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Economic Effects of Climate Change-Induced Loss of Agricultural Production by 2050: A Case Study of Pakistan

Muhammad Aamir Khan [1,*], Alishba Tahir [1], Nabila Khurshid [1], Muhammad Iftikhar ul Husnain [1], Mukhtar Ahmed [2,3,*] and Houcine Boughanmi [4]

1 Department of Economics, COMSATS University, Islamabad 45550, Pakistan; AlishbaTahir80@gmail.com (A.T.); nabilakhurshid@comsats.edu.pk (N.K.); Iftikharhusnain@comsats.edu.pk (M.I.u.H.)
2 Department of Agronomy, PMAS Arid Agriculture University, Rawalpindi 46300, Pakistan
3 Department of Agricultural Research for Northern Sweden, Swedish University of Agricultural Sciences, 90183 UMEÅ, Sweden
4 Department of Natural Resource Economics, College of Agricultural and Marine Sciences, Sultan Qaboos University, Muscat 123, Oman; boughanh@squ.edu.om
* Correspondence: m.aamir.khan@comsats.edu.pk (M.A.K.); mukhtar.ahmed@slu.se (M.A.)

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Abstract: This research combined global climate, crop and economic models to examine the economic impact of climate change-induced loss of agricultural productivity in Pakistan. Previous studies conducted systematic model inter-comparisons, but results varied widely due to differences in model approaches, research scenarios and input data. This paper extends that analysis in the case of Pakistan by taking yield decline output of the Decision Support System for Agrotechnology Transfer (DSSAT) for CERES-Wheat, CERES-Rice and Agricultural Production Systems Simulator (APSIM) crop models as an input in the global economic model to evaluate the economic effects of climate change-induced loss of crop production by 2050. Results showed that climate change-induced loss of wheat and rice crop production by 2050 is 19.5 billion dollars on Pakistan's Real Gross Domestic Product coupled with an increase in commodity prices followed by a notable decrease in domestic private consumption. However, the decline in the crops' production not only affects the economic agents involved in the agriculture sector of the country, but it also has a multiplier effect on industrial and business sectors. A huge rise in commodity prices will create a great challenge for the livelihood of the whole country, especially for urban households. It is recommended that the government should have a sound agricultural policy that can play a role in influencing its ability to adapt successfully to climate change as adaption is necessary for high production and net returns of the farm output.

Keywords: climate change; global climate models; economic models; agriculture production; computable general equilibrium; Pakistan

1. Introduction

Agriculture is one of the most climate-sensitive sectors of an economy. It responds to temperature, precipitation, soil radiation, etc., which are directly associated with climate change. Rising temperature, uneven distribution of precipitation, floods, droughts, and other climatic disasters have affected human life along with socio-economic sectors of the world's over-populated regions, i.e., South Asia [1]. The assessment of the ultimate economic effect of climate change on producers, consumers, and other agriculture-related agents requires a detailed evaluation of economic impacts using inputs from a different climate and crop models.

To study the potential impacts of changing climate, scientists and crop experts carried out integrated and collaborative research [2]. They have used global climate models that analyze the interaction of weather variables using different physical, biological, and chemical principles and then estimate their responses to rising levels of greenhouse gas emissions in the atmosphere. These models also consider different socio-economic projections, including income and population growth, energy use, and industrial growth to predict earth's future climate. These global climate projections are then used by bio-physical scientists in different crop models to simulate biological processes of crop growth and productivity [3–13]. They provide the estimated impact of climate change on crop yield and human health. These models overcome the requirement of time-consuming and expensive field surveys and experimentation to analyze the effects of weather variability on agriculture. Moreover, they can be easily used with different economic models to study the economic impacts of climate-induced- change in crop production. Two most commonly used models are DSSAT (Decision Support System for Agrotechnology Transfer) and APSIM (Agricultural Production Systems Simulator) [14–16]

The potential impact of weather conditions on crop production through biophysical models can be used as input in different partial and general equilibrium economic models to analyze the economic response of climate change by different socio-economic agents of society (Figure 1). In this paper, we only focus on the economic component of assessment by investigating the future endogenous economic response of agriculture to climate change scenarios of 2050. This includes agricultural production, crop yield, area, price, and consumption patterns. Moreover, the output and cost of other related industries are discussed.

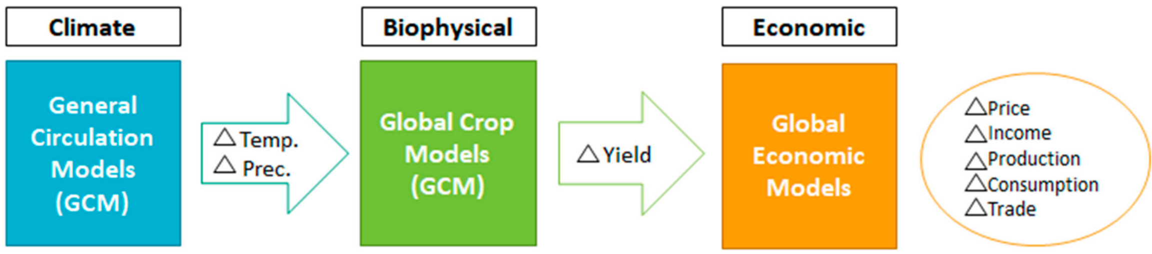

Figure 1. Integrated Assessment of Economic Effects of Climate-Led Change in Agricultural Production. Author's own design based on data (Nelson et al., 2014).

