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An Analysis of Adaption Policies to Climate Change: Gdyn-W Model

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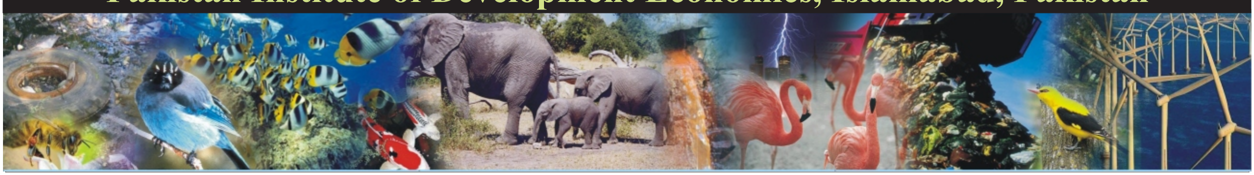

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C O N T E N T S

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ABSTRACT

This paper develops a dynamic CGE-Water (Gdyn-W) model to analyse the effectiveness of adaptation policies to climate change. In the model, water is introduced as an explicit primary factor of production used for irrigation purposes. For empirical analysis, we employ the latest GTAP database version 9 focusing on the South Asian countries: Bangladesh, India, Nepal, Pakistan and Sri Lanka. Our simulation results revel that the domestic production in all the countries under analysis decreases after the temperature rises by 1 °C until 2040. However, such production losses can be reduced greatly by the adaptation policy to climate change. The costs associated with such a policy are marginal compared to the overall benefits from such a policy.

JEL Classification: C68, Q15, Q25
Keywords: Water, CGE, Irrigation, Adaptation Policy, Climate Change

1. INTRODUCTION

Many countries are pursuing adaptation policies to encounter the detrimental effects of climate change. However, there is no dynamic computable general equilibrium (CGE) water model available that could analyse the dynamics of regional adaptation policies to climate change in the long-run. Only three static GTAP-Water (GTAP-W) models are available in the mainstream literature to date. Berrittella, *et al*. (2007) introduce the first static GTAP-W model, where water is an exogenous endowment. It assumes no substitution between water endowment and other primary factors of production. This paper analyses the impact of restricted water supply on the trade patterns of agriculture.

Calzadilla, *et al*. (2011) introduce the second static GTAP-W model. It assumes substitution possibility between water endowment and other primary inputs. It examines irrigation water efficiency by increasing irrigation efficiency by 73 percent for all crops. Taheripour, *et al*. (2013) develop the third static GTAP-W model, which distinguishes between the rainfed and irrigated agriculture by employing different production functions. Taheripour, *et al*. (2016) use this model to analyse the impact of water efficiency on South Asian countries by increasing water efficiency by 40 percent.

All these static CGE-Water models mentioned above ignore the element of time, and it is hard to evaluate the effectiveness of adaptation policies to climate change overtime using a static model. Our dynamic CGE-Water (Gdyn-W) model has several advantages over a static CGE-Water model. First, increasing water efficiency overtime in a dynamic CGE model is more realistic than a one-time huge efficiency increase in a static CGE model. Second, the Gdyn-W model portrays a new investment behaviour under a regional adaptation policy scenario. Third, all of the above-mentioned CGE-Water models simulate adaptation strategies without considering any climate change scenario. In the absence of a climate change scenario, it is not possible to quantify the effectiveness of an adaptation policy. Therefore, we first introduce a climate change scenario, then we analyse the effectiveness of adaptation strategies to climate change.

One exception to the above-mentioned literature is Robinson and Gueneau (2013). It develops a dynamic CGE-Water model for Pakistan to evaluate the adaptation policy to climate change. This is the only dynamic CGE-Water model available to date. However, its application is quite limited. This model is unable to compare the effectiveness of various adaptation policies in different countries because it is a single country model.

To fill all these gaps in the literature, we develop the Gdyn-W model. More specifically, we link the static GTAP-W model [Calzadilla, *et al*. (2011)] with a dynamic GTAP-Energy (GTAP-E) model [Golub (2013)]. It combines all the features of mitigation policies from the dynamic GTAP-E model and adaptation policies from the GTAP-W model in a single model.

