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The impact of climate change on food crop productivity, food prices and food security in South Asia☆

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ABSTRACT

South Asia has been identified as one of the most vulnerable regions in the world to the impact of climate change. Empirical studies carried out in recent years using the partial equilibrium approach suggest that climate change-induced yield losses in agriculture are becoming a serious concern. In this study, we use a global dynamic computable general equilibrium model to examine the impact of changes in crop productivity due to climate change on food prices and food security in South Asia, focusing on five large countries in the region, namely, Bangladesh, India, Nepal, Pakistan and Sri Lanka. Our results suggest that there is likely to be a significant negative impact on food production and prices in all South Asian countries due to climate change-induced agricultural productivity changes. The results further suggest that countries in this region are likely to face problems of food security given that nearly half of the world's poor reside in this region and agriculture plays an important role in the gross domestic product (GDP) and employment generation in the region. The results support the need for policy analysts and policy makers in the region to develop climate change adaptation measures that address the likely negative consequences of climate change-induced agricultural productivity losses.

1. Introduction

Among researchers in the field of climate change, there is a clear consensus on two key issues. First, global climate change (GCC) is happening and it is occurring at an exceedingly fast rate. The earth's average temperature has increased approximately 0.8 °C since the early 20th century. This global warming has been accompanied, as predicted, by a steady increase in the number and severity of climate-related natural disasters, such as cyclonic storms, floods, droughts, and heatwaves. It is predicted that in the absence of active carbon mitigation, global surface temperatures are likely to rise a further 2.4–6.4 °C by the end of the 21st century (see e.g., Intergovernmental Panel on Climate Change (IPCC), 2007, 2013).

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Second, it has been recognised that agriculture (mainly food production) is heavily dependent on weather and climate. Excessive heat or insufficient water can interrupt crop growth and reduce yields; extreme events, especially floods and droughts, can destroy harvest; climate variation affects irrigation, soil quality and the natural communities that agriculture relies on; and moreover, increase in the sea level as a result of polar ice melting reduces the availability of arable land (Gornall et al., 2010). Therefore, climate change is expected to have an impact on food production, food prices, and potentially threaten food security. Food demand is predicted to increase by around 300% by the year 2080 because of higher population, higher income, and demand for bio-fuel; and this rise is likely to create an imbalance between food supply and demand without the effects of GCC (Cline, 2008, p. 27). If, as expected, there is a decline in food production due to GCC, it is likely that there will be further upward pressure on food prices, multiplying the existing threats to food security (Inter-Agency Standing Committee (IASC), 2010).

The likely negative impact of climate change on agriculture has important implications for developing countries because agriculture is the most important contributor to poverty reduction (Cervantes-Godoy and Dewbre, 2010). The recent experience of the global food crisis in 2007 and 2008 demonstrates that populations in developing countries, which are already food insecure and vulnerable to shortages, are likely to be the most seriously affected in the world as a result of a future food crisis, which is likely to be multiplied by GCC (Nelson et al., 2009).

South Asian countries have been identified as some of the most affected countries by GCC, although their contribution to greenhouse gas emissions has been shown to be low (World Bank, 2013). The World Bank report (2013, p. 106) noted that, ''in the past few decades a warming trend has begun to emerge over South Asia, particularly in India, which appears to be consistent with the signal expected from human induced climate change''. The observed warming in the region varies significantly between 0.016 °C and 1.0 °C (see Appendix 1, adapted from Sivakumar and Stefanski, 2011, p. 17). In recent decades South Asia has witnessed numerous extreme weather events which are consistent with the predicted effects of GCC (see e.g., Sheikh et al., 2014). For instance, in 1999 a severe cyclonic storm hit coastal areas of Pakistan and India and brought devastation to both countries; during the period 1998–2001 Pakistan faced the country's worst drought; in July 2001 a record of 620 mm of rain fell in Islamabad, Pakistan, causing catastrophic losses to life and property; and during July 2005, 944 mm of rain fell in Mumbai breaking the city's 24-h rainfall record.

Strong evidence further supports the link between productivity in agricultural sectors in South Asia and the increase in extreme weather conditions, such as more extreme and frequent droughts and floods. The World Bank (2010) noted that ''domestic food prices have tracked the upsurge in global food prices, exacerbated by droughts'' (p. 28). It further notes that erratic monsoon weather conditions in India during 2009 reduced production of the main crops and led to higher food prices in 2009. This Indian food price inflation also spread to several of its neighbours, including Bangladesh, Bhutan, Nepal, and Sri Lanka. Domestic demand in India also increased during this inflationary period and was exacerbated by the El Nino weather pattern in 2009 that brought food shortages due to the increased occurrence of floods. This episode of rising food prices in South Asia provides an excellent case study for demonstrating that the considerable economic vulnerability in South Asia is likely to experience as GCC continues. In addition to the influence of extreme weather patterns and other climate change effects on agriculture, as highlighted by the World Bank (2009), increases in temperature in South Asia have also produced a decline in crop yields.

South Asian countries are expected to remain among the most affected countries by GCC. In some parts of the region, summer temperatures are projected to increase by 3 °C–6 °C at a scenario of 4 °C global warming and by 2 °C at a scenario of 2 °C global warming by 2100 (see World Bank, 2013). If, as expected, food production is heavily disturbed by GCC, this could have severe negative impacts on the South Asian economies due to the crucial role that agriculture plays in the regional economy. Over 70% of people in South Asia (that is, roughly 1.1 billion) live in rural areas dominated by agriculture and these people account for about 75% of the poor in the region (World Bank, 2012, 2013). More importantly, agriculture contributes towards nearly 18% of the region's GDP and employs more than 50% of the population (World Bank, 2013, p. 125).

Although there is clear evidence that South Asia is highly vulnerable to GCC, there have been relatively few detailed studies carried out within a global modelling framework that have examined the effects of climate change on crop productivity in South Asia. For example, Nelson et al. (2009) attempted to assess the impact of climate on global crop production. They found that crop production in South Asia is likely to be severely affected by climate change. Hertel et al. (2010) applied a computable general equilibrium (CGE) model, Global Trade Policy Analysis Project (GTAP), to evaluate the welfare implications of climate-induced crop yield changes on a global scale. They showed that South Asia countries, such as India, Pakistan and Bangladesh, are likely to be negatively impacted with respect to their trade and economic efficiency. Similarly, Laborde (2011) attempted to evaluate an optimal trade policy option for the region in the context of the impact of climate change on agriculture. With the exception of the above studies, most of the published literature focuses on estimating productivity changes for various crops in the five large countries in the region (Bangladesh, India, Nepal, Pakistan and Sri Lanka). This has led to a dearth of comprehensive studies that have investigated crop productivity in these countries in the region.

Therefore, the main purpose of this paper is to examine the impact of climate change-induced productivity changes in food crops, focusing on food prices and food security in the five large South Asian countries. The rest of the paper is organised as follows: the next section provides an overview on the topic focusing on changes in productivity in food crop sectors in the region with the purpose of preparing reasonable and realistic productivity shocks to be introduced to a dynamic computable general equilibrium model, known as GDyn. Section 3 briefly outlines the dynamic modelling framework used in the study, and Section 4 discusses the results of productivity simulations. Section 5 of the paper will provide some concluding remarks.