Climate change has long-lasting impacts on the livelihood of agricultural communities across the world (Burke and Emerick, 2016) [17]. The fifth annual report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) states that mean yearly temperature of South Asia will increase by 3.3 °C by the end of 21st century under Multi-Model Data (MMD)-A1B regional climate model. A significant amount of research portrays the poor state of the agriculture sector of South Asian economies, due to extreme climate events [1,18,19]. This sector will have difficulty providing food security to the rising population of the region. As more than 60% of the total population is involved in agricultural activities., loss of agricultural production, due to climate change is of serious socio-economic concern.

Pakistan is one of the most climate-sensitive nations despite the fact that it contributes merely 0.8% to atmospheric Greenhouse Gases (GHG), which places Pakistan at the 135th position in comparison to the other countries [20]. Global climate risk index 2017 ranks Pakistan at number 7 in the list of most vulnerable nations, due to its geographical and climatic features. It lies in the geographic region where an increase in temperature is predicted to be higher than global average temperature, where glaciers, the only source of feeding rivers, are receding rapidly and most of the land is arid and semi-arid. More than 40% of the population in this region is involved in agricultural production. Variability in the monsoon rains, massive floods and droughts further add to its vulnerability [21,22]. The cumulative effect of all these climate peculiarities puts the country in a severe threat of food, water and energy security [23–25].

Empirical literature based on crop modeling in Pakistan reports that production of its major cereal crops is prone to high temperature and low rainfall [26–29]. Cropping seasons in Pakistan require a certain amount of heat and precipitation [30]. Average temperature remains moderate during the wheat growing season. However; wheat does not receive enough rainfall to grow effectively. Most of the cultivated land is fed with irrigation water and post-monsoon rainfall. According to Pakistan economic survey 2016-17, 30% of the total cultivated area of the wheat crop is irrigated with canal water, while 55% is farmed through tube wells and other sources (Appendix A). However, no water is available for the remaining 15%. The extent and spread of monsoon rain are declining over time, due to climate change. The summer monsoon comprises 60% of the total annual precipitation. Moreover, Pakistan has inadequate water storage facilities and aging water infrastructure, including its vast irrigation network, making it a water-stressed country [31].

Despite the growing amount of literature on climate change-caused decline in crop yield in Pakistan, the nature and extent of its economic effects remain largely unstudied. Moreover, research on the consequences of these agricultural impacts for human livelihoods is quite limited. The majority of existing research focuses on partial equilibrium analysis of the direct effects of climate change variables, such as temperature and precipitation, on crop yields and output [32–42]. These studies suggest reduced crop yield and production, due to climate change. However, partial equilibrium analysis has three broad limitations. First, these studies only emphasize crop output or revenue, and therefore, give an incomplete understanding of the implication of crop yield changes for human livelihood. Secondly, they overlook the importance of climate change with respect to income and expenditure of different types of households. Lastly, they overlook the inter-connections of different countries and their production systems that might influence the domestic price. Keeping in mind the interlinkages of domestic and global economies, the effects of changing climate on agricultural production would not just be limited to crop yield, but would affect the whole economy. Agricultural output is consumed directly and indirectly as raw materials. Any change in crop production would affect the overall economy. Hence, the results of existing partial analysis studies do not provide complete guidance to policy-makers.

2. Materials and Methods

The economic analysis of the impact of climate change on agricultural production of Pakistan begins by introducing a common set of climate change scenarios and crop yield inputs to be used as shocks in the global economic model. This integrated economic modelling framework of climate change links global climate models to an economic model through biophysical models. This research considers GCM MPI-ESM-MR global climate model of the latest Coupled Model Inter-comparison Project (CMIP5) family that combines a representative concentration pathway 8.5 (RCP 8.5), i.e., the most extreme emissions scenario. Moreover, the model considers socio-economic pathways (SSP2) in order to describe the future economic and population growth of the world. The climatic projections of the mid-21st century from the climate model are used [43] to incorporate it into DSSAT and APSIM biophysical models. The mid-21st century climate change input in the crop models is used to simulate the impact of future climate on crop yield and production of the country. Within DSSAT, CERES-Wheat and CERES-Rice models (Crop Environment Resource Synthesis) are considered to predict the impact of future climate change on output of wheat and rice in Pakistan by 2050. The estimated decline of projected mean percentage in the output of wheat and rice from CERES-Wheat and CERES-Rice models under extreme emission scenarios is used in this research.

We use the output of these crop models in Global Economic Trade Model [44] to analyze the economic effects of climate-induced loss of agricultural production by 2050. The economic model describes the response of producers and consumers to declines in crop output. As illustrated in Figure 2, we combined global climate model, crop and economic models to examine the economic impact of climate change-induced loss of agricultural production in Pakistan.