The Gdyn-W model is a multi-sector, multi-region recursively dynamic CGE model. It distinguishes between irrigated and rainfed agriculture. Water is introduced in the model as an explicit primary factor of production used for irrigation purposes. The new production function allows substitution between irrigation water and other primary factors. It sets a time path for the global economy, irrigation agriculture, CO_2 emissions, and incentives to invest in various regions.

Furthermore, the dynamic GTAP-E model links a dynamic CGE model [Ianchovichina and McDougall (2001)] and a static CGE-Energy model [Burniaux and Troung (2002); McDougall and Golub (2007)]. The latter is specifically introduced for energy and mitigation policy analysis. It allows energy substitution in production and consumption and examines CO_2 emissions from fossil fuel burning and the global carbon emission trading. Hence, our dynamic CGE-Water model can be used to analyse global adaptation and mitigation policies to climate change in the short-run and long-run.

The rest of the paper is as follows: section II reviews the mainstream literature on recent adaptation policies to climate change. Section III discusses the theory behind our dynamic CGE-Water model and section IV describes our simulation design and data developed for this research work. Simulation results are provided in section V and finally, section VI concludes this paper.

2. ADAPTATION POLICY TO CLIMATE CHANGE

Industrial development has caused a rapid increase in GHG emissions leading to rising average surface temperature worldwide. It has also affected the key hydrologic variables, mainly precipitation and evaporation [IPCC (2014)]. Changes in temperature and precipitation have important significance for the irrigation water such as water quantity applied, irrigation timing, and the existing supply of water for irrigation [Frieler, *et al*. (2014)]. It is anticipated that climate change would result in major rainfall and temperature variations along with rising droughts and floods [Rosegrant, *et al*. (2014)].

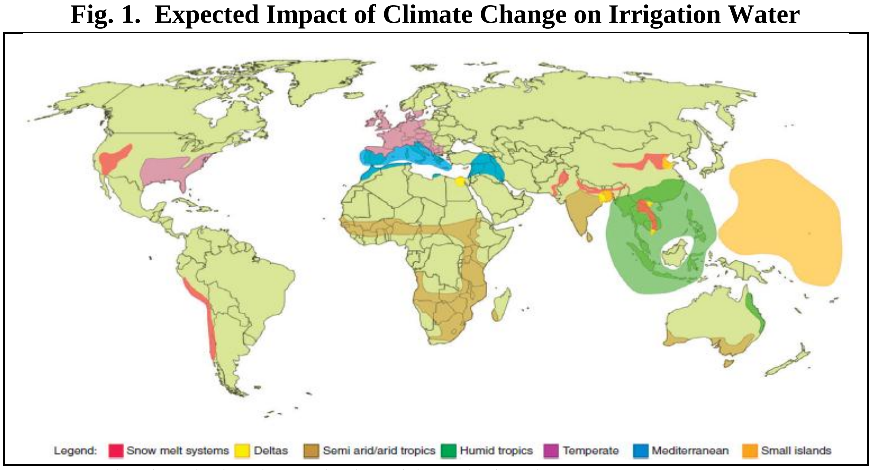
The above-mentioned factors are directly related to the crop production, which is adversely influenced by the climate change [Lobell, *et al*. (2011)]. The main reason behind this factor is water scarcity in many countries around the world caused by the new climate trends [Fereres, *et al*. (2011)]. Agriculture is primarily dependent on irrigation water and rainfall, and both of these variables are tightly dependent on climate variability. However, irrigation efficiency is also one of the main adaptation strategies that can decrease the exposure to growing climate risks [Knapp and Huang (2017)].

The tangible effects of climate change demand serious actions. These actions are mitigation or adaptation policies to climate change. The former prevents GHG emissions (or cut their atmospheric concentration), while the latter helps to adjust to actual (or expected) climate effects [Klein (2011); Pielke, *et al*. (2007)]. Mitigation and adaptation strategies are mirror images [Yohe (2001)] or they can be considered as substitutable [Buob and Stephan (2011)]. Hence, mitigation and adaptation both are widely recognised as interconnected actions in addressing the climate change.