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Table 1
Summary of research on estimated crop productivity changes for countries in the South Asia region.

Source	Country	Crop	Productivity change	Comment
Jacoby et al. (2011)	India	All	17% decline in overall land productivity across districts	Ricardian estimates using 1.25 °C change in temperature over next three decades
Knox et al. (2011)	Sri Lanka	Rice	Increases by +6.6%	
	Pakistan		Increases by +7.5%	
	Bangladesh		Decreases by −5% by 2020s and by −10% by 2080s	
	India		Decreases by −13% and up to −27% (main season rice) and −40% by the 2080s	
	Bhutan		An increase in +10% up to 2020s and 2050s and decreases by −4% by the 2080s	
	Nepal		Decreases by −2% by the 2020s and up to −32% by 2080s	
Knox et al. (2011)	India	Wheat	Decreases by −60% by 2050s under the worst-case scenario	Projections vary depending on the methodology and the region
	Pakistan		−31% by 2050s	Some potential positive effects have also been predicted
	Bangladesh		Negative	
Knox et al. (2011)	India	Maize	−25% in 2020s and increases up to +60% by 2080s	
	Other South Asia regions		+ 10% to +40% increases with time	

Note: this table is mainly based on a systematic literature survey of Knox et al. (2011).

2. Climate change and agricultural productivity in South Asia: a brief overview

As noted in the introduction, countries in the South Asian region are likely to be severely affected by the impact of climate change, particularly in the agricultural sector. Sivakumar and Stefanski (2011, p. 17) used the results of Cruz et al. (2007) to summarise key observed past and present trends of regional temperatures and precipitations. Their summary showed that temperatures had increased in all five major countries in the region (Bangladesh, India, Nepal, Pakistan and Sri Lanka) since the 1960s. These observed climate-related factors, such as seasonal water scarcity, rising temperatures and extreme weather patterns, have all negatively affected crop productivity (see Appendix A). A recent World Bank report (2013) noted that rice and wheat yields in Asia had declined since the 1980s by approximately 8% for every temperature increase of 1 °C. Moreover, the World Bank report (2013) highlighted the impact of climate change on the rice–wheat system of the Indo-Gangetic Plain which covers large areas of India, Pakistan, Bangladesh and Nepal and observed a decline in rice and wheat productivity using empirical evidence from Pathak et al. (2003) and Lin and Huybers (2012).

Being the most populous and powerful country in the South Asia region, many researchers have investigated the link between rising temperatures and crop yields in India. According to some projections, by the year 2020, 10% of India's crop areas are likely to be negatively affected due to rising temperatures, increasing up to 15% by 2030 (World Bank, 2013). Kumar and Sharma (2013) have reviewed empirical evidence for the impact of climate change on crop yields in India. According to their review, although there is general agreement on the negative impact of climate change on crop productivity in India, most of the empirical studies have focused on only a small number of crops and these results vary according to crop type and geographical location in India. For example, Hundal and Prabhjyot-Kaur (2007) found that an increase in temperature between 1.0 °C and 3.0 °C could reduce rice productivity in Punjab by 3%–10%. Similarly, Geethalakshmi et al. (2011) found that rice yield had declined in Tamil Nadu by up to 41% due to a temperature increase of 4 °C. Kumar and Sharma (2013) have further demonstrated that the adverse impact of rising temperatures has differed according to crop type. That is, while Srivastava et al. (2010) have projected up to a 14% decline in monsoon sorghum yield in the central zone (CZ) and up to a 2% decline in the south central zone (SCZ) by 2020, they have projected a decline in winter crop yield up to 7%.

Recently, Knox et al. (2011) undertook a systemic review of the projected impact of climate change on food crop productivity in Africa and Asia. Their study provided different estimates on productivity changes in agriculture crops in all South Asian countries. As demonstrated in this review, there is no agreement among analysts on the exact percentage of productivity change related to different crops in the region. This is consistent with the study of Wheeler and von Braun (2013). Table 1 provides different values of productivity changes of various crops in countries in the region surveyed by Knox et al. (2011). Notably, certain crops in some countries are not negatively affected by GCC (e.g., rice yield is expected to be positively affected in Pakistan and Sri Lanka). Despite the variations in estimates of productivity losses due to climate change within and across countries in the region, some of these estimations can be used as inputs for our modelling analysis described in the next section.

3. Modelling framework

Although it is difficult to examine the effects of all factors related to climate change on agriculture in a quantitative study, some studies have recently attempted to quantify the effects of climate change using global CGE models. As Nelson and Shiverly (2014) noted, "quantitative models of economic behaviour are an essential part of global efforts to understand the causes and consequences of climate change" (p. 1). The use of global computable general equilibrium models in analysing the impact of climate change on agriculture has become very popular. In fact, *Agricultural Economics* recently published a special issue in 2014 on the performance and comparison of results of some of the well-known global CGE models which focus on climate change and agriculture (see e.g., Nelson and Shiverly, 2014; Nelson et al., 2014; Muller and Robertson, 2014; Robinson et al., 2014; von Lampe et al., 2014; Valin et al., 2014).

Some of the modelling approaches used by these studies have examined the impact of climate change on agriculture in the South Asian region as a whole, and separately in India. However there is a lack of detailed research on the impact of climate change in other large countries in the South Asian region. A review of the research suggests that the interaction between climate-induced productivity change and changes in the economic structure can be well captured in a dynamic multi-sector–multi-country global computable general equilibrium model with a more disaggregated South Asian region sample.

In this study, we use the Dynamic GTAP (Global Trade Analysis Project) model known as GDyn (see Ianchovichina and McDougall, 2012). Being a general equilibrium global trade model with dynamic elements (see Ianchovichina and McDougall, 2012 for details) the GDyn is an extension of the widely-used GTAP model (Hertel, 1997). It can be applied to analyse various issues, such as trade policy, regional economic integration, and climate change. The core GTAP model is a global comparative static general equilibrium model which links bilateral trade flows between all countries or regions in the world, and explicitly models the consumption and production for all commodities of each national or regional economy. Similar to any other neoclassical CGE or applied general equilibrium (AGE) model, in the GTAP, producers are assumed to maximise profits and consumers are assumed to maximise utility (in GTAP). Product and factor market clearing requires that supply equals demand in each market (see Hertel, 1997 for details).

The GDyn is an extension of GTAP and retains all its basic features. It also provides an improved treatment of the long-run within the GTAP modelling framework. It is a recursive model, generating a sequence of static equilibria based on the investment theory of adaptive expectations, and is linked by a number of dynamic features. The main features of the model include "the treatment of time; the distinction between physical and financial assets, and between domestic and foreign financial assets; and the treatment of capital and asset accumulation, assets and liabilities of firms and households, income from financial assets, and the investment theory of adaptive expectations" (Ianchovichina and McDougall, 2012, p. 5). Recently, the complete dynamic GTAP model (labelled as GDyn) has been documented and published as an edited volume (for details, see Ianchovichina and McDougall, 2012).