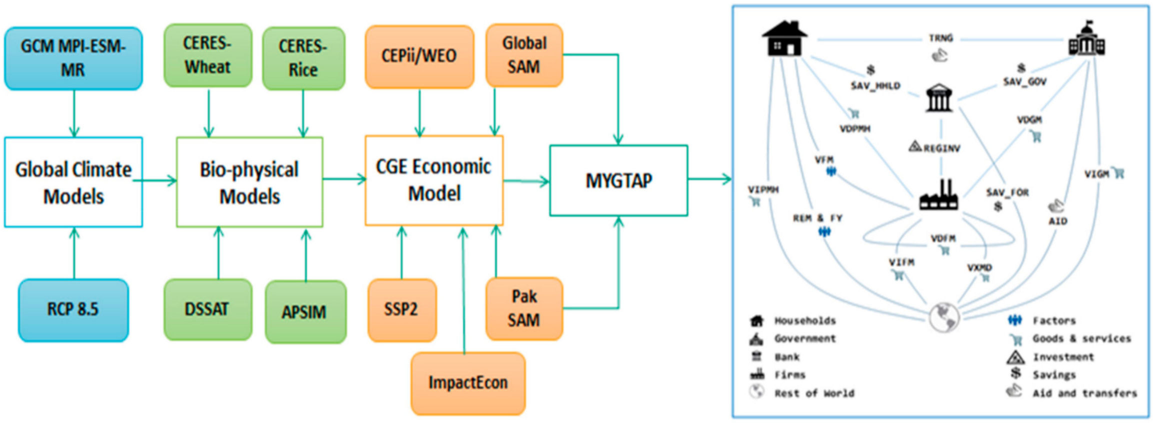

Figure 2. Model layout. Source: Author's own design. GCM MPI-ESM-MR, global circulation model max plank institute-earth system models-mixed resolution; RCP, representative concentration pathway 8.5; CERES, crop environment resource synthesis; DSSAT, the decision support system for agrotechnology transfer; APSIM, agricultural production systems simulator; CEPii, Centre d'Etudes prospectives et d'informations internationales; WEO, world economic outlook; SSP2, socio economic pathways; SAM, social accounting matrix.

MyGTAP model differentiates between a private household and government and provides the option to include multiple households and factors to explain comprehensive interlinkages within the economy. The graph shows the flow of all national and international economic transactions that take place within an economy.

2.1. Economic Analysis

The global computable general equilibrium model provides a framework for the economic analysis of the response of different producers and consumers to policy change. Global CGE model is supported by the newly-developed MyGTAP modeling framework [44], and its global database provides data for the model. It is a multi-sector, multi-region modeling framework and is an extension of a standard GTAP model [45]. In the standard GTAP model, there is only one representative household, which limits its ability to incorporate multiple households and evaluate the flow of income and expenditure within the economy. Instead, MyGTAP model differentiates between a private household and government and provides the option to include multiple households and factors to explain comprehensive interlinkages within the economy. The number of disaggregated households in the model enhances its ability to evaluate the impact of a policy change on the welfare of all households. Expenditure is divided into three categories, private expenditure, government expenditure and savings. All factors of production are owned by the regional household, which supplies their endowments to different firms. Firms use them to produce goods and supply further to households and government to satisfy their demand. Total saving consists of both private households and government saving which is further channelized for investment. New features introduced in the model are regional transfers, including remittances, foreign aid and foreign income. Income transfer between household and government is also incorporated in the model.

The GTAP database represents the world economy for three reference years; 2004, 2007 and 2011. The latest reference year, 2011, is used in this study. The database comprises 140 regions, 119 countries and 21 aggregated regions. The database also includes 57 sectors for every region. Keeping in mind the importance of the agriculture sector in Pakistan's economy, and trade profile of this sector, the number of regions have been aggregated into 21 regions. Similarly, a number of sectors have been aggregated to 12 commodities, out of which six belong to the agriculture sector.

Since MyGTAP model differentiates private household and government in a separate account, it can be mapped with a Social Accounting Matrix (SAM). A SAM represents the flow of all national and international economic transactions that take place within an economy. The recently released Pakistan SAM 2011 is used in this study. It consists of income and expenditure flow of 16 types of households and 12 types of production factors. Household types are further differentiated as rural or urban. There are 12 types of rural households which are further divided based on land ownership, farm size and non-farm activity. This classification includes six types of farmers, two farmworkers, and four types are based on non-farming activity. The small and medium farmer owns less than and more than 12.5-acre agriculture land, respectively. The rest of the rural-based types are employed in farm work, but do not own land. The last four households are urban-based (Appendix B).

The SAM contains 62 types of commodities where 16 types belong to the agriculture sector. It incorporates 87 different activities, including services. The share of each factor of production in the production of 87 activities has been mapped with the 12 aggregated sectors of GTAP. Similarly, household consumption of 62 types of commodities is mapped with GTAP sectoral aggregation of 57 commodities. Moreover, households' income is linked with returns of factors of production as factor ownership shares. Twenty-one factors from SAM (Appendix C) are mapped with five standard factors of production in MyGTAP model. SAM also enlists transfer of income between households and the government. Households pay taxes to the government, while they receive income in the form of government spending. The income transfer within SAM is mapped with MyGTAP single private household and government entity. Figure 2 explains the economic integration of MyGTAP and SAM 2013.

One of the significant advantages of the Global CGE model is its ability to relate cross-linkages within the economy [44]. The MyGTAP model has also been used to examine policies in Pakistan [46,47], Nepal [48], Oman [49] and Nigeria [50] Based on neoclassical theory, the model assumes perfect competition in the market. Therefore, market adopts constant returns to scale, where producers' decisions are based on profit maximization and cost minimization, while consumers strive to achieve utility maximization [51]. It is a consistent model and can capture both economy-wide effects, as well as interaction and inter-linkages between different sectors of the economy.

2.2. Baseline

To analyze economic impacts of climate-based changes in agricultural production, a baseline representing the business as usual (BAU) scenario of the world economy in 2050 has been created by using projected data of macroeconomic variables, including GDP, population, and supplies of factors like labor and capital (Table 1). Baseline represents an economy with no change in the climate. The MyGTAP database contains eight types of elements of production that are aggregated to five factors. This includes skilled labor, unskilled labor, capital, land, and natural resources. SAM 2013 holds 21 factors of production where three belong to farm labor, two from non-farm labor, three from land, one belongs to livestock and three are capital types. These factors are mapped with five standard elements of MyGTAP framework. The share of each labor and capital factor in total labor and capital supply is calculated and projected to the year 2050.