Adaptation to climate change is crucial to reduce the climate-related damages. It generates new options to tackle the rapid climate changes that are already occurring or expected in future [Lesnikowski, *et al*. (2016); Pearce, *et al*. (2011)]. There is a wide range of adaptation options such as better irrigation scheduling, new crop varieties, altering crop mix and finally improving irrigation efficiency [Howden, *et al*. (2007)]. At this point, it would be important to highlight the countries which are about to meet their irrigation water resource limits.

The IPCC (2014) states that global warming would change the structure of the freshwater system, affecting its availability and quality. Many countries are close reaching their water resource limits where agriculture is cultivated in large amounts, such as South Asian countries. Further, the typology proposed by FAO (2011) highlights the regions that would confront climate-related issues worldwide (Figure 1). More importantly, irrigation will be affected severely in South Asia where surface irrigation systems are mainly fed by snowmelt and glaciers [Cai, *et al*. (2015)]. However, a major challenge is how to model a regional adaptation policy to climate change in a research framework, which is discussed in the next section.

Fig. 1. Expected Impact of Climate Change on Irrigation Water



Source: Food and Agricultural Organisation of the United Nations [FAO (2011)].

3. DYNAMIC GTAP-WATER (Gdyn-W) MODEL

The Gdyn-W model is a multi-sector, multi-region, recursive dynamic CGE model which links the static CGE model [Calzadilla, *et al*. (2011)] and the dynamic GTAP-Energy model [Golub (2013)]. It is an extension of the standard static CGE based GTAP model [Hertel (1997)]. The new production function facilitates substitution possibilities between irrigation water and various other primary factors of production. It also distinguishes between the irrigated and rainfed land.

The standard GTAP model combines land with natural resources, while labour and capital-energy composite are in the value-added nest in the GTAP-E model. However, the GTAP-W model incorporates substitution possibility between irrigation land and irrigation water by employing a nested CES functional form. Further, the irrigable land-water nest is combined with the rainfed land, pasture land, natural resources, labour and capital-energy nest through a CES function.

The principal characteristic of the GTAP-W model belongs to its new production structure. Here, the land endowment is been divided into rainfed land, irrigated land and pasture land in the value-added nest. The rainfed land and irrigated land differ as the former is free but the irrigation development is expensive in the latter and yield per hectare is higher in the latter. Therefore, land prepared for irrigation is more valuable. Further, irrigated agriculture has been divided into the value of irrigation and the value of land.

In the production structure, irrigation water is combined with the value-added nest. Moreover, irrigation water is added to the irrigable land generating an irrigated land-water composite. This composite is further combined with other factors in the value-added nest using a CES function. As the basic land endowments are split into the rainfed land, irrigated land, pasture land, and irrigation water, our dynamic GTAP-W model provides discriminating as well as substituting irrigated and rainfed crop production (Figures 2-3).

The GTAP-W model employs the Walrasian (perfect competition) paradigm for the adjustment processes. In this paradigm, industries operate through a representative firm, maximising profits in the perfectly competitive markets. A series of nested CES (constant elasticity of substitution) functions specify the production functions. Domestic and foreign inputs are imperfect substitutes, the so-called Armington assumption. This allows the product heterogeneity among the world regions.

In this model, a representative consumer receives income (defined as service value of the national primary factors such as natural resources, rainfed land, irrigable land, pasture land, irrigation water, capital, and labour) in each region. The last two factors capital and labour are (perfectly) mobile domestically; however, they are immobile internationally. Rainfed land, irrigable land, pasture land, irrigation water and natural resources are imperfectly mobile across the agricultural sectors. The perfectly mobile factors can earn the same return in market irrespective of the place of employment. However, the market returns may differ for imperfectly mobile factors across various sectors.