In order to simulate the impact of GCC in South Asia, this study distinguishes 11 regions or countries[1] in the world with a maximum possible disaggregation of the South Asian region by separately identifying the five largest (Bangladesh, India, Nepal, Pakistan and Sri Lanka). Each country or region's economy is disaggregated into 25 sectors. We mainly focus on agricultural sectors[2] that produce various crop and livestock products including the crops of rice, wheat, coarse grains, vegetable and fruits, sugar, oilseeds, cotton and fibres, and other crops. The GDyn model was built using the dynamic version of the GTAP 8 database. In this study, the simulations with the GDyn begin at 2007, covering a three-year period to 2010 and thereafter in five-year periods to 2030. The economic consequences of climate change-induced land productivity change using the GDyn need to be evaluated against a business-as-usual scenario in which there is no climate change (the "baseline"). The period-on-period comparison between the baseline and the scenario with climate change-induced land productivity change will allow us to estimate the dynamic impact of climate change on food crop productivity, food prices and food security in South Asia. Our baseline was calibrated according to the method of Chappuis and Walmsley (2011), which relies on the IMF's World Economic Outlook and projections of future population growth and labour supply that were estimated by the Institute for Research on the International Economy (known as CEPII) and the International Institute for Applied Systems Analysis (IIASA).

In order to address the link between climate change and food security in South Asia via crop yields, we focus on the three staple food crops most commonly consumed by South Asians, namely, rice, wheat and cereal grains. In this study, productivity shocks to rice, wheat and cereal grains in South Asian countries due to climate change over the period of 2007–2030 were selected based on the Knox et al. (2011) review shown in Appendix A.[3] Based on Table 1, Appendix B lists the period-on-period land productivity shocks from 2007 to 2030 that are used in this paper. On the whole, with the exception of

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1 They are Bangladesh, India, Nepal, Pakistan, Sri Lanka, Rest of South Asia, Rest of Asia, Oceania, North and South America, Europe, and Middle East and Africa.

2 They are rice, wheat, coarse grains, vegetable and fruits, sugar, oilseeds, cotton and fibres, other crops, processed rice, sugar, vegetable oils and fats, bovine cattle, bovine cattle products, meat products, animal products, raw milk, dairy products, other food products, wool and silk, forestry, fishing, beverages and tobacco, mining, manufacturing, and services.

3 Introducing climate-induced productivity changes in agriculture has been considered a complex undertaking. As noted by Muller and Robertson (2014), "the assessment of future climate change impacts on agricultural productivity is complex and many interacting processes contribute to the large uncertainty" (p. 37).

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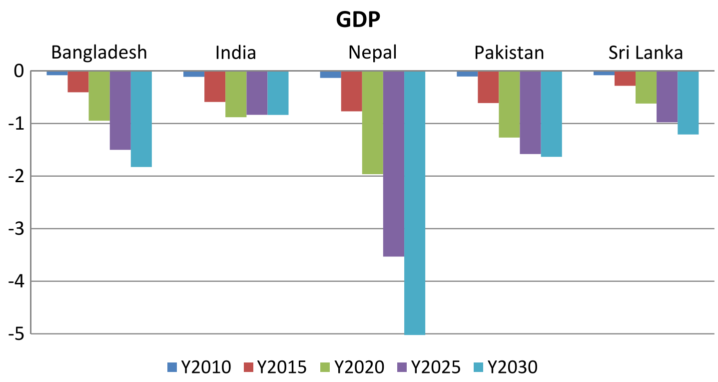

Fig. 1. Deviation of real GDP from baseline in South Asia under climate change (unit = %).

paddy rice in Pakistan and Sri Lanka, other crops sectors in all South Asian countries are expected to be negatively shocked by climate change.

For simplicity, we assumed in the analysis that climate change only affected land productivity. By doing so, we refrained from modelling potential future impacts of climate change based on human health (labour productivity) and capital productivity. Additionally, estimates were made without consideration of the adaptations that may reduce negative or enhanced positive outcomes, such as the development of new crop varieties or the significant expansion of irrigation infrastructure in a region. As such, we treated these as pure land productivity shocks in the GDyn model. In the scope of this paper, we did not consider productivity changes in agriculture in other regions.

4. Results

As noted in the previous section, the GDyn model was used to simulate the impact of climate-induced agricultural productivity shocks on macroeconomic variables, such as GDP and food consumption, and microeconomic variables, such as crop production and food prices, in all five South Asian countries. The effects of productivity shocks on different variables are presented as deviations from their baseline projections.

The overall impact of GDP in each of the five South Asian countries was examined in order to explain the significance of the impact of climate change on agriculture. The reason for this, as stated earlier, is that the impact of climate change is much more important in South Asia relative to the rest of the world. Agriculture plays an important role in the South Asian region in terms of its contribution to GDP (18%) and has a much larger share than agriculture in the global GDP (2.4%). Therefore, it is not surprising that the projected impact of climate change on agricultural productivity affects real GDP negatively and significantly (see Fig. 1). The model projections shown in Fig. 2 suggest that the output of many agriculture products is likely to be affected by climate change-induced productivity changes. These negative output effects are likely to lead to a decline in GDP in these countries. The magnitude of the impact on GDP in countries such as Nepal and Bangladesh is relatively higher than other countries due mainly to the larger role that agriculture plays in these small countries.

After identifying the overall impact of climate change-induced productivity changes in agriculture on the GDP we can examine the detailed effects of climate change-induced productivity changes on different agricultural products in South Asian economies. As expected, land productivity losses are expected to lead to reduced crop food production and higher food prices, as shown in Fig. 2. This figure shows that the output levels of all agricultural sectors are expected to decline and that, as an example, the output level of rice in India and Bangladesh is expected to decline rapidly. Considering the huge population in these countries, this is likely to create significant food security issues. The exception to this pattern of decline is Pakistan in which output of paddy rice is expected to rise over the whole simulated period. The main reason for this is that we introduced a positive productivity shock to paddy rice in Pakistan on the basis of empirical evidence available in the literature.

Apart from rice, wheat is the other staple food produced in South Asia. The second panel of Fig. 2 demonstrates that the effects of climate change-induced productivity changes on wheat in South Asian countries are negative. The wheat output level in all South Asian countries is expected to decline. The magnitude of this effect is considerably higher in Pakistan than other South Asia countries. The third panel of Fig. 2 shows the simulated effects of climate-induced productivity change on other cereal grains in the region. It also shows negative effects on the output level of that sector in all countries. Overall, the results indicate that negative output effects related to staple food items in the region are likely to increase food security concerns.