Table 1. Baseline development (percent change).

Variables (Growth Rate)	2011–2020	2020–2030	2030–2040	2040–2050
GDP	55.7	41.07	29.11	22.56
Population	21.13	17.45	15.10	12.99
Capital	44.29	61.39	33.12	28.30
Skilled Labor	68.32	42.02	27.51	23.09
Unskilled Labor	25.68	24.23	18.5	16.16

Source: Author's own calculations based on the data from IMF/WEO 2018, CEP II, SSP2, ImpactEcon.

2.3. Simulation Design

The experiment on the updated database from baseline is carried out by incorporating adverse production shocks of wheat and paddy rice from the CERES-Wheat and CERES-Rice DSSAT biophysical models, respectively. Simulated shocks are based on DSSAT Bio-Physical Models in case of Pakistan [43]. A comparison between baseline, i.e., without climate change, and the counter-experiment with climate change effects describe the economic impact of climate change-induced decline in wheat and rice production in Pakistan by 2050.

Simulation I: −14.5% reduction in CERES-wheat output
Simulation II: −20.5% reduction in CERES-Rice output

2.4. Model Closure (Assumptions)

The standard MyGTAP closures are taken as the starting point for our analysis. This assumes that there is perfect competition (zero economic profits) in all sectors. The production factors, capital and labor, are considered to be fully mobile between areas, whereas, land and natural resources factors are sluggish to move. Government spending is assumed to be a constant share of government income, and there is no tax replacement. Private households are assumed to allocate income across consumption, assuming a CDE utility function. Foreign income flows are assumed to rise or fall with factor prices in the country in which they are located. Investment is driven by the expected rate of return as in standard GTAP and total domestic savings by the sum of private household savings and the government budget deficit. Hence the trade balance is endogenous.

2.5. Mathematical Model

Income-expenditure: The income-expenditure flow of global accounts is presented in Figure 2. The government collects income from taxes and foreign aid and consumes it in the form of government expenditure. The difference between income and expenditure could either be deficit or saving. It is expressed in the equation, where GOVINC is government income, AIDI and AIDO is the foreign aid in and out of the country, HHLD TRNG is the transfers from government to households in the form of public expenditure. In MYGTAP model, coefficients are capitalized, while variables are represented in lower case letters [44].

$$GOVINC(r) = AIDI(r) - AIDO(r) + TTAX(r) - sum(h, HHLD, TRNG(h,r)) \tag{1}$$

Similar to the government account, private household collects income factors of production, remittances, and government. Each household supplies endowments to firms and the total supply of each grant are the sum of grants supplied by all households [44]. The ownership of capital is also included in the total household income, and therefore, an appropriate amount of depreciation is reduced from the income. It is expressed in an equation, where EVOAH is the income received from factors of production less depreciation (VDEPH), plus net foreign labor remittances (REMIH and REMOH) and foreign capital income (FYIH and FYOH), transfers between households (TRNH) and from the government (TRNG). The subscript ′*i*′ represents the factor type, ′*h*′ is the household type, while ′*r*′ represents the region in the model [44].

$$\begin{aligned} HHLDINC(h,r) \quad &= sum\{i,\ ENDW_{COMM},\ EVOAH(i,h,r)\} - VDEPH(h,r) \\ &+\{REMIH(h,r) - REMOH(h,r)\} + \{FYIH(h,r) - FYOH(h,r)\} \\ &+sum\{k, HHLD,\ TRNH(k,h,r) - TRNH(h,k,r)\} + TRNG(h,r) \end{aligned} \tag{2}$$

Gross Domestic Product: GDP from the expenditure side is calculated by adding regional consumption, investment, exports at world prices, and subtracting imports at market prices. However, from the source side, it is a summation of net factors income (NETFACTINC), net taxes (NETAXES), and capital depreciation (VDEP) [44].

$$GDPEXP(r) = Cons(r) + \{Inv(r) * qcdgs(r)\} + (VXWD * qxs) - (VIMX * qiw) \tag{3}$$

$$GDPSRC(r) = NETFACTINC + NETAXES + VDEP \tag{4}$$

Exports and Imports: The decomposition of exports at world price includes the value of exports at market price plus the export tax. Similarly, the decomposition of imports at market price includes the value of imports at the world price plus import taxes [44].

$$VXWD = VXMD + XTAX \tag{5}$$

$$VIMX = VIWS + MTAX \tag{6}$$

Within microeconomic variables, domestic sectoral production, private domestic consumption, and the sectoral price at both supply and demand are the chosen variables. Private consumption is based on Armington elasticities. First ESUBD_R, the standard GTAP region-generic elasticity is defined and read into the model from the GTAP Database. Next, a region-specific elasticity is defined. This is initially set equal to the region-generic unless an additional header exists, "ESDR" containing region-specific details [44]. The formula for the industry output is given in Equation (7). Here '*qo*' represents the output of industry '*i*' in region '*r*'. It is equal to the sectoral share and output of each household as *SHREVOMH(I,h,r)* and *qoh(i,h,r)*.

$$qo(i,r) = sum\{(h,\ HHLD,\ SHREVOMH(i,h,r) * qoh(i,h,r)\} \tag{7}$$

Equation (8) provides the formula to calculate supply price, where $SHREVOAH(i,h,r)$ is a share of each household in total sectoral production in region *r* and *psh* is supply price for each household.