Total income is spent on household and public consumption while the rest is saved. A Cobb-Douglas utility function is used to devote constant budget to domestically produced goods and imported commodities. The private consumption is divided into a composite of Armington aggregates. At this level, a CDE (constant difference in elasticities) functional form is used, which is a non-homothetic function. It accounts for the possible changes in income elasticities for various consumption goods. A measure of the economic welfare (equivalent variation) can be calculated from the model results. It measures the change in the overall welfare in a country after a policy change.

Fig. 2. Production Structure of Dynamic CGE-Water Model

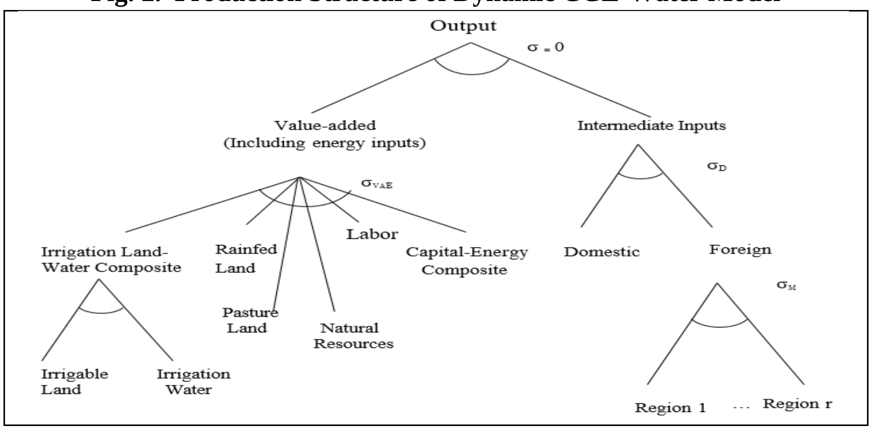
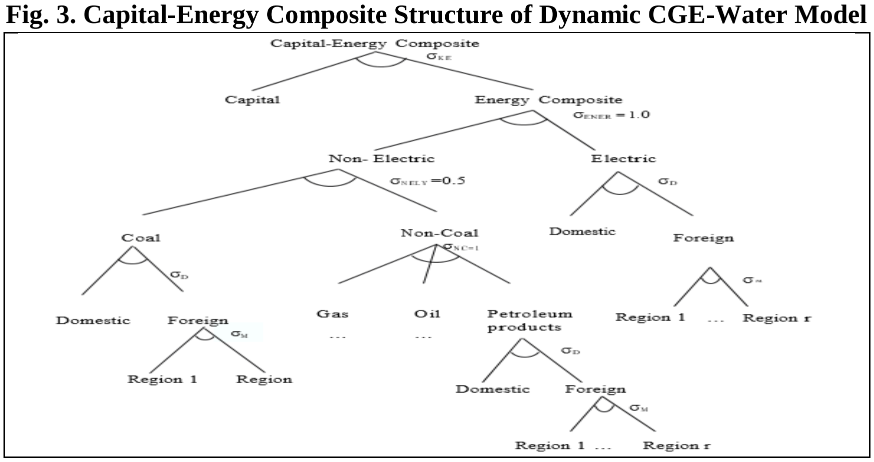


Fig. 3. Capital-Energy Composite Structure of Dynamic CGE-Water Model



Two industries are not related to any region in the GTAP model. The international transport industry produces the transportation services, such as the movement of goods worldwide. The transport services are formed from the factors submitted by each region but in different proportions. In the same fashion, a global bank gathers savings from various regions and it allocates various investments to achieve the expected rates of return at parity.

The theoretical structure of dynamic GTAP-Energy (GDyn-E) model includes all features of the standard dynamic GTAP (GDyn) model. It treats time as a variable, facilitates capital accumulation and provides a stylised representation of the financial assets and investment theory. A summary of all these features is described below. Ianchovichina and McDougall (2001) provide details of the theoretical structure in GDyn. Ianchovichina and Walmsley (2012) provide details of database structure and parameterisation of this model.