Not surprisingly, given the negative output effect, domestic food prices in all of these countries are projected to rise with the exception of rice in Pakistan and Sri Lanka. This predicted rise is mainly due to the relatively less elastic demand for food products. These price effects are shown in Fig. 3, suggesting that there will be a large increase in food prices, particularly in Bangladesh, India and Nepal. The percentage changes in prices vary according to country and product. Overall, all countries in South Asia are expected to face food inflation[4] (see Fig. 4), and as a result, it is expected that households are

[4] In this paper, food inflation is defined as the aggregated price level of rice, wheat and cereal grains.

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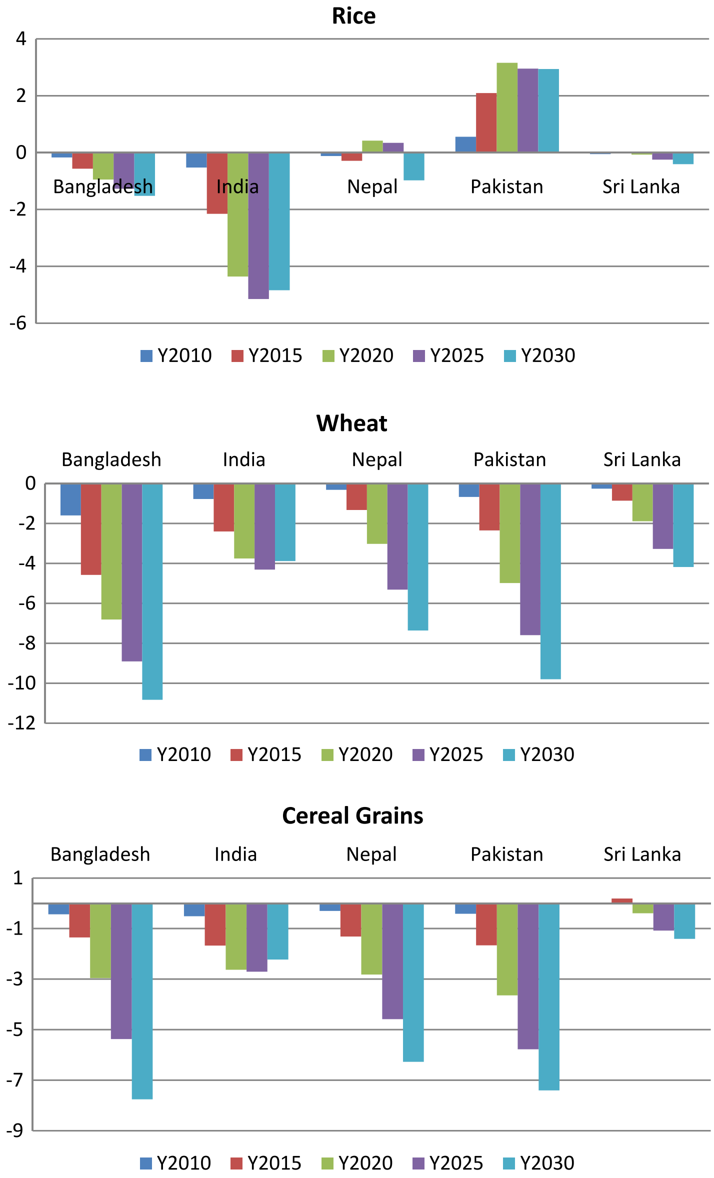

Fig. 2. Deviation of production from baseline in South Asia under climate change (unit = %).

likely to reduce the quantity of food consumed. This is supported by the results displayed in Fig. 5 in which all three panels demonstrate that household food consumption is projected to decline.

These results suggested that the overall impact of climate-induced productivity changes on the agricultural sectors in South Asian countries was predicted to be significant. Fig. 6 shows the production-to-consumption ratios of food (that is, the sum of rice, wheat and other grains) for these countries. The ratios are often simply read as a measure of food self-sufficiency and food security. However, in the context that food production and consumption are likely to decline in all countries of interest, these ratios should be interpreted with care. The rise in the ratios in India and Pakistan is likely to be driven by the decline in consumption (the denominator) rather than by an increase in production (the numerator). Therefore, this decline is expected to lead to serious food intake and nutritional concerns in these countries.

To understand the effect of climate-induced food productivity changes on the expected decline in GDP in South Asian countries (as shown in Fig. 1), we need to decompose the GDP results into different contributing sources. There are several ways of measuring GDP. The income method suggests:

$$\text{GDP} = \text{Rents} + \text{Wages} + \text{Interests} + \text{Profits} + \text{Taxes}. \quad (1)$$

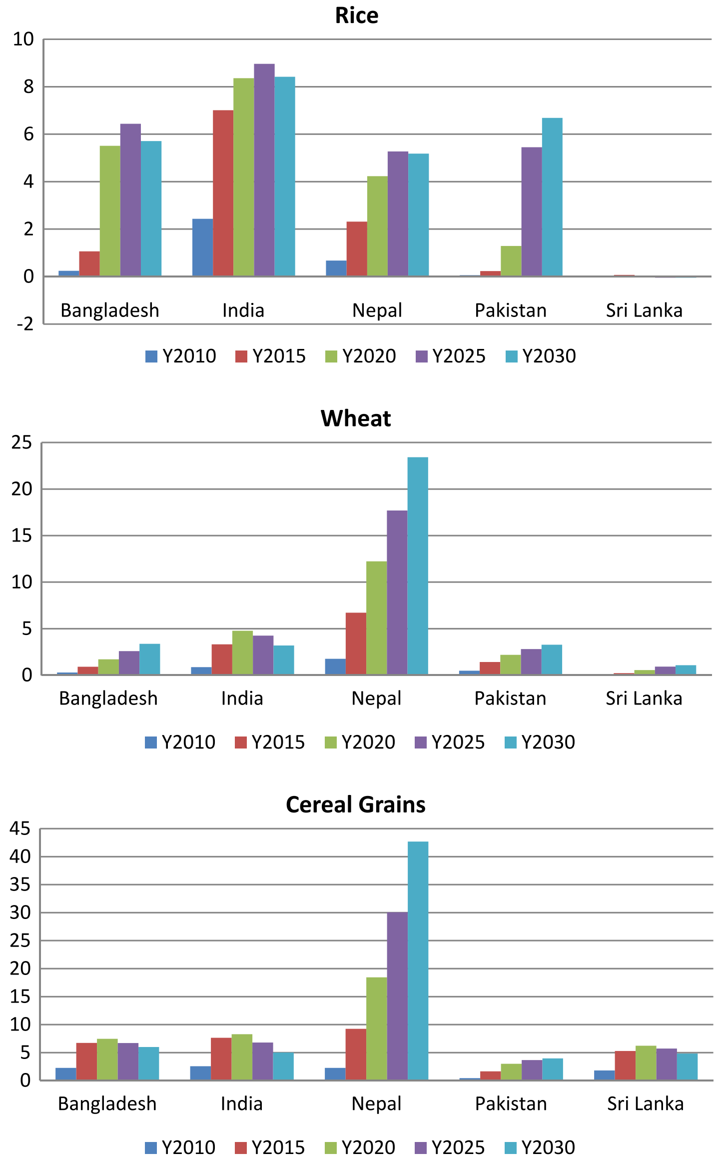

Fig. 3. Deviation of prices from baseline in South Asia under climate change (unit = %).