$$ps(i,r) = sum\{(h,\ HHLD,\ SHREVOAH(i,h,r) * psh(i,h,r)\} \tag{8}$$

Sectoral Export Share in total Output: Equation (9) provides the formula to calculate the export share. Here *Qxw* is the total exports of the country, while *Qo* is total production. Moreover, the subscript i represents the sector, while r is the region

$$Export\ Share = \frac{Qxw(i,r)}{Qo(i,r)} * 100 \tag{9}$$

Sectoral Import Share in total Consumption: The formula to calculate the import share is given in Equation (10). Here *Qpm* represents the domestic consumption of imported goods, and *Qpd* is the domestic consumption of domestic goods.

$$Import\ Share = \frac{Qpm(i,r)}{Qpd(i,r) + Qpm(i,r)} * 100 \tag{10}$$

2.6. Database and Aggregations

This research has gathered and analyzed data from seven different databases. The two major datasets used in this study are the latest available GTAP database [52] and Pakistan's Social Accounting Matrix (SAM) for the year 2011 constructed by International Food Policy Research Institute (IFPRI) under the Pakistan Strategy support program. The Pakistan's SAM 2011 is incorporated in the MyGTAP modelling framework to augment required data. To develop constant climate baseline values, we use projected growth rates from the base year, 2011, through to 2050, for GDP, population, factor supplies, and food production to feed the projected population. Projected data for GDP and population is acquired from the IMF World Economic Outlook 2017 database and CEPII database. These data are then cross-checked from socioeconomic pathways (SSP2) projected data of moderate economic and population growth. Projected data for capital and skilled and unskilled labor is gathered from ImpactEcon (www.impactecon.com).

3. Results

Climate change is important, due to its wide socio-economic effects. Researchers, economists, and policy makers have been working on estimating the possible effects of changing climate on different aspects of the country. Agriculture is the vital element of an economy as it provides raw material to many down-line industries and helps in poverty alleviation. Its growth depends on favorable weather conditions, therefore, making it the most climate-sensitive sector. Agriculture in Pakistan is the backbone of the economy. Climate change can reduce the production of wheat and rice by 14.7 and 20.5 percent by 2050, respectively [43]. The results of the experiment reported here, estimating the economic effect of climate-induced agricultural production losses, can be analyzed in two different stages. The first part focuses on the changes in the overall macroeconomic variables, while the second stage explores the impact on different factors of production and household types.

3.1. Macroeconomic Indicators

Although the share of agriculture in the country's GDP is only 19.9 percent, it provides a livelihood to more than 40 percent of the population. Considering the farm sector role in employing a large portion of the labor force, potential macro-economic results of climate-induced agricultural production diminution is of great importance. Table 2 represents the real macroeconomic effects of climate-induced loss of agricultural production. Considering the business as usual scenario up to 2050, the economy of Pakistan will be more than twice the base period of 2011. The real GDP will increase by 247 percent along with an increase of 81.25 percent in the country's population by 2050. The real GDP of the country would be $527,804 million in 2050. Moreover, with a constant and unchanged climate, the country's real exports and imports will increase tremendously. This baseline represents the business as a usual economy of Pakistan in 2050. However, when we include the external shock of climate change, the results are different. The amount in brackets represents the monetary change of million dollars. The real GDP will decline by 3.7 percent of the base value, due to the yield loss of wheat and rice under extreme scenarios of climate change. This represents a loss of almost $19,528 million to Pakistan economy. A major factor of such a significant fall in GDP is the rapid decline in output of many agricultural products and other industrial outputs related to agriculture (Table 3). Both rice and wheat will cause real exports to decline by 2.3 percent; imports will increase by $1631.2 million.

Table 2. Impact on real macroeconomic variables.

	Baseline 2050 (Million $)	Simulated Shocks % Change (Monetary Change)
Real GDP	527,804	−3.7 (−19,528)
Population	319.37	-
Real Exports	74,770	−2.3 (1719.8)
Real Imports	105,927	1.54 (1631.2)

Source: Results based on the author's own simulation.

3.1.1. Impact on Domestic Production and Consumption

Table 3 reports the impact of climate led to yield loss of wheat and rice on production and consumption of major sectors. Table 3 shows that sectoral output is expected to increase significantly under business as usual scenario by 2050. The production of wheat and rice will almost double with a constant and unchanged climate by 2050. Moreover, the output of the processed rice will be $82,117 million in 2050, which is unrealistically phenomenal. Under extreme climate scenarios, production of agricultural products is expected to stagnate over time. Wheat and rice production are expected to decline by 15 and 20 percent, respectively. These results are consistent with [43] projected output of the wheat-rice cropping system of Pakistan based on DSSAT and APSIM crop modelling framework. The decline in wheat and rice will lead to a drop of 23 percent in the 2050 base production of processed rice. Moreover, the output of the meat and livestock subsector of agriculture will decrease by 2.7 percent, which is a loss of $538 million. The majority of livestock have a diet that is composed of grass, by-products of different crops, including wheat, silage, etc. High heat waves would cause fewer animal pregnancies and low milk production [53], and due to low production of wheat and rice crop, the diet of livestock would be affected which in turn would reduce its productivity substantially. Since the economy is composed of different interactive sectors, low output of livestock will cause a decline in the output of leather by 2.3 percent. Moreover, the tourism and business service sector will face a loss of $4.5 and $190 million, respectively.

Table 3. Impact on domestic production (%).

