2\ 2009) + 265.6333\ (\text{Avg. Temp}2009) + 16.29369\ (\text{Avg. Prep}2009) + 95.77185\ (\text{Water } 2009) + 0.028147\ (\text{Area } 2009) \\
&= -7210.404 + 0.186449\ (24033) + 0.131691\ (48174) + 265.6333\ (22.6) + 16.29369\ (39.2) + 95.77185\ (142.9) + 0.028147\ (9046) \\
&= 24197.09
\end{aligned}
$$

So the estimated production of wheat according to our calculation for 2010 is 24197.09 thousand ton, however the actual production of wheat in 2010 according to the government calculated figure was 23864 thousand ton [*Economic Survey* (2010)].

4.4. Results of Impulse Response Function

The objective of the impulse response function traces the effect of a one-time shock to one of the innovation on current and future values of the endogenous variables. The results of the Cholesky Impulse Response Function for our model are shown in Figure 1 and in Table 4.

Table 4

Cholesky Impulse Response Function

Period	Area	CO2	Precip	Temp	Water
1	547.6505	128.5776	89.04947	25.52728	13.30635
	–125.604	–112.014	–110.895	–110.499	–110.461
2	199.3847	120.2491	251.5133	187.6724	260.7115
	–149.547	–81.2038	–153.907	–111.358	–84.2251
3	273.3583	98.95197	101.1266	151.1796	262.7725
	–106.539	–73.5843	–110.064	–110.598	–68.4551
4	272.8148	94.79574	109.7557	156.5153	266.374
	–106.043	–80.4612	–111.075	–121.652	–68.4594
5	275.5361	91.83941	116.4325	161.4013	270.72
	–111.915	–87.6574	–119.489	–129.8	–72.1443
6	279.7032	89.408	121.5303	164.8469	273.917
	–117.516	–94.6738	–128.411	–136.443	–75.7086
7	283.4604	87.45754	126.5841	167.8656	276.8978
	–122.933	–101.391	–137.444	–141.63	–79.0905

Cholesky Ordering: Area CO2 Precip Temp Water Wheat.

The results in Table 4 depict that one standard deviation shock to area increases the wheat production by 547.6505 points but in second period production decreases to 199.3847 points and in next periods it shows little increase to this level. Similarly, one standard deviation shock to CO_2 increases the wheat production by 128.5776 but in second period the production increases 120.2491 points and so on. However, one standard deviation shock of temperature creates positive impact on the production of wheat and increases it by 25.5273 points in the first period and after that a significant increase of 187.6724 points in the second period and after that in each period the impact remains positive. The results also express that one standard deviation shock to precipitation increases the wheat production by 89.05 points, in the second period the impact becomes significant and increase the wheat production by 251.51 points. The results show that one unit shock to water increases the wheat production by 13.30635 points but in second period the impact becomes significant and increase the wheat production by 260.7115 points and after that in each period it creates positive effect on wheat production. The results of these innovations are portrayed graphically in Figure 1.