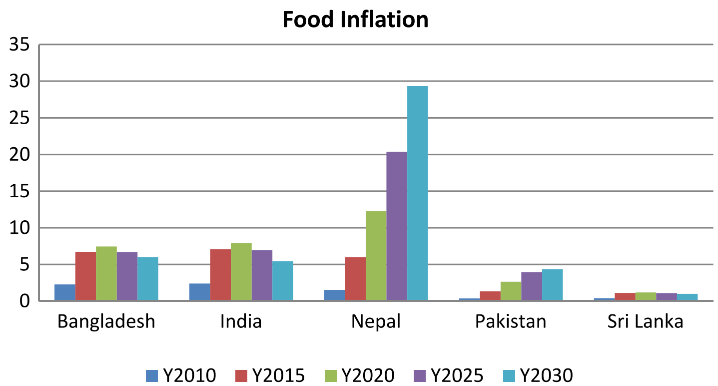

Fig. 4. Deviation of aggregated food price from baseline in South Asia under climate change (unit = %). Note: aggregated food price is calculated as the weighted sum of rice, wheat and other grain prices.

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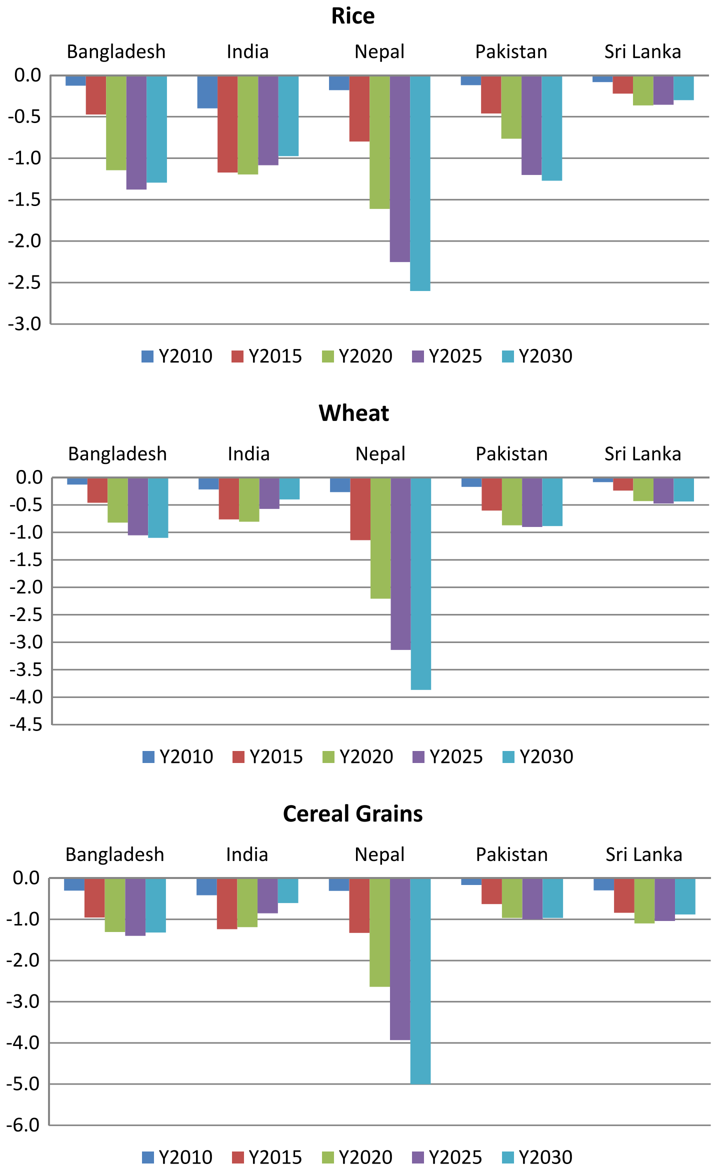

Fig. 5. Deviation of consumption from baseline in South Asia under climate change (unit = %).

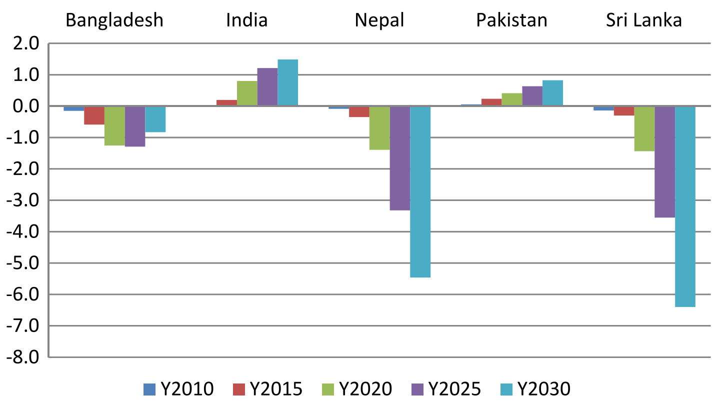

Fig. 6. Deviation of food production-to-consumption ratio from baseline in South Asia under climate change (unit = percentage point).

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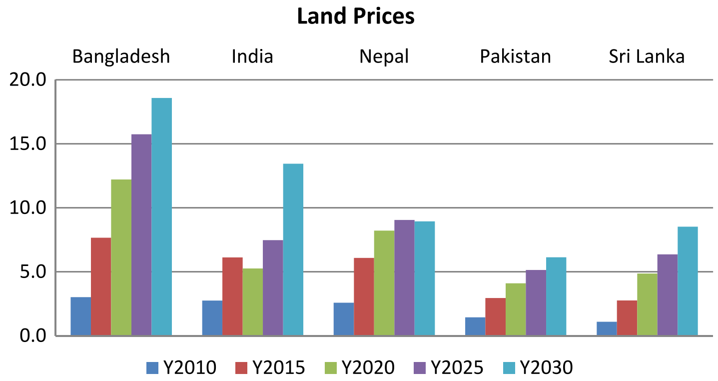

Fig. 7. Deviation of land prices from baseline in South Asia under climate change (unit = %). Note: all prices are deflated by CPI.

In the GTAP framework, firms are assumed to have zero profits. Because tax policies were not changed in our simulation, the changes to taxes (driven by changes in national income and sectoral outputs) were not relevant.[5] As such, we focused on the first three terms of the GDP identity (Eq. (1)). Furthermore, because the supplies of land, natural resources and labour are fixed at the national level it is sufficient to investigate the real prices of land and resources (that is, rents), real wages, and the real price and use of capital (that is, interests). Our results suggest that, given the adverse impact of climate change on agriculture, more land will be demanded for crop production which is likely to drive up regional real prices of land (see Fig. 7). On the other hand, the increase in land prices is expected to significantly lower regional real wages (see Fig. 8) with Nepal in particular likely to experience a 10% reduction in real wages by 2030. Unskilled labour is expected to be more severely affected than skilled labour, although the difference is likely to be small. Similarly, the real prices of natural resources and capital are predicted to drop due to the loss of agricultural productivity (see Figs. 9 and 10). In particular, this is likely to lead to less capital use in South Asia (see Fig. 10). Again, Nepal is likely to be the most affected among these countries. Overall, the simulation results show that the increase in land rents is expected to be overwhelmed by the drop in wages and capital interests,[6] leading to a lower level of national income in all these countries.