	Sectoral Production		**Sectoral Consumption**	
	Baseline 2050	Simulated Shocks	Baseline 2050	Simulated Shocks
	Million ($)	% Change	Million ($)	% Change
Grain Crops	40,727	−0.01	11,746	0.08
Paddy Rice	11,027	−20	0	-
Wheat	15,399	−14.6	0	-
Processed Rice	82,117	−23.1	67,853.8	−23.47
Meat Livestock	35,505	−2.7	10,007	−2.72
Processed Food	223,300	−2.1	172,866	−2.05
Textile	53,149.7	−0.3	5492	0.06
Wearing Apparel	68,093.6	−0.1	50,694.9	0.04
Leather	54,737.8	−2.3	52,173	−2.24
Tourism	10,227.4	−0.1	10,008.6	−0.1
Business	296,990.5	−0.2	24,271.9	−0.11

Source: Results based on the author's own simulation.

A reduction in the production of a good boosts the price and shrinks consumption. The decreasing demand for major agricultural commodities in Table 3 justifies this statement. A significant decrease of 23 percent can be noted in processed rice, due to the climate-induced yield decline of paddy rice. Direct consumption of whole wheat and paddy rice is zero because it is not consumed in the raw form. Both crops must be milled and processed in order to be consumed. Processed food includes the milled and flour wheat. It is reduced by 2.05 percent.

3.1.2. Impact on Producer/Consumer Price

The instantaneous outcome of climate-induced loss of agricultural yield is the rise in commodity prices. The business as usual scenario of 2050 will lead to a significant increase in the production of domestic goods and services, thereby reducing the respective domestic prices. However, the decreased output of major crops will cause a significant increase in the producer, as well as consumer price. Table 4 reports changed the domestic price by 2050. The amount of processed rice shows the highest increase among all. A shortage of rice will cause the production of different varieties of white and brown rice, and rice products, such as rice flour to decline and hence, lead to a higher price. Such high costs of the staple crops will bring about food insecurity in the country by 2050.

3.1.3. Impact on the Returns of the Factors of Production

To understand the substantial loss in the country's Gross Domestic product, due to the agricultural production decline under specific climatic scenarios requires an estimation of the change in individual parameters that determine real GDP from income side: Land rent, labor wages, capital interests, profits, and taxes. A decline in production causes a shortage in the market that leads to an increase in the price level. Yield decline of wheat and rice would lead to a rise in their price and the price of related commodities. Therefore, factors involved in agricultural production are expected to find a higher return as compared to those in other sectors (Table 4).

Table 4. Impact on domestic price (%).

Impact on Domestic Prices		Impact on Real Factor Wages	
Sector types	% Changes	Factor Types	% Changes
Grain Crops	0.5	Labor-Small Farmer	1.6
Paddy Rice	26.4	Labor-Medium Farmer	2.81
Wheat	17.8	Labor-Farm Worker	1.09
Processed Rice	31.4	Labor-Non-Farm Low Skilled	−1.75
Meat Livestock	3.4	Labor-Non-Farm High Skilled	−1.57
Processed Food	2.7	Land-Small	6.76
Textile	0.5	Land-Medium	7.59
Wearing Apparel	0.6	Land-Large	8.76
Leather	2.9	Livestock	−5.36
Manufacturing	0.6	Capital-Agriculture	7.11
		Capital-Formal	−2.06
		Capital-Informal	−1.85

Source: Results based on the author's own simulation.

3.1.4. Impact on the Households' Income

To understand the effects of climate change-induced production loss, it is essential to see differences in impacts between different household groups in terms of their income and consumption. According to SAM (2011) of Pakistan, rural farm, small, medium, and large households collect their income from livestock, small, medium, and large laborers, respectively. These factors of production generate more than 90% of their returns from the agricultural sector. Similarly, rural non-farm and urban households are largely involved in the services and industrial sectors. Their incomes are composed of low and high skilled labor wages. However, urban households do own a small portion of the country's total livestock.

The effects of climate change in terms of production decline of wheat and rice on the real income of households are reported in Table 5. Due to the notable increase in the domestic price of major agricultural commodities, real incomes of most of the households will decline significantly. However, rural medium and large households will find an increase in real income because these households consume homegrown cereal grains and are not affected much by high market prices. Moreover, they produce major staple crops; therefore, any decline in production would lead them to higher market price, and hence, higher profit.

Despite an increase in wages of farm workers, due to the climate-induced production decline of wheat and rice, their real income will decrease significantly. Rural non-farm and urban households are expected to experience the most significant decrease in real income as compared to rural farm households as they do not produce agricultural commodities and depend on highly-priced products from producers, who primarily belong to rural farm households. Punjab households are the least affected among all households in the urban and rural non-farm category. This is because more than 60 percent of total wheat and rice is grown in Punjab. The market price in other provinces also involves transportation cost. Therefore, the same commodity costs relatively less in Punjab than the rest of the country. The households from Baluchistan face the largest decline in their real income.

Table 5. Impact on households' income.

HHLD Types	Simulated Shocks	
	% Change	Monetary Change (million $)
HHLD-Rural Small-Punjab	−0.3	−7.09
HHLD-Rural Small-ROP	−0.67	−123.49
HHLD-Rural Medium-Punjab	3.4	4.04
HHLD-Rural Medium-ROP	2.55	182.21
HHLD-Rural Large-Punjab	1.49	23.93
HHLD-Rural Large-ROP	0.90	73.00
HHLD-Rural farm worker-Punjab	−3.01	−57.41
HHLD-Rural farm worker-ROP	−3.64	−216.79
HHLD-Rural Non-Farm-Punjab	−2.14	−86.47
HHLD-Rural Non-Farm-Sindh	−2.14	−133.41
HHLD-Rural Non-Farm-ROP	−2.14	−190.21
HHLD-Rural Non-Farm-ROP	−2.20	−336.16
HHLD-Urban-1	−1.85	−46.96
HHLD-Urban-2	−2.06	−134.15
HHLD-Urban-3	−2.17	−317.05
HHLD-Urban-4	−2.23	−1747.77

Source: Results based on the author's own simulation.