Response to Cholesky One S. D. Innovations

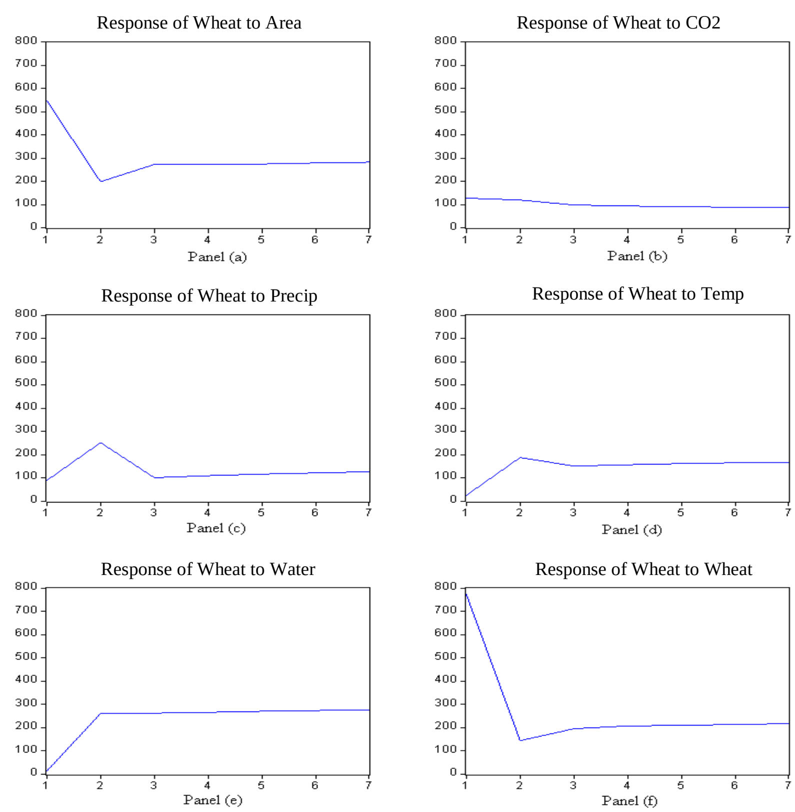

Fig. 1. Cholesky Impulse Response Function[11]

[11]Keeping in view the basic objective of the study, we are only representing the wheat impulse responses.

Figure 1 (panel a to f) shows the responses of wheat to one standard deviation shock to area, CO_2, precip, temp, water and wheat. Panel (a) demonstrates that the significant positive impact of area on wheat but after that the impact becomes insignificant. Similarly, in panel (b) CO_2 is creating positive impact on wheat which remains positive and insignificant. Panels (c & d) offer positive and significant impact of precip and temp on wheat in the initial periods. Thereafter the effect remains positive but insignificant. Similarly, panel (e) demonstrates that initially the impact of water is significant but after that the impact becomes insignificant.

4.5. Results from Variance Decomposition

Variance Decomposition or Forecast error variance decomposition shows the value each variable contributes to the other variables in a Vector Autoregression (VAR) model:

Table 5

Variance Decomposition

Period	S.E.	Area	CO2	Precip	Temp	Water	Wheat
1	409.261	32.49411	1.791134	0.859133	0.0706	0.019183	64.76584
2	474.4401	29.17053	2.661524	6.113525	3.080654	5.852353	53.12142
3	504.4951	29.82685	2.935434	5.859948	4.226994	9.874881	47.27589
4	527.3033	30.11328	3.065968	5.757519	5.126905	12.82279	43.11353
5	546.9704	30.28802	3.121553	5.739494	5.860545	15.09399	39.89641
6	564.2343	30.42154	3.132041	5.762170	6.455877	16.86583	37.36255
7	579.6429	30.52334	3.116208	5.815396	6.947042	18.27793	35.32009

Cholesky Ordering: Area CO2 Precip Temp Water Wheat.

Table 5 demonstrates percentage variation in wheat production due to other variables. In period one 32.5 percent of the variation is due to area under wheat cultivation and less variation due to CO_2 (1.79 percent), precipitation (0.85 percent), temperature (0.07 percent) and water (0.02 percent). In second period 29.2 percent of variation in wheat production is due to area under wheat cultivation whereas values of variations in wheat production due to CO_2, precipitation, temperature and water are 2.66 percent, 6.11 percent, 3.08 percent, 5.85 percent, respectively. The results show that in the second and following periods CO_2, precipitation, temperature and water are showing positive impact on wheat production. In the seventh period the values of the climate change variables cause 34 percent of variation in wheat production including water availability (18 percent), temperature (7 percent), precipitation (6 percent) and carbon dioxide (3 percent) whereas the share of area under wheat cultivation remains at about 30 percent.

The graphical representations of these results are expressed in Figure 2.