Another way of measuring GDP is by the expenditure approach, which states:

$$\text{GDP} = \text{Consumption} + \text{Public Spending} + \text{Investment} + \text{Net Export}. \tag{2}$$

As a result of reduced national income, private consumption of these South Asian countries is predicted to be 0.5%–3% lower than the baseline as of 2030 (see Fig. 11). Similarly, public spending is likely to decline by roughly 1%–5% (see Fig. 12). The third element of GDP in Eq. (2), that is investment, is predicted to decline between 2% and 10% (Fig. 13). Our results thus suggest a progressive pattern of impacts on private consumption, public spending and investment, as a result of climate-induced food productivity changes. In terms of net exports, the results were quite mixed and insignificant (see Fig. 14). The simulation suggested[7] that only India and Pakistan are likely to be running a trade surplus from 2015 to 2030. However, it was predicted that these two countries are likely to see their net exports shrinking in 2030 due to climate change, and Bangladesh, Nepal and Sri Lanka are likely to be continuously in trade deficit. Over time, our simulation results suggest that these countries' deficits will be reduced; however this is likely to be due to their sluggish domestic demands, as has been shown in Fig. 11.

The impact of climate change on food production is likely to spread to the rest of the economy in each of the five South Asian countries, though there is no consistent pattern in the sectoral results (other than agricultural sectors) with the exception of the services sectors. As shown in Fig. 15, the sectoral results of our simulation unambiguously indicate that while services sectors in all South Asian countries are likely to be affected by the climate change-induced productivity changes in agriculture, manufacturing sectors only in India and Pakistan are likely be affected. However, manufacturing sectors in the other three countries (Bangladesh, Nepal and Sri Lanka) are not predicted to be affected by the shock. Our results suggest that the mining sector is likely to grow in all of these countries (see the top panel of Fig. 15).

5. Concluding remarks

This study evaluated the impact of climate change-induced crop productivity loss on food production and food security, particularly focusing on five large countries in South Asia. As discussed in the previous section, the simulation results of this study demonstrated that agricultural sectors in five large South Asian countries were predicted to be adversely affected

5 Detailed simulation results are available upon request from the authors.

6 This is mainly because land rents account for less than 10% of the national value added in South Asia.

7 The simulation results are not shown in the paper but are available upon request from the authors.

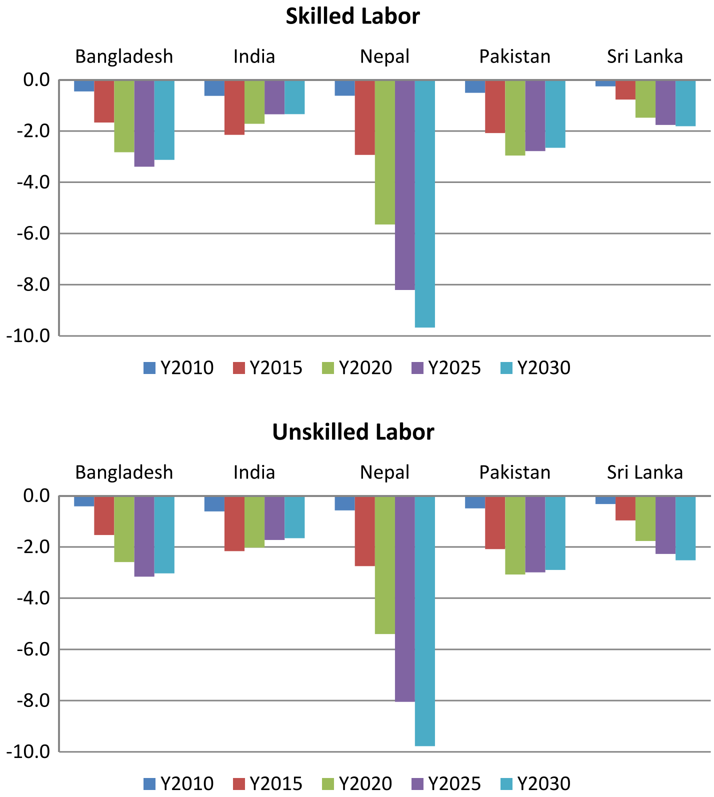

Fig. 8. Deviation of real wages from baseline in South Asia under climate change (unit = %). Note: all prices are deflated by CPI.

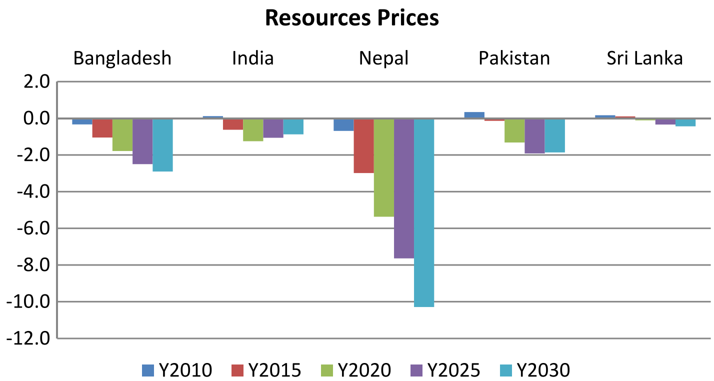

Fig. 9. Deviation of resource prices from baseline in South Asia under climate change (unit = %). Note: all prices are deflated by CPI.

by the climate changed-induced productivity changes leading to a food shortage by 2030. As a result, food prices are likely to increase creating food security concerns. Our simulation results further indicated that GDP in all five large South Asian countries was predicted to decline as the agricultural sector plays an important role in terms of contribution to GDP and employment generation.