3.1.5. Impact on Sectoral Exports and Imports

Along with remarkable growth in the country's GDP and factors' productivity, the sectoral exports will also increase significantly in the baseline scenario of 2050. Within the agricultural sector, both rice and wheat are the largest exported crops. The effects of climate change on their productivity would lead to a significant decline in their exports, as well as the overall real exports of the country. Table 6 shows the impact of climate change on sectoral exports by 2050. Exports of paddy and processed rice are expected to decline by 18 and 19 percent from the baseline, respectively. Similarly, wheat shows a notable reduction in its exports. The exports of processed food, including wheat husking and milling, will also decrease by almost 2 percent.

Table 6. Impact on sectoral exports and imports.

	EXPORTS		IMPORTS	
	Baseline 2050	Simulated Shocks	Baseline 2050	Simulated Shocks
	Million ($)	(%)	Million ($)	(%)
Grain Crops	2851.8	−0.41	15,057.12	0.51
Paddy Rice	523.4	−18.23	310.726	0.65
Wheat	1887.8	−14.17	160.303	0.58
Processed Rice	6372.6	−19.06	70.8643	0.57
Meat Livestock	544.3	−3.01	756.808	0.57
Processed Food	4791.6	−2.14	21,195.81	0.56
Textile	34,106	−0.47	22,664.23	0.55
Wearing Apparels	13,613.7	−0.49	1417.78	0.58
Leather	2088.7	−2.62	2482.103	0.59
Manufacturing	4277.8	−0.5	21,593.73	0.52
Tourism	121.9	−0.69	1191.775	0.59
Business	3591	−0.7	19,026.41	0.5

Climate-caused loss of wheat and rice production would create a sense of food insecurity in the country, and food products would have to be imported. The imports of major agricultural commodities show a notable increase, as illustrated in Table 6.

3.1.6. Import Share in Private Consumption (%)

The integrated assessment of climate change and agriculture requires analyzing the shift in trade-dependency of agricultural production and consumption. Pakistan has a huge share of imports in the private consumption of light and heavy manufacturing products. Household demand for agricultural commodities mainly consists of domestically produced goods. The effects of climate change on food production would increase the share of imported commodities in processed food consumption (Figure 3).

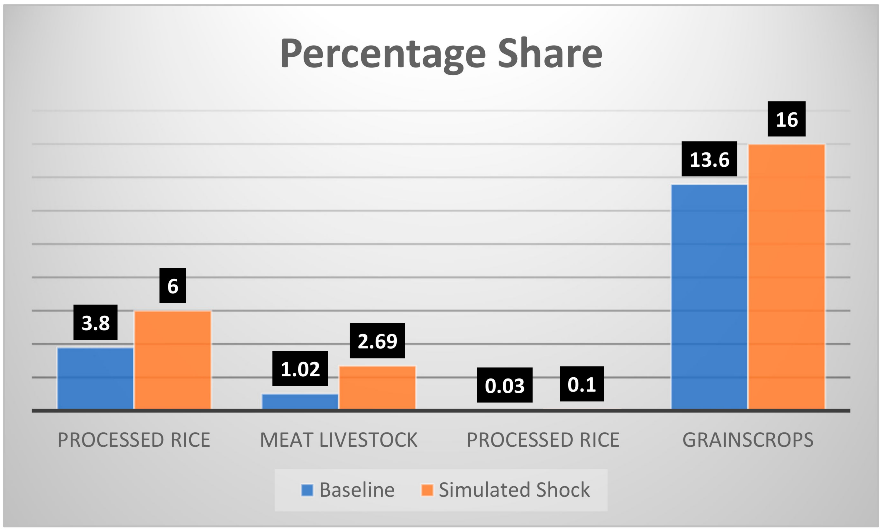

Figure 3. Impact on share of imports in private consumption (%).

3.1.7. Exports Share in Total Output

Pakistan has a relatively large export share in the total output of agricultural commodities. The country is one of the largest exporters of different varieties of rice and rice products. This share is around 5 and 8 percent for paddy and processed rice, respectively. Textile is another exporting sector with an export share of 64 percent. However, the effects of climate change on the production of rice and wheat will reduce their share of exports, as well as exports of related industries (Figure 4). The export share of both paddy and processed rice in total output will decline notably. Due to an increase in the production of other cereal crops, such as maize, sugarcane, etc., the share of exports of these crops will also increase.