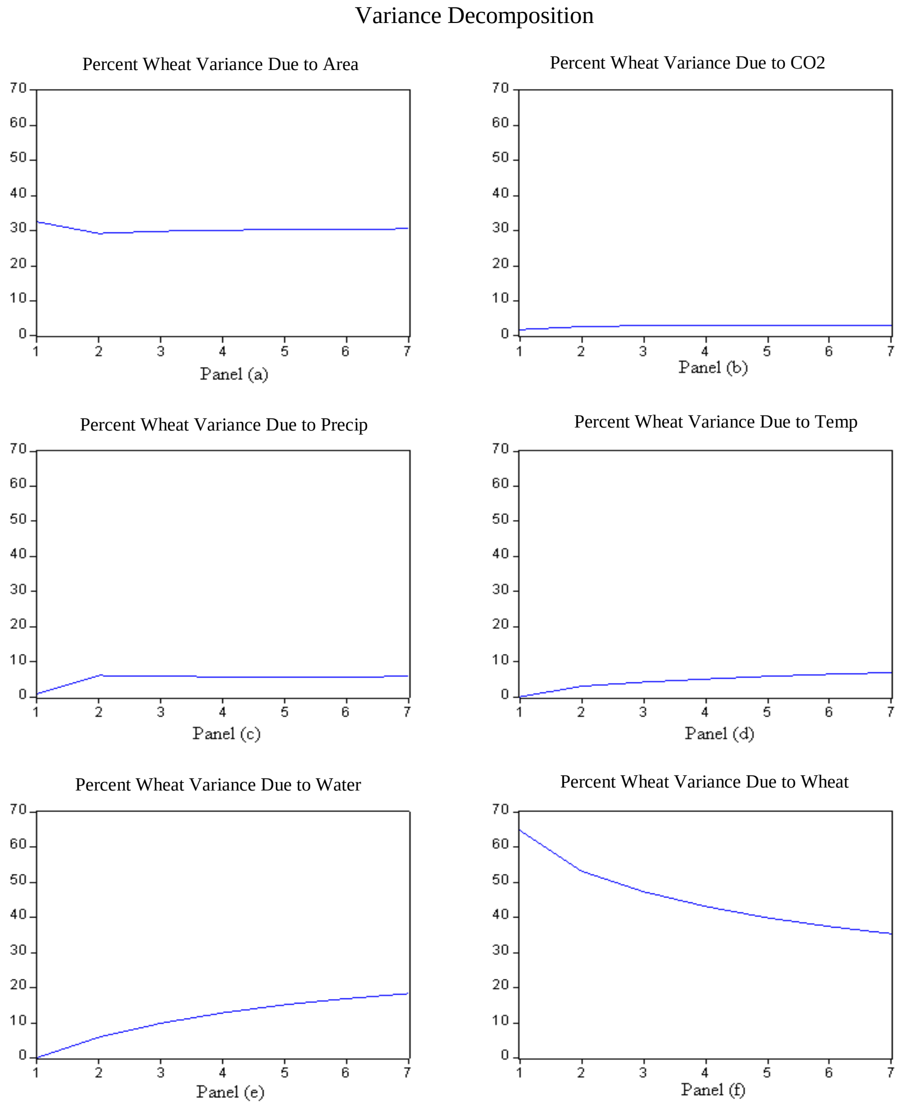

Fig. 2. Variance Decomposition

Almost all the results of our study are showing positive impact on the wheat production in Pakistan up to 2010. These results might appear contrary to the theoretical as well as empirical consideration of possible negative impact of global warming on the agricultural (wheat) production in the tropical and sub-tropical regions. However, following factors might be positively affecting the wheat production in Pakistan:

(1) Land under wheat cultivation is also increasing due to increased water supply and other factors which may be creating positive impact on the production of wheat.

(2) The pattern and direction of rain is changing worldwide due to climatic change. More rain and higher level of precipitation in the areas of wheat cultivation may have positively impacted the wheat production.
(3) Improvement in technology regarding new ways of cultivation, hybrid seeds, fertilisers, extension services and attractive procurement prices are also creating positive impact on the production of wheat.

4.6. Forecast of Wheat Production 2060

We are considering three scenarios for the year 2060. In first scenario we are assuming that both the temperature and precipitation increase and in second scenario we assume that temperature increases and precipitation remains constant whereas, in third scenario we assume that temperature increases but precipitation decreases. We are considering three alternative increases in temperature, namely 2°C, 4°C and 5°C. Moreover, we assume 10 percent increase or decrease in precipitation. Besides temperature and precipitation we assume double level concentration of CO_2 in all the three scenarios. We do not assume any increase in water availability on the basis of water scarcity [IPCC (2007)] and take the current level of water availability.

We use the coefficient values of the variables and constant term value from the VAR model estimation (Table 2). Moreover, the values of our variables for 2059 are generated through extrapolation.