Overall, our results are consistent with previous studies. In almost all countries in South Asia, with a few exceptions related to some crops, food production as of 2030 is expected to decline by up to 4%, 11% and 7% for rice, wheat and cereal grains, respectively, due to climate change-induced land productivity change compared with the baseline food production. This is comparable to Hertel et al. (2010)'s medium-scenario estimate for rice (−5% from the baseline), low-scenario estimate for wheat (−10% from the baseline), and medium-scenario estimate for cereal grains (−10% from the baseline). Climate-induced reduction in food production is projected to put pressure on food prices and food security in the region. The prices of rice, wheat and other grains are expected to rise at significantly high rates (up to 10%, 25% and 45% higher than in the baseline for rice, wheat and cereal grains, respectively), which is again comparable to the estimates of Hertel et al. (2010)

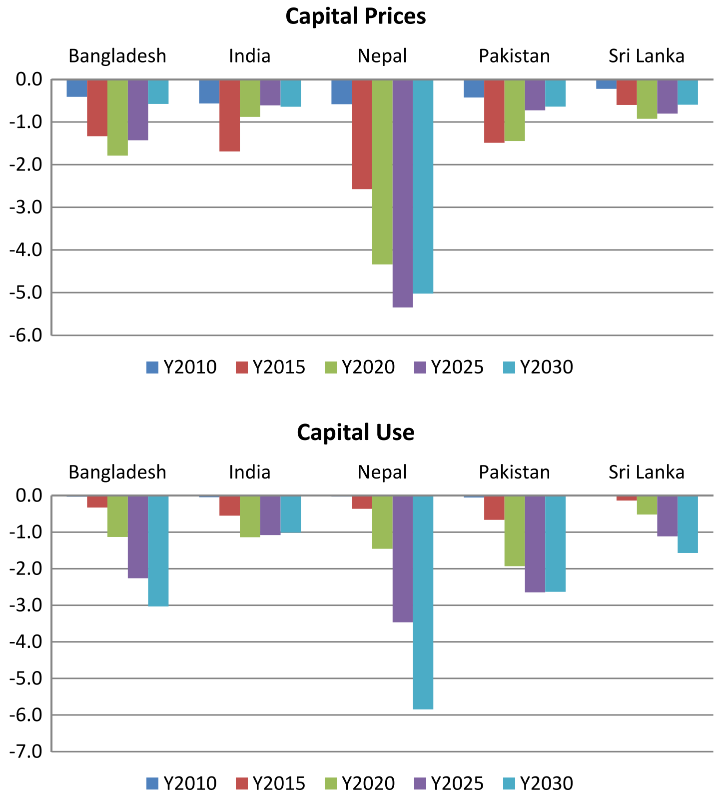

Fig. 10. Deviation of capital prices and capital use from baseline in South Asia under climate change (unit = %). Note: all prices are deflated by CPI.

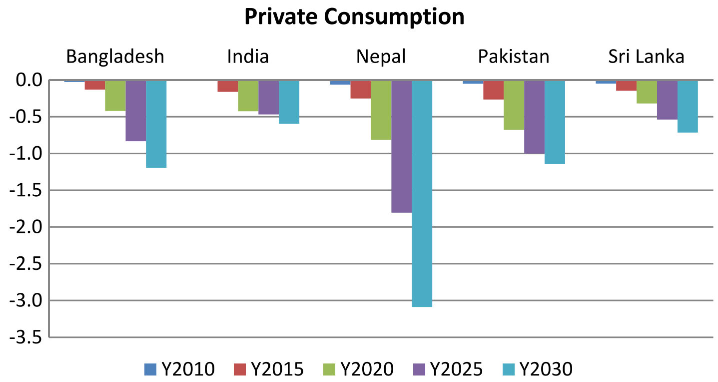

Fig. 11. Deviation of private consumption from baseline in South Asia under climate change (unit = %).

which found global prices to rise over 20% for rice, nearly 10% for wheat and over 60% for cereal grains from the their baseline projection. The simulation results of our study indicate that regional consumption of rice, wheat and cereal grains is also expected to decline from the baseline by 0.5%–5% in 2030 as a result of higher food prices and reduction in food production. Our results, therefore, support Lobell (2010)'s advocacy for the need to prioritise climate change adaptation for food security. Finally, GDP is projected to decline in all five South Asian countries as a result of projected decline in agricultural output from the baseline and its spill-over effects on the rest of economies. This is within the ranges of estimates that are reviewed by the IPCC (2007, 2013).

Drawing on the simulation results of this study, it is important to highlight the key policy implications related to climate change and food security. Although current economic growth and policies contribute to a reduction in poverty and vulnerability in South Asia, the simulated analysis in our study demonstrates that the region is likely to face a high degree of vulnerability by 2030 as a result of predicted climate-induced changes in crop productivity. As a result policy makers in the region are likely to face significant challenges in reducing poverty through high economic growth and addressing predicted issues of food security in the coming years.

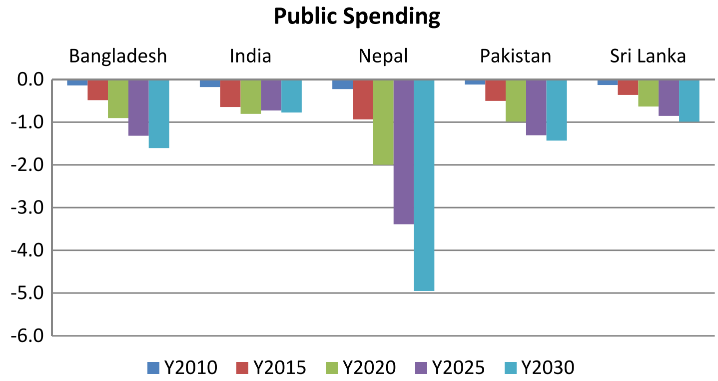

Fig. 12. Deviation of public spending from baseline in South Asia under climate change (unit = %).

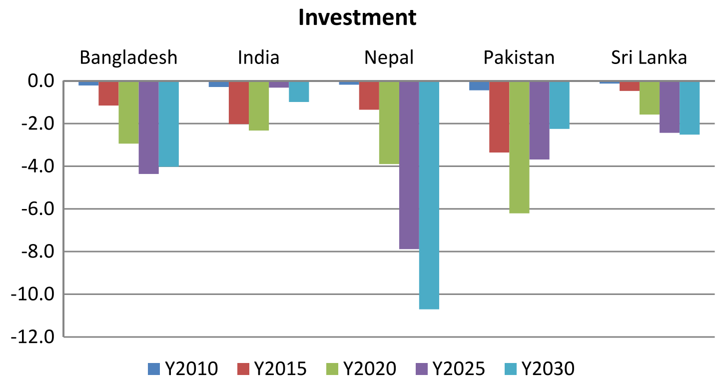

Fig. 13. Deviation of investment from baseline in South Asia under climate change (unit = %).

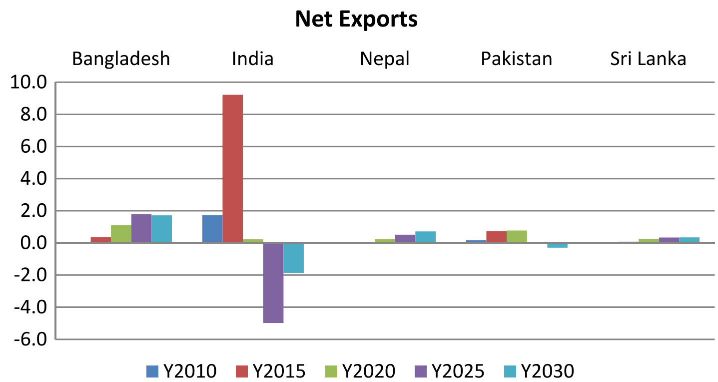

Fig. 14. Deviation of net exports from baseline in South Asia under climate change (unit = Billion US$).

