



Research article

An integrated assessment model for food security under climate change for South Asia

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ABSTRACT

The present study develops an integrated assessment model (IAM) for food security under climate change for South Asia. For IAM, initially, an econometric model is estimated that identifies the impact of climate change on crop yields, using the historical relationships between temperature, precipitation, and the production of cereals. Subsequently, future projections have been collected for temperature and precipitation from climate models of the Coupled Model Inter-comparison Project Phase 5 (CMIP5), and the previous econometric model is applied to obtain the implied future cereal yields changes. Then, the yield variations are fed into a multiregional Global Trade Analysis Project (GTAP) model, calibrated to the GTAP 9 database, taking the form of decreases in factor-augmenting productivity of the grains sector. Further, the present study evaluates the effects of climate change on an individual South Asian country. The results indicate that change in climate decreases food production, increases food prices, decreases food consumption, and thus affects the welfare. Trade and fiscal policy responses are investigated to combat the problem of food security. It is revealed that these two policies fail to compensate climate change damage in all the selected South Asian countries.

1. Introduction

There is a consensus among agriculture scientists and economists that food production is at a high risk due to climate change in large areas of the world. The South Asian Countries are the most vulnerable to such climate changes (Alvi and Jamil, 2018). The agricultural sector is a major source of employment in these countries, since more than 40 percent of the population directly or indirectly relies on agriculture (Kühn, 2019). Apart from that, this sector succeeds so far in providing consumers with food at low prices. While the current climate changes keep steadily increasing in damaging crops, population, and income in the South Asia. This region currently hosts more than 1.8 Billion people, and in the mid of this century the figure is expected to exceed to 2 Billion (World Bank, 2017). As a result, experts and policy makers are increasingly concerned about the availability of food for the growing population in the upcoming years (Mughal and Fontan Sers, 2020).

In this era of globalization and competition, there is an urgent need for both macro and micro-economic policy measures to insure the sustainability of food provision by making the economy more competitive

through a structural change. So, for this purpose General Equilibrium Models (GEMs) are developed. According to GEMs analysis the economy is made up of a complex network of several independent components which includes factors of production, different industries, institutions and the condition of international economies (Ianchovichina et al., 2001; Calzadilla et al., 2010; De-Salvo et al., 2013). One of the specifications of the GEMs are that it can adopt to the global changes occurring at an economy level and can measure the change of climate on their economic sectors (Calzadilla et al., 2013; Nikas et al., 2019).

The various models are employed to assess the effects of climate change on agriculture. The latest model, which is mostly used for analysis is an IAM. In IAM, climate was first integrated into the macro-economic model by representation of carbon dioxide concentrations in the classical model of the long-run growth (Nordhaus 1975, 1977, 1992). This model consists of combined data on the growth of crops, usage of soil and some other economic models (Mendelsohn et al., 2016; Prinn et al., 1999; Fujino et al., 2006; Cai et al., 2020; Müller et al., 2020; Meijl et al., 2020). The IAM developed a single entity by using the cause and effect of change in climate and by collecting the knowledge

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from different disciplines into a single entity and ultimately developing a network of information for developing policies (Dinar and Mendelsohn, 2011; Vanschoenwinkel et al., 2020). IAM is a comprehensive framework that evaluates the environment and its associated issues from a detailed viewpoint, utilizing all interdisciplinary scientific technicalities and modeling aptitudes, and all of it is used to aid the effective policy formulation and decision making (Laniak et al., 2013; Straatsma et al., 2020). In the past a few attempts have been made to develop an Economic Model for South Asia under the climate change by Hertel et al. (2010), Cai et al. (2016), Dissanayake et al. (2019) Chalise et al. (2017). These models focus on macroeconomic variable change along with climate such as GDP, population and prices. The economic modeling framework which is used in the present study is different from the previous economic models because it focusses on the trade and fiscal policies response to climate change.

Regarding the magnitude of climate challenge, an IAM for food security is developed for South Asia under climate change. For this purpose, the initial goal is to estimate an econometric model that identifies the impact of climate change on crop yields, using the historical relationships between temperature, precipitation, and the production of cereals in South Asia. Subsequently, future projections are collected for temperature and precipitation from the climate models of the Coupled Model Inter-comparison Project Phase 5 (CMIP5), and the previous econometric model is applied to obtain the implied future crop yield changes. Then, these yield variations are fed into a multiregional GTAP model, calibrated to the GTAP 9 database, taking the form of decreases in factor-augmenting productivity of the grain sector. Further, this study evaluates the effects of climate change in the South Asian countries. Through

this IAM, this study aims to examine the impact of climate change on income, food production, prices, local consumption, and welfare. Moreover, this setting also evaluates the effect of fiscal and trade policies on structural change, food security and eventually welfare.

This study is organized as follows; Section 2 is about the Methodology and Framework of the Integrated Assessment Model, Section 3 is about the empirical model and analysis, Section 4 is the projection of future cereal yields, Section 5 simulates the economic impact of climate change, Section 6 discusses the results of the compensatory policy responses, and section 7 concludes the study and gives policy implications and recommendations.

2. Methodology and framework of the integrated assessment model

An Integrated Assessment Model that considers the biophysical development and the economic models together, is to report the future uncertainty about climate change (Cai et al., 2016). Figure 1 explains IAMs framework which follow four steps:

- First goal is to estimate an econometric model that identifies the impact of climate change on cereal yields, using the historical relationships between temperature, precipitation and the production of cereals in South Asia.
- Secondly, the aim is to collect the future projections for temperature and precipitation from climate models of the CMIP5 and apply the previous econometric model to obtain the implied future crop yield changes till the mid of this century.