Scenario 1

If both the temperature and precipitation increase:

Case 1: If temperature increases by 2°C and precipitation increases by 10%	
E (Wheat 2060)	= –7210.404 + 0.186449 (wheat2059) + 0.131691 (CO_2 2059) +265.6333 (Avg. Temp2059) + 16.29369 (Avg. Prep2059) + 95.77185 (Water 2059) + 0.028147 (Area 2059) = –7210.404 + 0.186449 (115778.2) + 0.131691 (98070) + 265.6333 (24.6) + 16.29369 (43.2) + 95.77185 (142.9) + 0.028147 (19307) = 48758.9
Case 2: If temperature increases by 4°C and precipitation increases by 10%	
E (Wheat 2060)	= –7210.404 + 0.186449 (wheat2059) + 0.131691 (CO_2 2059) +265.6333 (Avg. Temp2059) + 16.29369 (Avg. Prep2059) + 95.77185 (Water 2059) + 0.028147 (Area 2059) = –7210.404 + 0.186449 (115778.2) + 0.131691 (98070) + 265.6333 (26.6) + 16.29369 (43.2) + 95.77185 (142.9) + 0.028147 (19307) = 49290.1
Case 3: If temperature increases by 5°C and precipitation increases by 10%	
E (Wheat 2060)	= –7210.404 + 0.186449 (wheat2059) + 0.131691 (CO_2 2059) +265.6333 (Avg. Temp2059) + 16.29369 (Avg. Prep2059) + 95.77185 (Water 2059) + 0.028147 (Area 2059) = –7210.404 + 0.186449 (115778.2) + 0.131691 (98070) + 265.6333 (27.6) + 16.29369 (43.2) + 95.77185 (142.9) + 0.028147 (19307) = 49555.7

Scenario 2

If temperature increases but precipitation remains constant:

Case 1: If temperature increases by 2^{o}C and precipitation remains constant	
E (Wheat 2060)	= –7210.404 + 0.186449 (wheat2059) + 0.131691 (CO_2 2059) +265.6333 (Avg. Temp2059) + 16.29369 (Avg. Prep2059) + 95.77185 (Water 2059) + 0.028147 (Area 2059) = –7210.404 + 0.186449 (115778.2) + 0.131691 (98070) + 265.6333 (24.6) + 16.29369 (39.2) + 95.77185 (142.9) + 0.028147 (19307) = 48693.6
Case 2: If temperature increases by 4^{o}C and precipitation remains constant	
E (Wheat 2060)	= –7210.404 + 0.186449 (wheat2059) + 0.131691 (CO_2 2059) +265.6333 (Avg. Temp2059) + 16.29369 (Avg. Prep2059) + 95.77185 (Water 2059) + 0.028147 (Area 2059) = –7210.404 + 0.186449 (115778.2) + 0.131691 (98070) + 265.6333 (26.6) + 16.29369 (39.2) + 95.77185 (142.9) + 0.028147 (19307) = 49224.9
Case 3: If temperature increases by 5^{o}C and precipitation remains constant	
E (Wheat 2060)	= –7210.404 + 0.186449 (wheat2059) + 0.131691 (CO_2 2059) +265.6333 (Avg. Temp2059) + 16.29369 (Avg. Prep2059) + 95.77185 (Water 2059) + 0.028147 (Area 2059) = –7210.404 + 0.186449 (115778.2) + 0.131691 (98070) + 265.6333 (27.6) + 16.29369 (39.2) + 95.77185 (142.9) + 0.028147 (19307) = 49490.5

Scenario 3

If temperature increases and precipitation decreases:

Case 1: If temperature increases by 2^{o}C and precipitation decreases by 10%	
E (Wheat 2060)	= –7210.404 + 0.186449 (wheat2059) + 0.131691 (CO_2 2059) +265.6333 (Avg. Temp2059) + 16.29369 (Avg. Prep2059) + 95.77185 (Water 2059) + 0.028147 (Area 2059) = –7210.404 + 0.186449 (115778.2) + 0.131691 (98070) + 265.6333 (24.6) + 16.29369 (43.2) + 95.77185 (142.9) + 0.028147 (19307) = 48630.1
Case 2: If temperature increases by 4^{o}C and precipitation decreases by 10%	
E (Wheat 2060)	= –7210.404 + 0.186449 (wheat2059) + 0.131691 (CO_2 2059) +265.6333 (Avg. Temp2059) + 16.29369 (Avg. Prep2059) + 95.77185 (Water 2059) + 0.028147 (Area 2059) = –7210.404 + 0.186449 (115778.2) + 0.131691 (98070) + 265.6333 (24.6) + 16.29369 (43.2) + 95.77185 (142.9) + 0.028147 (19307) = 49161.4
Case 3: If temperature increases by 5^{o}C and precipitation decreases by 10%	
E (Wheat 2060)	= –7210.404 + 0.186449 (wheat2059) + 0.131691 (CO_2 2059) +265.6333 (Avg. Temp2059) + 16.29369 (Avg. Prep2059) + 95.77185 (Water 2059) + 0.028147 (Area 2059) = –7210.404 + 0.186449 (115778.2) + 0.131691 (98070) + 265.6333 (24.6) + 16.29369 (43.2) + 95.77185 (142.9) + 0.028147 (19307) = 49427

In all the three scenarios the carbon dioxide, temperature and precipitation are creating positive impact and increase the wheat production at double level as compared to the current level of wheat production. In order to attain this level of production we have to increase land under wheat cultivation. We may conclude from the results of our study for 2060 that the level of production in 2060 would not be much higher as compared to the current level of wheat production. The annual population growth of Pakistan is 1.6 percent at present and according to our results wheat production around 49000 thousand ton after 50 years would not be sufficient to fulfil the wheat requirement of huge population.

5. CONCLUSIONS AND RECOMMENDATIONS

The Vector Autoregression (VAR) model is used in this study in order to check the impact of climate change on wheat production in Pakistan. The study used data of the last half century. The results of historical data estimation reveal that up to now there is no significant negative impact of climate change on wheat production in Pakistan. However, future wheat production will significantly depend on the area under wheat cultivation and the climate change variables. On the basis of variance decomposition analysis the values of the area under wheat cultivation and the climate change variables cause 30 percent and 34 percent variation in wheat production, respectively. Therefore, in terms of climate change the water availability and temperature become focal point for future wheat production.

Wheat is main food crop of Pakistan. The newly emerging threat of climatic change may influence the level of wheat production in Pakistan. Being an agricultural country we should be capable to secure domestic consumption by increasing the level of wheat production and the surplus production can be exported abroad to earn foreign exchange. In order to cope with any type of emerging hazard of climate change the agriculture sector in Pakistan needs some adaptation strategies. In this regard some strategic measures are mentioned below:

(1) Water conservation management and the irrigation system have to be improved.
(2) New heat and drought resistant seeds and plants of wheat have to be produced.
(3) Wheat cultivation methods shall be adjusted according to the changing pattern of climate change.

Appendices

APPENDIX-1
INTERNATIONAL EFFORTS TO ABATE THE GHGs

In order to cope with the global warming, a globally emerging threat, UN formed a body known as United Nation Framework Convention on Climate Change (UNFCCC) in March, 1994. Most of the countries are members of this body. Purpose of this body is to share information regarding emission among signatories' countries [Tisdell (2008)]. It does not impose penalty on the countries, rather it provides a plate form for the member countries to negotiate and to formulate policies. It was the success of this body that Kyoto agreement was first negotiated in 1997 which was ultimately ratified in 2005. The basic motive of this protocol was to bring back the emission of GHGs, namely Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydroflorocarbon (HFCs), Perflorocarbons (PFCs) and Super hexafluoride (SF6) at 1990 level. For this purpose the protocol proposed different mechanism to abate the CO_2 emission. These include clean development mechanism, emission trading and joint implementation.

USA, being one of the main polluters, has not ratified the protocol yet. Countries like China and India are also increasingly contributing toward emission of GHgs, however, these countries are not obligated per Kyoto protocol to reduce the emission. In this scenario the perspectives for success of the Kyoto Protocol in abating GHGs are not quite promising.

APPENDIX-2

APPENDIX-2

APPENDIX-2

REFERENCES

Afzal, Muhammad (2005) Estimating Long Run Trade Elasticities in Pakistan-Cointegration Approach. Pakistan Society of Development Economists.