It is important that forthcoming policies focus on the formulation of climate change adaptation in the South Asia region. As suggested by previous studies, these policies include major investments in infrastructure in the agricultural sectors, improved land use rotations, changes to crop planting seasons and the development of new varieties of crops that are resistant to high temperature and droughts (Sivakumar and Stefanski, 2011; World Bank, 2013). It is likely to be advantageous if these adaptation policies are implemented within a broader framework of a climate risk management strategy, which includes the identification of climate change-induced crop yield changes and a willingness to use adaptation strategies. Furthermore, the success of these adaptation strategies is likely to be increased if they become not only a central or local government respon-

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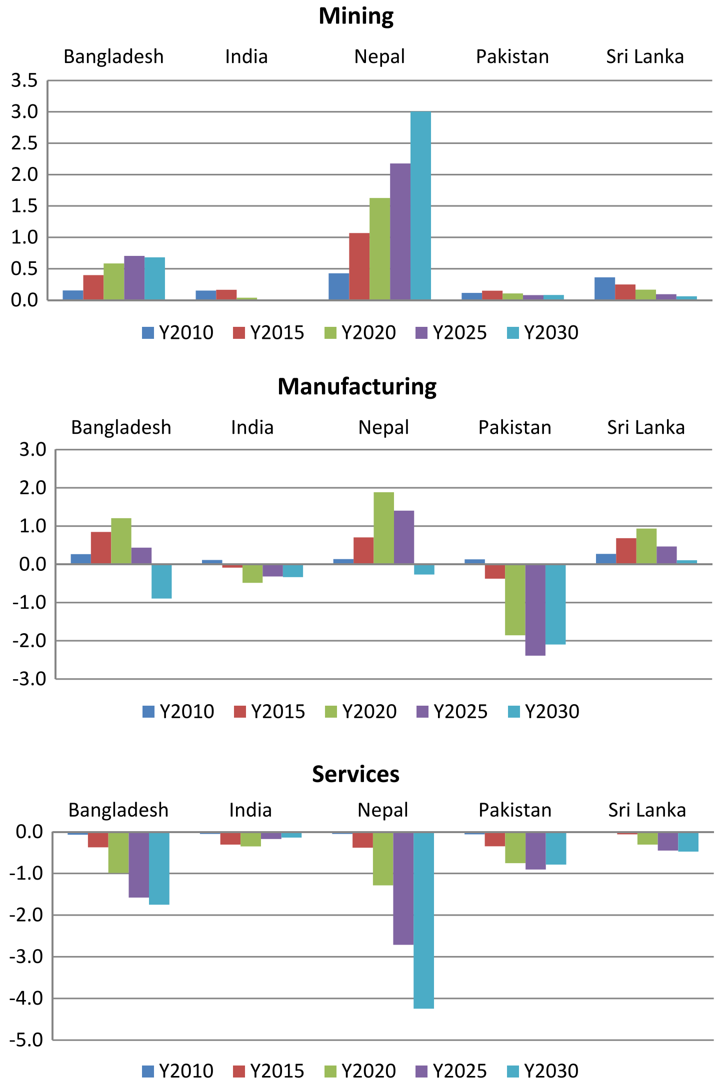

Fig. 15. Deviation of sectoral output from baseline in South Asia under climate change (unit = %).

sibility, but also a responsibility of individuals, civil societies and business communities. This will mean that an improved awareness of the impact of climate change on food production and food security and the need to adopt adaptation strategies within the broader community will be key development considerations.

It is necessary to highlight the limitations of our study. As stated by the World Bank (2012, p. xiv), "uncertainties remain in projecting the extent of both climate change and its impacts". First, our study only focused on the three staple food crops in South Asia. There are, however, other food crops that are important in terms of food security. Second, our modelling exercise did not incorporate climate change adaptation policies such as the development of new varieties of crops, land use switching, changes to planting seasons, investment in irrigation infrastructure and flood mitigation strategies. Therefore, the details and techniques of climate change models and the GDyn model used here are likely to improve in their sophistication over time when these aspects of climate change adaptation policies and strategies are incorporated in the analysis of climate change effects. Even with the above limitations, however, the results of our study that considered the three food staples provided evidence that serious policy planning and implementation of adaptation strategies in the near future is required to help reduce the study's predictions of the detrimental impact of climate change on food production, food prices and food security.

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Appendix A. Summary of key observed past and present climate trends and variability in five main South Asian countries.

Country	Change in temperature	Change in precipitation
Bangladesh	Increasing trend of about 1 °C in May and 0.5 °C in November from 1985 to 1998	Decadal rain anomalies above long term averages since 1960s
India	0.68 °C increase per century with increasing trends in annual mean temperature and warming more pronounced during post-monsoon and winter	Increase in extreme rains in northwest during summer monsoon in recent decades and lower number of rainy days along east coast
Nepal	0.09 °C increase per year in Himalayas and 0.04 °C in the Terai region with more in winter	No distinct long-term trends in precipitation records for 1948–1994
Pakistan	0.6–1.0 °C increase in mean temperature in coastal areas since early 1900s	10%–15% decrease in coastal belt and hyper arid plains and increase in summer and winter precipitation over the last 40 years in northern Pakistan
Sri Lanka	0.016 °C increase per year between 1961 and 1990 over entire country and 2 °C increase per year in central highlands	An increase trend in February and decrease trend in June

Source: Adapted from Sivakumar and Stefanski (2011, p. 17) and is based on Cruz et al. (2007).

Appendix B. Inter-period land productivity change in South Asia under climate change (unit = %).

		Y2010	Y2015	Y2020	Y2025	Y2030	Cum.
Rice	Bangladesh	−0.7	−1.1	−1.1	−1.1	−1.1	−5.0
	India	−1.8	−3.0	−3.0	−3.0	−3.0	−13.0
	Nepal	−0.3	−0.4	−0.4	−0.4	−0.4	−2.0
	Pakistan	0.9	1.5	1.5	1.5	1.5	7.0
	Sri Lanka	0.1	0.2	0.2	0.2	0.2	1.0
Wheat	Bangladesh	−1.8	−3.0	−3.0	−3.0	−3.0	−13.0
	India	−1.8	−3.0	−3.0	−3.0	−3.0	−13.0
	Nepal	−1.8	−3.0	−3.0	−3.0	−3.0	−13.7
	Pakistan	−0.9	−1.5	−1.5	−1.5	−1.5	−6.9
	Sri Lanka	−1.8	−3.0	−3.0	−3.0	−3.0	−13.0
Cereal grains	Bangladesh	−2.4	−4.0	−4.0	−4.0	−4.0	−17.0
	India	−2.4	−4.0	−4.0	−4.0	−4.0	−17.0
	Nepal	−2.4	−4.0	−4.0	−4.0	−4.0	−17.0
	Pakistan	−2.4	−4.0	−4.0	−4.0	−4.0	−17.0
	Sri Lanka	−2.4	−4.0	−4.0	−4.0	−4.0	−17.0

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