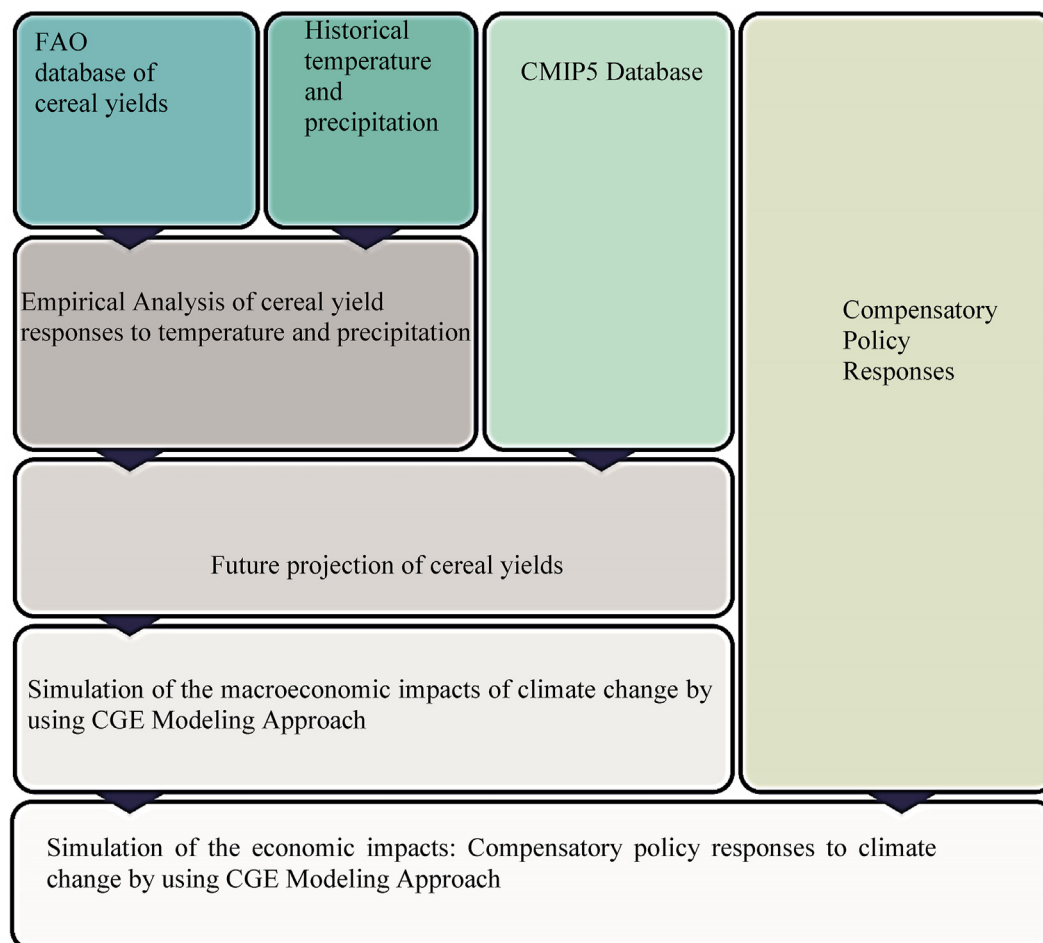


Figure 1. Framework of integrated assessment model.

Table 1. Impact of Climate change on Cereal yields.

| Variable | |
|--------------------|------------------|
| GDD | -0.364** (0.050) |
| GDD _{t-1} | 0.339* (0.098) |
| GDD _{t-2} | -0.160 (0.402) |
| Pr | -0.030 (0.273) |
| Pr _{t-1} | 0.086*** (0.000) |
| Pr _{t-2} | -0.008 (0.764) |
| K | 0.030* (0.081) |
| LF | -0.038 (0.337) |
| Y _{t-1} | 0.888*** (0.000) |
| C | 1.87 |
| N | 92 |
| R-squared | 0.87 |
| ∑GDD | -0.185 |
| F-value (P-value) | 3.854* (0.053) |
| Long run effect | -1.65 |
| ∑PR | 0.046 |
| F- value (P-value) | 3.634* (0.060) |
| Long run effect | 0.410 |

Notes: ***, **and *denote significance at the level of 99, 95 and 90 % respectively. Source: author's own calculations.

- Thirdly, these yield variations are fed into a multiregional GTAP model, calibrated to the GTAP 9 database, taking the form of the decrease in factor-augmenting productivity of the grain sector. Further, the objective is to evaluate the effects of climate change on the South Asian countries.
- Finally, through the GTAP 9 database, this setting also evaluates the effect of some fiscal and trade policies. The aim of this analysis is to examine the impact of climate change on income, food production, prices, local consumption, and welfare.

Simulation of the macroeconomic impacts of climate change by using CGE Modeling Approach.

3. Empirical model and analysis

To check the impact of climate change on cereal yields, first, the variable of climatic and non-climatic variables at a level are included in the empirical Eq. (1). Further, the lagged variables of temperature, precipitation and cereal yields are also taken into account to determine the longterm relation between climate change and cereal yields by following the work of Korhonen et al. (2019) and Alvi et al. (2020) in the field of climate change. The fixed effect dynamic model is shown as follows:

$$y_{it} = \sum_{k=0}^n \psi_{i,t-k} (GDD_{i,t-k}) + \sum_{k=0}^n \varphi_{i,t-k} (Pr_{i,t-k}) + \Pi_1(K_{it}) + \Pi_2(LF_{it}) + \sum_{l=1}^m \rho_{i,t-k} (y_{i,t-k}) + \beta_0 + \beta_t + \alpha_i + \varepsilon_{it} \quad (1)$$