Anwar, Muhuddin Rajin, O'Leary Garry, McNeil David, Hossain Hemayet, Nelson Roger (2007) Climate Change Impact on Rain Fed Wheat in South-eastern Australia. *Field Crops Research* 104, 139–147.

Brown, Stephen P. A. (1998) Global Warming Policy: Some Economic Implication. Federal Reserve Bank of Dallas. *Economic Review* 4th Quarter.

Carbon Dioxide Information Analysis Center. Http://cdiac.ornl.gov/trends/emis/pak.html

Cerri, Carlos, P. Eduardo, Gerd Sparovek, Martial Bernoux, Willian E. Easterling, Jerry M. Melillo, and Cerri Carlos Clemente (2007) Tropical Agriculture and Global Warming: Impacts and Mitigation Options. Sci. Agric. (Piracicaba, Braz) 64:l, 83–99.

Chouard, P. (1960) Vernalisation and its Relations to Dormancy. *Annual Review of Plant Physiology* 11, 191–238.

Cline, William R. (2007) Global Warming and Agriculture: New Country Estimates Show developing Countries Face Declines in Agriculture Productivity. Centre for Global Development (brief).

Deschenes, Olivier and Michael Greenstone (2007) The Economic Impacts of Climate Change: Evidence from Agriculture Output and Random Fluctuations in Weather. *The American Economic Review* 97:1, 354–385.

Edwards, Paul N. (1999) Global Climate Science, Uncertainty and Politics: Data-Laden Models, Model-Filtered Data. *Science as Culture* 8:4, 437–472.

Encyclopedia Britanica (2005) *The New Encyclopedia*. Vol 25. (edition 15th).

Gbetibouo, G. A. and R. M. Hassan (2004) Measuring the Economic Impact of Climate Change on Major South African Field Crops: A Ricardian Approach. *Global and Planetary Change* 47, 143–152.

Harry, M., Kaiser Susan J. Riha, Daniel S. Wilks, David G. Rossiter, and Radha Sampath (1993) A Farm-Level Analysis of Economic and Agronomic Impacts of Gradual Climate Warming. *American Agriculture Economics Association* 75, 387–398.

Hussain, Syed Sajidin and Muhammad Mudasser (2007) Prospects for Wheat Production Under Changing Climate in Mountain Areas of Pakistan—An Econometric Analysis. Agricultural Systems 94, 494–501.

IPCC (2007) Intergovernmental Panel on Climate Change. 4th Assessment Report: Climate Change.

Kumar, K. S. and Parikh Jyoti Kavi (2001) Indian Agriculture and Climate Sensitivity. *Global Environmental Change* 11, 147–154.

Lang, Gunter, *Land Prices and Climate Conditions: Evaluating the Greenhouse Damage for the German Agriculture Sector*.

Lobell, David B., J. Ivan Ortiz-Monasterio, P. Gregory Asner, Pamela A. Matson, Rosamond L. Naylor, and Walter P. Falcon (2005) Analysis of Wheat Yield and Climatic Trends in Mexico. *Field Crops Research* 94, 250–256.

Margin, G. O., M. I. Travasso, G. R. Rodrignez, Silvina Solmon, and Mario Nunez (2009) Climate Change and Wheat Production in Argentina. *International Journal of Global Warming* 1:1/2/3, 214–226.

Mendelshon, Robert, Wendy Morrison, Michael E. Schlesinger, and Natalia G. Andronova (2000) Country-Specific Market Impacts of Climate Change. *Climate Change* 45, 553–569.

Mendelshon, Robert, William D. Nordhaus, and Daigee Shaw (1993) Measuring the Impact of Global Warming On Agriculture. Cowles Foundation for Research in Economics at Yale University. (Cowles Foundation Discussion Paper No. 1045).

Mendelsohn, Robert, Ariel Dinar, and Apurv A. Sanghi (2001) The Effect of Development on the Climate Sensitivity of Agriculture. *Environment and Development Economics* 6, 85–101.

Nasir, Muhammad and Wasim Shahid Malik (n.d.) The Structural Shocks and Contemporaneous Response of Monetary Policy in Pakistan: An Empirical Investigation.