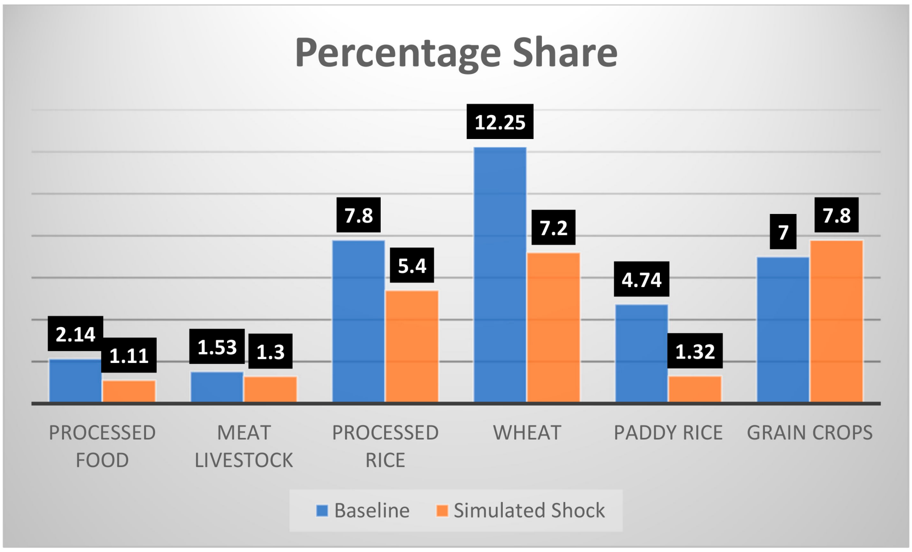

Figure 4. Impact on share of exports in total output.

4. Conclusions

This research has explored both macro and micro-level economic effects of climate change on Pakistan's wheat and rice crops by employing a country-specific computable general equilibrium (CGE) model of the Pakistani Economy. The research provides evidence of the negative effects of climate change-induced loss of crop production on the overall Pakistani economy by 2050. Since agriculture is one of the dominant sectors of the economy, real GDP will decline significantly. A decline in crop production, due to climate change not only affects the agricultural sector, but its results could extend to all agriculture-related industries and beyond, such as manufacturing and services. The change in crop production will have a multiplier effect.

By using an integrated model with a global and national database of GTAP and SAM, respectively, this study concludes that climate change will have some serious implications at the household level. Climate-led changes in crop production will have consequences on the returns of factors of production, incomes and consumption of different types of households. A huge rise in commodity prices will create a great challenge for the livelihood of the whole country, especially for urban households. The domestic price of wheat and rice will go up by as much as 17 and 31 percent, respectively. Hence, upward pressure on food prices will cause food security problems in the country. If the adaptation to climate change is ineffective, the resulting massive increase in commodity prices will pose significant challenges for the country's livelihoods.

The research draws some severe policy implications of broader perspective related to climate change. The government needs to undergo long-term strategies related to climate variability to support small and medium farmers and farm workers. Considering the likelihood of future climatic disasters, especially flash floods, the country needs to invest in irrigated and non-irrigated water management technologies. The government should provide farm advisory services, and weather forecasting and marketing information to the agriculture growers. It is suggested that the government have a sound agricultural policy that can play a role in influencing its ability to adapt successfully to climate change as adaptation is necessary for high production and net returns of the agricultural output [54–56].

5. Limitations

Like any other economic research, this study is not free of limitations. It focuses only on the economic component of assessment by investigating the future endogenous response of an economic model of agriculture to the different climate change scenarios by 2050. It does not explore the biophysical aspects of climate change impacts in detail, including those determining the actual cost of damage to crop production and yield. Therefore, a crop modelling study, along with economic modelling, is required to evaluate the actual climatic factors responsible for the loss of crop yield and output.

Furthermore, a numerical assessment of the impacts and possible adaptation to climate change would require a much-expanded modelling framework. Despite the above limitations, our results provide evidence that serious policy planning and implementation of adaptation strategies are required in the near future to help reduce the negative impact of climate change on the agricultural sector.

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Appendix A. Province-Wise Area under Wheat and Rice Crop (%)

Wheat						Rice					
Irrigated Land			Non-Irrigate Land			Irrigated Land			Non-Irrigate Land		
Punjab	Sindh	Rest	Punjab	Sindh	Rest	Punjab	Sindh	Rest	Punjab	Sindh	Rest
71.3	21.08	5.50	1.96	0.14	0	64.9	31.7	2.9	0.14	0.035	0.05

Source: Author's calculations from Agriculture Statistics of Pakistan (2018).

Appendix B. Household Types in Pakistan SAM 2011 Used in this Study

	Household Types	HH Code
1	HHD-RS1	Rural small farmer (quartile 1)
2	HHD-RS234	Rural small farmer (quartile 234)
3	HHD-RM1	Rural medium+ farmer (quartile 1)
4	HHD-RM234	Rural medium+ farmer (quartile 234)
5	HHD-RL1	Rural landless farmer (quartile 1)
6	HHD-RL234	Rural landless farmer (quartile 234)
7	HHD-RW1	Rural farm worker (quartile 1)
8	HHD-RW234	Rural farm worker (quartile 234)
9	HHD-RN1	Rural non-farm (quartile 1)
10	HHD-RN2	Rural non-farm (quartile 2)
11	HHD-RN3	Rural non-farm (quartile 3)
12	HHD-RN4	Rural non-farm (quartile 4)
13	HHD-U1	Urban (quartile 1)
14	HHD-U2	Urban (quartile 2)
15	HHD-U3	Urban (quartile 3)
16	HHD-U4	Urban (quartile 4)

Source: Pak SAM 2011 (IFPRI, 2018).

Appendix C. Factors Types in Pakistan SAM 2011 Used in the Study

	Code	Description
1	flab-s	Labor-small farmer
2	flab-m	Labor-medium+ farmer
3	flab-w	Labor-farm worker
4	flab-l	Labor-non-farm low skilled
5	flab-h	Labor-non-farm high skilled
6	flnd-s	Land-large
7	flnd-m	Land-medium
8	flnd-l	Land-small
9	fliv	Livestock
10	fcap-a	Capital-agriculture
11	fcap-f	Capital-formal
12	fcap-i	Capital-informal

Source: Pak SAM 2011 (IFPRI, 2018).

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