Where y is cereal yields, GDD is growing degree days, Pr is precipitation, K is capital stock, LF is labor force, k is the lag length of climatic variables; l is the lag of the dependent variable; $\psi_{i,t}$ and $\varphi_{i,t}$ coefficients represent the current effect of growing degree days and precipitation on cereal yields respectively. The sum of the coefficients of growing degree days, $\psi_{i,t} + \psi_{i,t-1} + \psi_{i,t-2} + \dots + \psi_{i,t-n}$ gives the full effect of growing degree

days change. Similarly, $\varphi_{i,t} + \varphi_{i,t-1} + \varphi_{i,t-2} + \dots + \varphi_{i,t-n}$ gives the full effect of precipitation change over the time. A null hypothesis is set for growing degree days, $H_0 : \psi_{i,t} + \psi_{i,t-1} + \psi_{i,t-2} + \dots + \psi_{i,t-n} = 0$, and similarly for precipitation. If the null hypothesis is accepted then it means there is no impact of climate change on cereal yields, in other words, there is no long run relationship between the dependent and independent variable. In the case the null hypothesis is rejected, then the long run effect (LRE) can be computed of climate change on cereal yields. The long run effect will be calculated, e.g. GDD is as follows:

$$LRE = \frac{\sum_{k=0}^n \psi_{1i,t-k}}{1 - \sum_{l=0}^m \rho_{1i,t-1}} \quad (2)$$

For empirical estimation, a historical data from 1991 to 2015 is used for climatic and non-climatic variables. The data of cereal yields, labor force and capital stock are taken from the Food and Agriculture Organization (FAO, 2019). The data of climatic variables, and the GDD and precipitation is obtained from World Bank Climate Change Knowledge Portal. GDD is the sum of heat that a crop receives over the growing period above the lower threshold. Following Schlenker and Roberts (2009), and Zhang et al. (2017), the study used 8 °C as the lower threshold. The growing degree days are calculated from the average monthly temperature as follows:

$$GDD(T) = \begin{cases} 0 & \text{if } T \leq 8 \\ T - 8 & \text{if } T > 8 \end{cases}$$

3.1. Empirical results of cereal yield responses to temperature and precipitation

The results indicate (Table 1) that the increase in growing degree days has significantly negative impact in the Southern Asia region. The absolute value of the growing degree days is significant and different from zero. Which means that there is a long run association between the growing degree days and yields. So, the long run impact of growing degree days in the Southern Asian region is calculated which is -1.68. The increase in precipitation has a positive impact in South Asia, the absolute value of three coefficients of precipitation is statistically significant and different from zero. It means that there is a long run relationship between precipitation and yield. So, the long run impact of precipitation in South Asia is 0.410.

4. Projection of future cereal yields -2050

By using the value of the long run impacts of climate change the future cereal yields for the mid of this century for the four south Asian countries: Bangladesh, India, Pakistan, and Sri-Lanka (see Table 2) are predicted. For that purpose, the Representative Concentration Pathways (RCP) 6.0 is used, this scenario uses a high greenhouse gas emission rate and is a stabilization scenario where total radiative forcing is stabilized after 2100 by the employment of a range of technologies and strategies for reducing greenhouse gas emissions. In which global warming is expected to rise on average 1.3 degree Celsius in the mid of this century and 2.2° by the end of the century. The future projections are given in Table 2 by using the data of the Geophysical Fluid Dynamics Laboratory (GFDL) which indicates that Bangladesh and Pakistan will be the most affected countries in the South Asia, where cereal yields will decrease by 40.42 and 35.49 percent in the mid of this century. However, India will be the

Table 2. Projection of future cereal yields-2050.

| | Bangladesh | India | Pakistan | Sri-Lanka |
|----------------|------------|--------|----------|-----------|
| RCP 6.0 (GFDL) | -40.42 | -11.83 | -35.49 | -29.24 |

Source: author's own calculation.

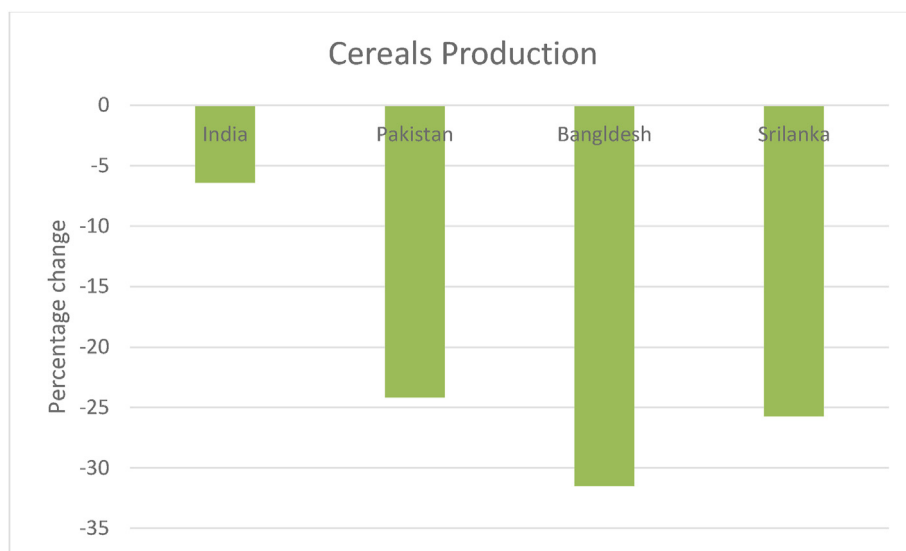


Figure 2. Impact of climate change on cereals production.

least affected country in south Asia, where cereal yields can be decreased by 11.83 percent. While, in Sri-Lanka, this decrease is 29.24 percent.

5. Economic impacts of climate change

In this section, the economic impacts of climate induced cereal productivity changes in South Asia are discussed for each individual country using the Integrated Assessment Model framework. The future decrease in cereal yields data is incorporated from the previous section and fed into a multiregional GTAP model, calibrated to the GTAP 9 database. The results indicate that Cereals production can be decreased up to 31.49, 24.19, 25.74 and 6.4 percent in the mid of this century-2050- as compared to the base year 2011 in Bangladesh, Pakistan, Sri-Lanka and India respectively. It is revealed from the results that GDP can decrease in all South Asian countries (see Figures 2, 3, and 4).