Nigol, Seo Sung-No., Robert Mendelsohn and Mohan Munasinghen (2005) Climate Change and Agriculture in Sri Lanka: A Ricardian Valuation. *Environment and Development Economics* 10, 581–596.

Pakistan, Government of (2008-09) *Pakistan Economic Survey 2008-09.* Chapter No. 2, Agriculture.

Pecican, Eugen st. (2010) Forecasting Based on Open VAR Modeling. *Romanian Journal of Economic Forecasting* 1.

Reilly, J., F. Tubiello, B. McCarl, D. Abler, R. Darwin, K. Fuglie, S. Hollinger, C. Izaurralde, S. Jagtap, J. Jones, L. Mearns, D. Ojima, E. Paul, K. Paustian, S. Riha, N. Rosenberg, and C. Rosenzweig (2003) U.S. Agriculture and Climate Change: New Results. *Climate Change* 57, 43–69.

Rosegrant, Mark W., Mandy Ewing, Gary Yohe, Ian Burton, Saleemul Huq, and Rowena Valmonte-Santos (2008) *Climate Change and Agriculture Threats and Opportunities*. Federal Ministry for Economic Cooperation and Development. 1-36.

Rosenzweig, Cynthia and Francesco N. Tubiello (1996) Effects of Changes in Minimum and Maximum Temperature on Wheat Yields in the Central US: A Simulation Study. *Agricultural and Forest Meteorology* 80, 215–230.

Rosenzweig, Cynthia and Martin L. Parry (1994) Potential Impact of Climate Change on World Food Supply. *Nature* 367, 133–138.

Saseendran, S. A., K. K. Singh, S. L. Rathore, S. V. Singh, and S. K. Sinha (2000) Effect of Climate Change on Rice Production in the Tropical Humid Climate of Kerala, India. *Climate Change* 44, 495–514.

Sims, A. Christopher (1980) Macroeconomics and Reality. *Econometrica* 48:1, 1–48.

Stern (2006) *Stern Review on the Economics of Climate Change*. H. M. Treasury.

Tisdell, Clem (2008) Global Warming and Future of Pacific Island Countries. *International Journal of Social Economics* 35:12, 889–903.

Tobey, James, John Reilly, and Sally Kane (1992) Economic Implication of Global Climate Change for World Agriculture. *Journal of Agricultural and Resource Economics* 17:1, 195–204.

Tubiello, F. N., C. Rosenzweig, R. A. Goldberg, S. Jugtap, and J. W. Jones (2002) Effect of Climate Change on US Crop Production: Simulation Results Using Two Different GCM Scenario. Part I. Wheat, Potato, Maize, and Citrus. *Climate Research* 20, 259–270.

Warrick, R. A. (1988) Carbon Dioxide, Climate Change and Agriculture. *The Geographical Journal* 154:2, 221–233.

Wassenaar, T., P. Lagacherie, J. -P. Legros, and M. D. A. Rounsevell (1999) Modelling Wheat Yield Responses to Soil and Climate Variability at the Regional Scale. *Climate Research* 11, 209–220.

Winters, Paul, Rinku Murgai, Elisabeth Sadoulet, Alain De Janvry, and George Frisvold (1996) Climate Change Agriculture, and Developing Economies. (Working Paper No. 785.)

Wolf, J., L. G. Evans, M. A. Semenov, H. Eckersten, and A. Iglesias (1996) Comparison of Wheat Simulation Models Under Climate Change. I. Model Calibration and Sensitivity Analyses. *Climate Research* 7, 253–270.

Xiao, Guoju, Qiang Zhang, Yubi Yao, Hong Zhao, and Runyuan Wang (2008) Impact of Recent Climatic Change on the Yield of Winter Wheat at Low and High Altitudes in Semi Arid Northwestern China. *Agriculture, Ecosystems and Environment* 127, 37–42.

Zhai, Fan and Zhuang Juzhong (2009) Agriculture Impact of Climate Change: A General equilibrium Analysis with Special Reference to Southeast Asia. Asian Development Bank Institute. (ADBI Working Paper 131).

Zhanga, X. C. and M. A. Nearing (2005) Impact of Climate Change on Soil Erosion, Runoff, and Wheat Productivity in Central Oklahoma. *Catena* 61, 185–195.