Where the loss to GDP is 6.4, 24.19, 31.49, and 25.74 percent in India, Pakistan, Bangladesh, and Sri-Lanka respectively. It is found that prices will increase due to climate change and the highest increase is expected in Bangladesh and Pakistan which are 97.19, and 60.25 percent, respectively. While this increase in India is 21.64, and 47.33 in Sri-Lanka. These simulations are also indicating that the imports can

increase due to climate induced change in the cereal production in South Asia. While the exports can be reduced dramatically in the mid of this century. Where, Bangladesh and Pakistan are the most affected countries (see Figures 5 and 6). Further, it is found that decrease in cereal production not only increases the prices of cereal goods but also effect the consumption of individual households which is expected to decrease in all four countries (see Figure 7). This can be seen as that these South Asian countries can face more problems of food security, as they are already lagging in average yields and facing already a largely undernourished population (Bandara and Cai, 2014; Cai et al., 2020). Further the loss of welfare is identified due to the climate change which is 49.224 billion US \$ in India, 32.161 billion in Pakistan, 28.198 billion in Bangladesh, and 5.661 billion in Sri-Lanka (see Figure 8).

6. Compensatory fiscal and trade policy responses

In this section, the fiscal and trade policy responses to climate Change are checked and this section is devoted to the discussion of the results in Figures 9, 10, 11, 12, 13, 14, and 15. First, the model is simulated with a very optimistic approach, in which it is considered that

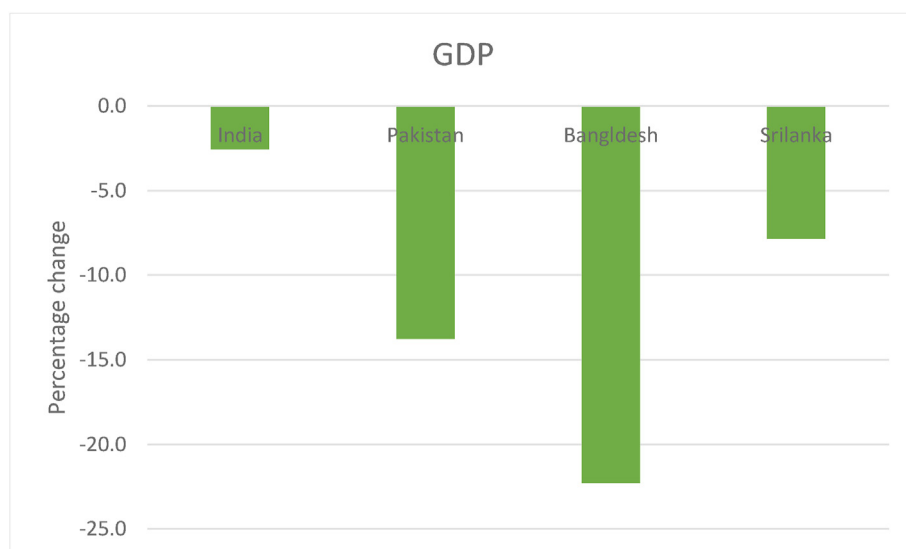


Figure 3. Impact of climate change on GDP.

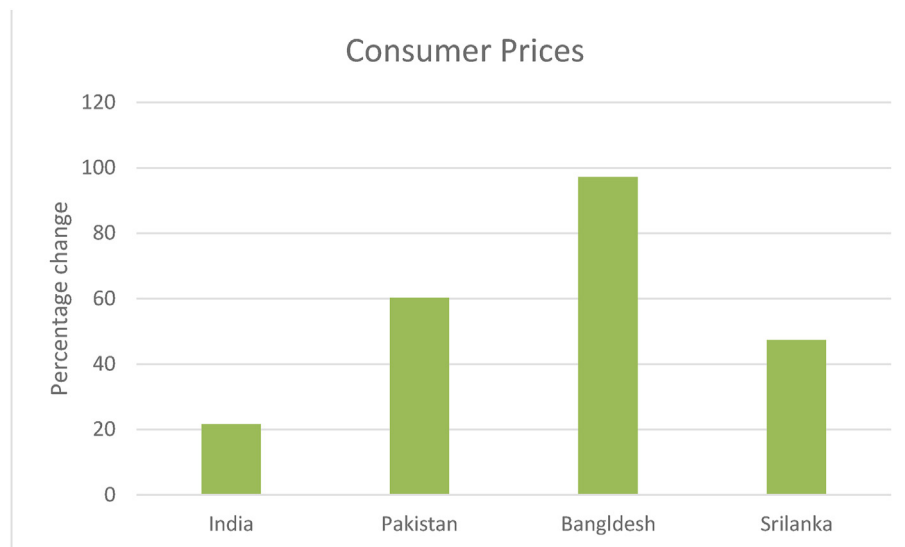


Figure 4. Impact of climate change on consumer prices.

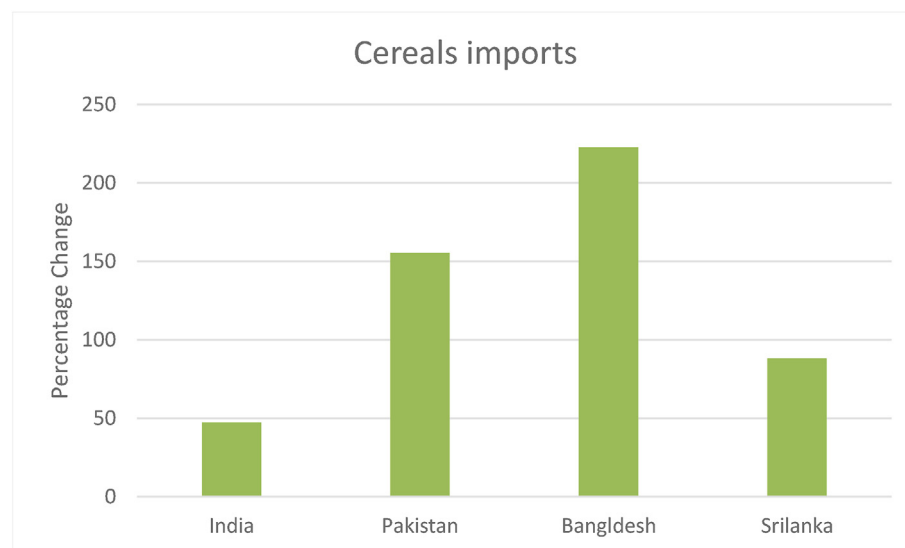


Figure 5. Impact of climate change on cereals imports.

if the South Asian countries start giving subsidies to the farmer's equivalent to Europe then how will it affect the situation. The results indicate an output will improve in all selected South Asian countries. But this improvement is not enough to cover the loss of climate change. Further, due to an increase in subsidies it affects other sectors of the economy and the GDP. An increase in subsidies instead of compensating it is creating a loss in the GDP. Due to subsidies, consumers' prices can be increased less and imports can be reduced, exports can improve and there can be a slight improvement in the availability of food for the individual households, but all these improvements due to subsidies are not enough and are not compensating the climate change shock. Even the simulations are identifying that welfare has not improved due to subsidies.

In the last, another model is simulated by considering the future regional trade developments in the South Asia. Where is in the top of the discussion. South Asian Free Trade Area (SAFTA) has been applied and implemented to see what will happen to the economic variables, and the results in Figures 9, 10, 11, 12, 13, 14, and 15 show that SAFTA is not that useful in compensating the loss of climate. It can fail in

improving the food security in South Asia. India can get little benefit from SAFTA because of being a larger country which cannot be considered significant. However, the welfare is improved significantly in Bangladesh.

7. Conclusion

The present study analyzed an integrated assessment model on food security for South Asia under the climate change. First, an econometric model is estimated that identifies the impact of climate change on crop yields, using the historical relationships between temperature, precipitation, and the production of cereals in South Asia. Subsequently, future projections for temperature and precipitation are collected from climate models of the CMIP5 and the previous econometric model is applied to obtain the implied future crop yield changes for the mid of this century. Finally, these yield variations are fed into a multiregional GTAP model, calibrated to the GTAP 9 database, taking the form of decreases in factor-augmenting productivity of the grain sector. Further, the effects of climate change on South Asian countries are evaluated. The simulations

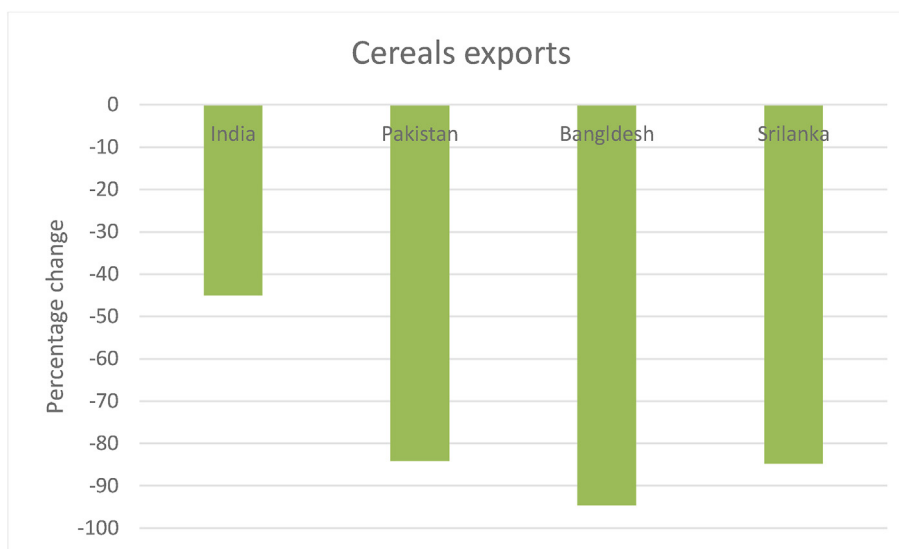


Figure 6. Impact of climate change on cereal exports.

conclude that a decrease in cereal production due to climate change in the mid of this century will result in ex-post increases in grain prices, decrease in income and consequently loss of welfare. Furthermore, such decrease in local food consumption could be catastrophic for the region, which is already dealing with a notable share of the undernourished population.

The model is simulated to check two compensatory policy responses to combat the problem of food security: fiscal policy response in form of subsidies and trade policy response by considering full implication of SAFTA. It is found that these two policies fail to compensate to the climate change shock in all the selected South Asian countries. The results of the empirical model are aligned with [Laborde et al. \(2012\)](#), [Cai et al. \(2016\)](#) and [Alvi et al. \(2020\)](#)

7.1. Policy implications and recommendations

Simulations, based on the Integrated Assessment model, reveals a threatening situation for the South Asian countries in terms of food security by the middle of this century, whereas, these countries are already dealing with a large number of the undernourished population. This part

of the study suggests that the South Asian countries are required to be more integrated globally and should find a solution other than SAFTA, having said that, SAFTA is ineffective for ensuring food security. Further, providing subsidies to the farmers is not ensuring food security both endogenously and regionally. It is therefore suggested that welfare losses due to climate change, should be mitigated through structural transformation from agriculture to manufacturing so that per capita income may be enhanced substantially and accordingly the food security. Further, it is also suggested that the focus should be on agreements of global cooperation for technology transfer and to increase trade with Europe and North America.

Climate change has important implications for future food insecurity which can be dealt with technology adoption. Given the importance of technology adoption for productivity growth and lag in technology adoption, it is suggested that policy makers of the respective countries should take initiatives to promote advanced technology, which may increase the agricultural production and meet the challenge of food security. Different programs can be designed to deal with the lag to adopt technology. Firstly, technology adoption can be dealt with by offering easy credit which must be linked with technology adoption. Secondly,

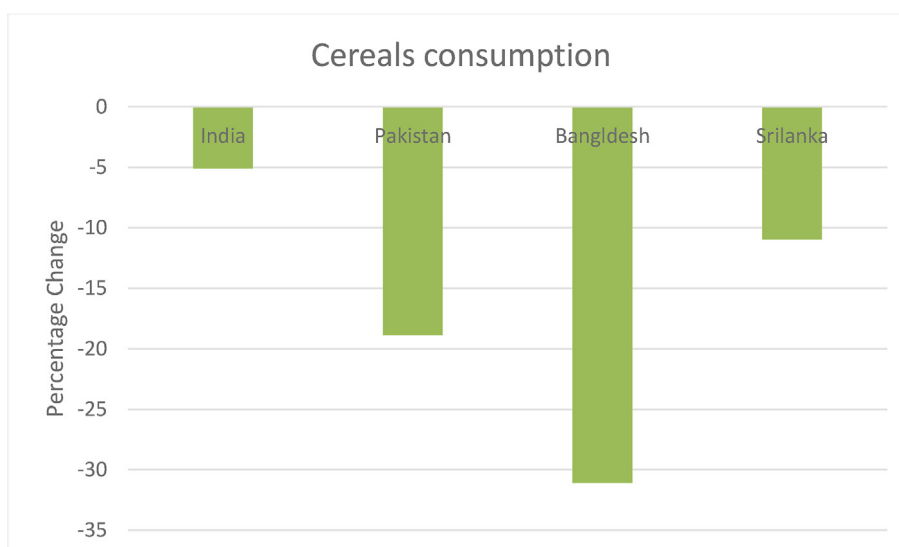


Figure 7. Impact of climate change on cereals consumption.

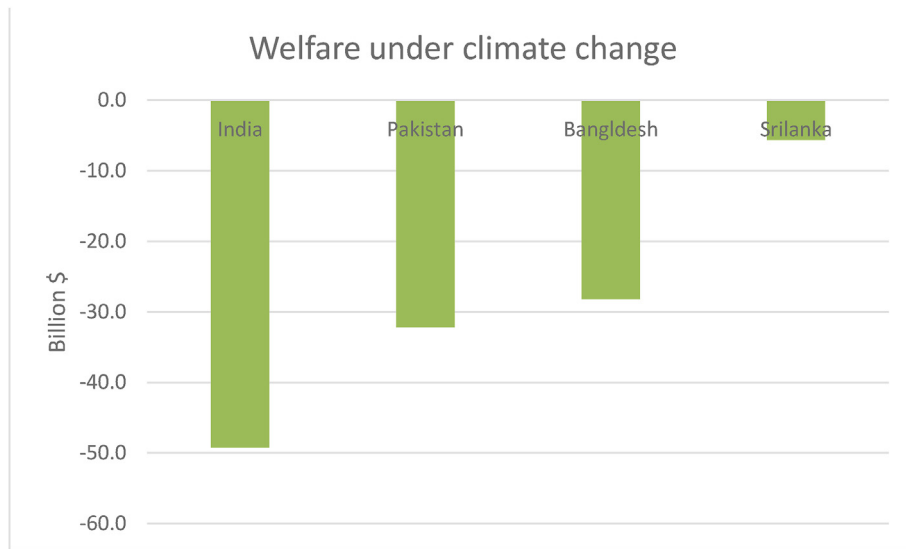


Figure 8. Impact of climate change on welfare.

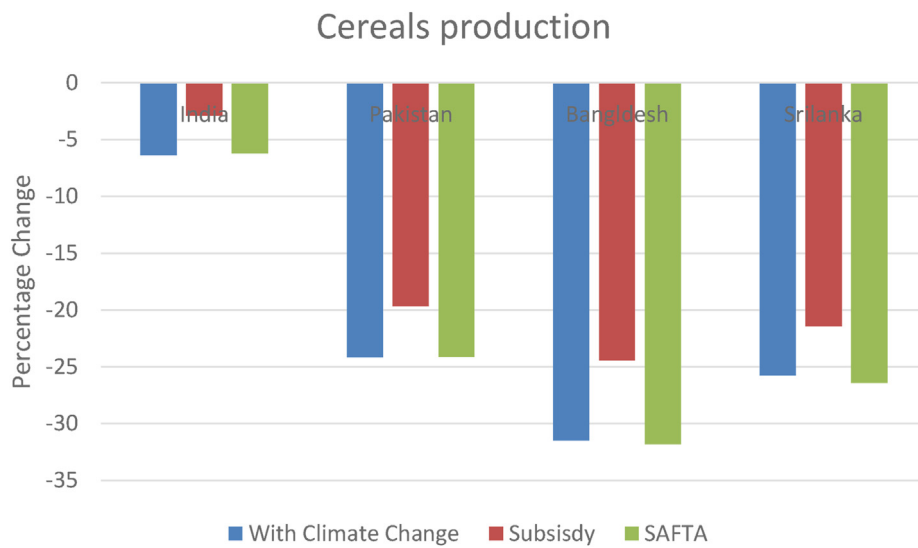


Figure 9. Impact of compensatory policies on cereals production.

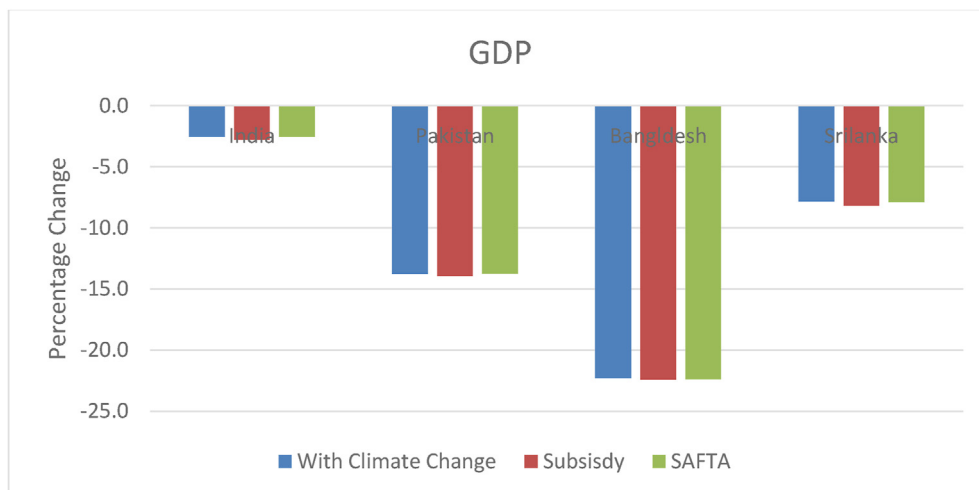


Figure 10. Impact of compensatory policies on GDP.

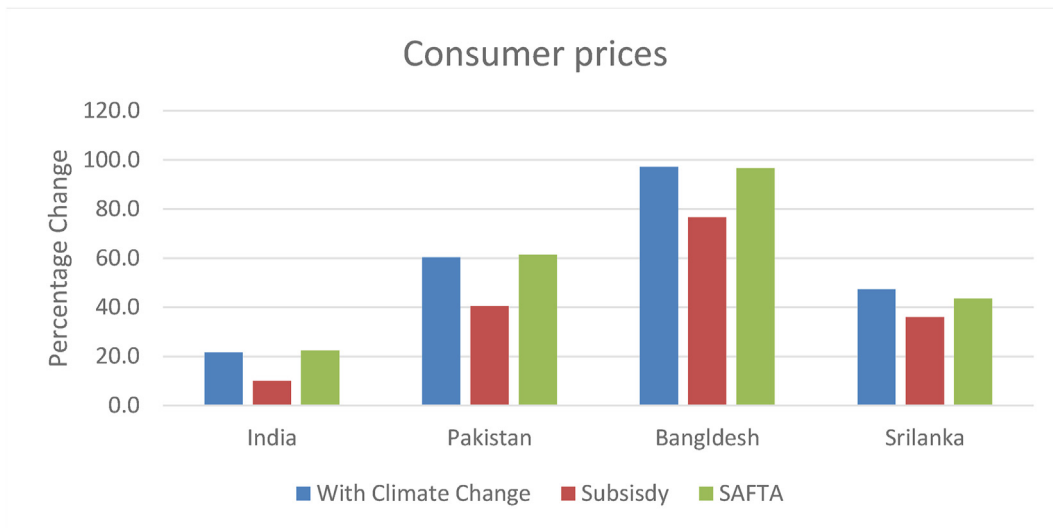


Figure 11. Impact of compensatory policies on consumer prices.

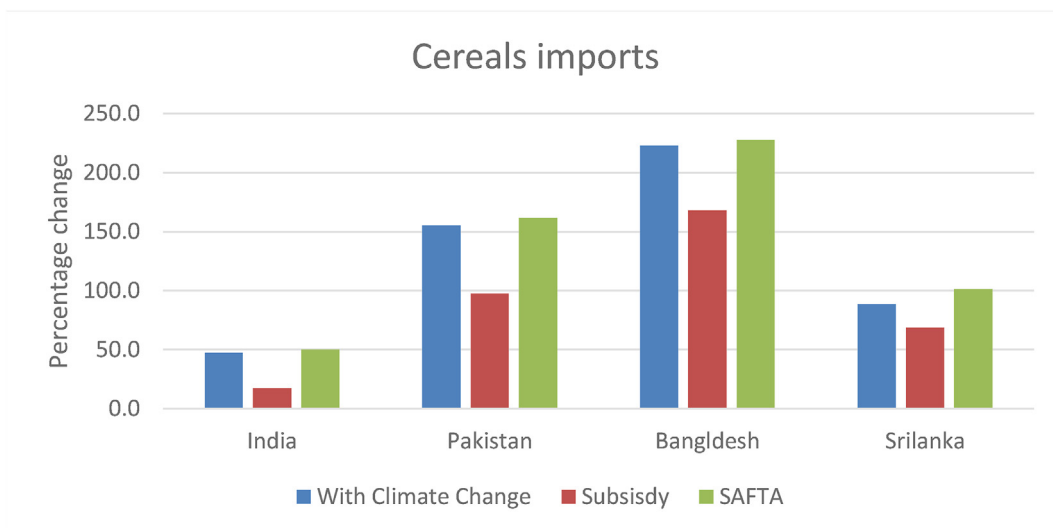


Figure 12. Impact of compensatory policies on cereals imports.

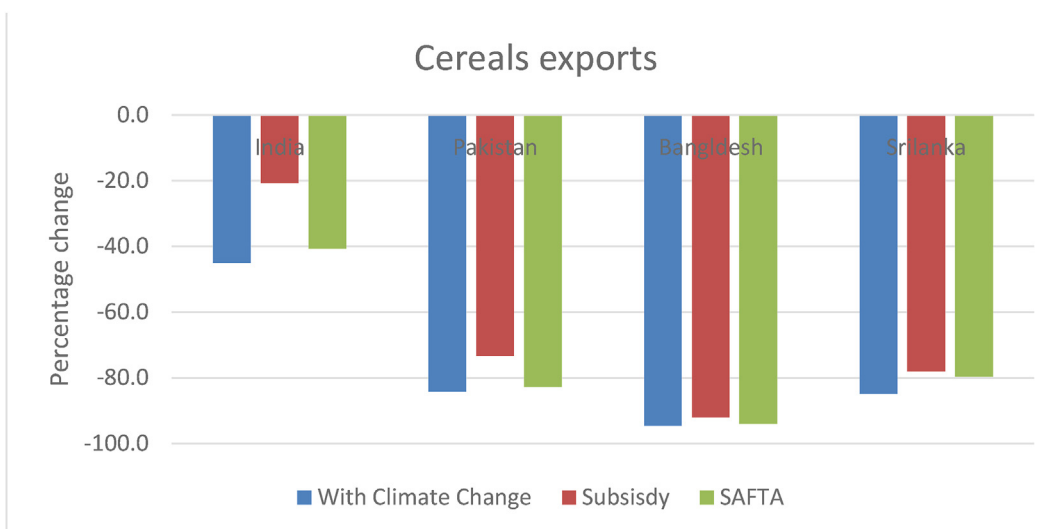


Figure 13. Impact of compensatory policies on cereals exports.

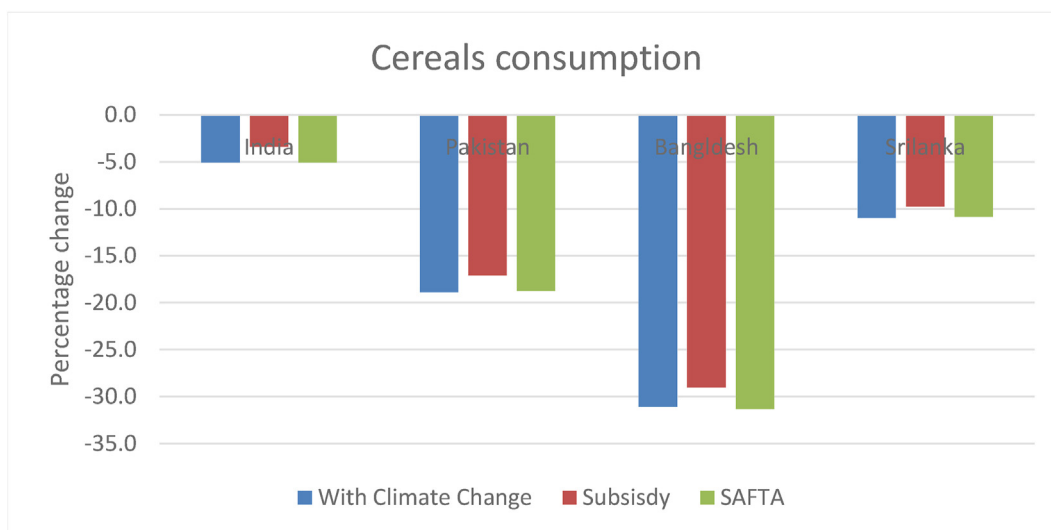


Figure 14. Impact of compensatory policies on cereal consumption.

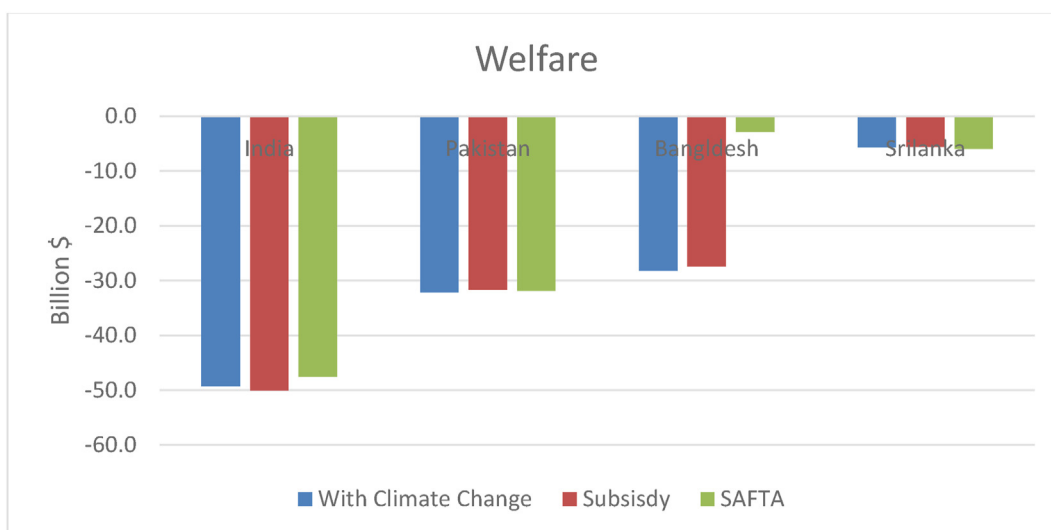


Figure 15. Impact of compensatory policies on welfare.

insurance coverage to farmers should be enhanced appropriately. Thirdly, transaction cost on market access should be reduced significantly through appropriately designed infrastructure programs, and tax and non-tax incentives. However, availability of information about the latest technology and its benefits for productivity growth is a necessary condition for technology adoption which should be the key priority of the governments of the South Asian countries. It can be ensured through making the agriculture extension services more influential through timely transfer of relevant information to the farmers by using different platforms such as agro-dealers, community organizations and social networks. Further, the governments should develop policies to reduce GHG emissions and control population growth.

Certain adaptive measures can mitigate the risk attached with food security. Specifically, the South Asian countries are not successful in adapting to climate change. It is therefore suggested that an enabling framework, harmonized with climate change, can be made available to the farmers to ensure food security, whereas, an enabling framework must ensure better scientific and physical infrastructure. Adaptive Strategies can accelerate the productivity which can be framed by understanding the experience of developed countries. In this perspective, international cooperation is needed to enhance rigorous cooperation

models. Acquiring technologies suitable for the agro-ecological system and their adaptation would be the key component of these strategies to ensure food security. It is important to examine farmers' adaptation strategies and their impact on each crop's yield at a country level. However, this topic will be left to future research.

Declarations

Author contribution statement

Shahzad Alvi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Roberto Roson: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Martina Sartori: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Faisal Jamil: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

The authors do not have permission to share data.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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