The main feature that differentiates the GDyn framework from all other dynamic CGE frameworks is its disequilibrium methodology to model the capital mobility. This approach facilitates the short-run and medium-run differences in the rates of return that can be eliminated in the long-run. That feature allows imperfect capital mobility among various regions in the short-run to medium-run and allows perfect capital mobility among regions in the long-run.

Financial assets in this model are treated in a highly stylised way. This treatment aims to represent global capital mobility without generating leaks in the foreign financial accounts. In the real world, there are many types of finical assets, however, this model comprises only one type of financial asset: equity. This asset indicates an indirect claim to a single physical asset: physical capital. In this model, firms can own physical capital; however, they rent other endowments from regional households such as land and natural resources. Hence, regional households own these endowment resources and lease them to firms [Ianchovichina and McDougall (2001)].

As capital is mobile worldwide, regional households own equity in the firms across all regions. This procedure requires bilateral data on assets and liabilities held worldwide. However, Ianchovichina and McDougall (2001) introduce a global trust serving as a monetary intermediary for all global investment. This global trust reduces the data requirement on global assets and liabilities. Regional households cannot own equity in foreign firms; however, they can hold it in the global trust and local firms. Therefore, the total wealth of the regional household comprises equity in the global trust and in local firms.

4. SIMULATION DESIGN AND DATA DESCRIPTION

South Asian countries are dependent on irrigation water that is generated by melting snow from glaciers (Figure 1). This water is used as an input in agriculture and changing climate conditions are affecting its availability. The recent United Nations (2015) report states that the South Asian countries might face water shortage by 40 percent in near future. In this section, we define our simulations to examine the climate change effects on economy along with the adaptation strategy.

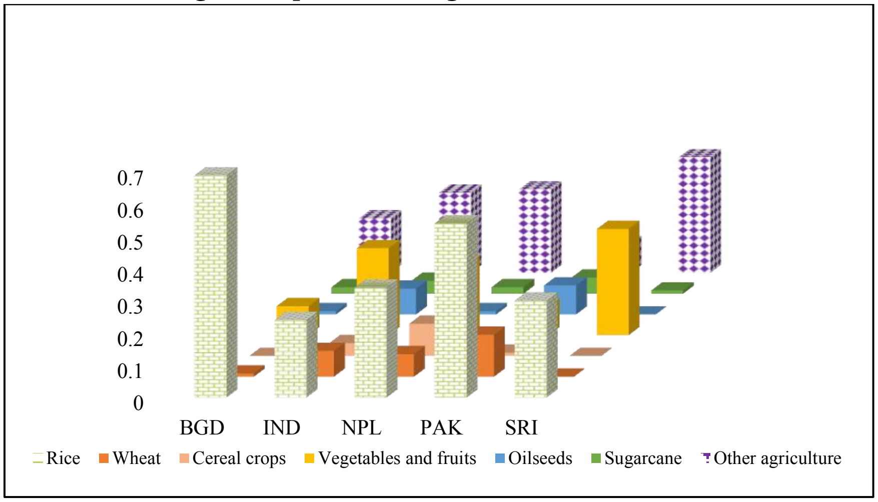
We run three simulation scenarios in this paper. In scenario 1, we introduce a climate change scenario where rising temperature is an indicator of climate change. Under this simulation, we increase temperature by 1 °C till 2040. In scenario 2, we increase irrigation water efficiency by 40 percent till 2040. In scenario 3, we simulate the first and second simulations simultaneously to examine how effective our adaptation strategy to climate change is.

Various data sources are used to run these simulations. The IPCC (2014) offers estimates of changes in various crops' productivity and distinguishes these crops from tropical and temperate regions. A region type such as temperate or tropical is linked to its latitude, assuming a reference tropical area that has a central latitude of 0° at the equator and the reference temperate region that has a central latitude of almost 40° (North or South). It is assumed that the change in agricultural crop yield ranges in a linear function from its baseline point at equator up (or down) to the position at 40° latitude and beyond. Following these steps, Roson and Sartori (2016) estimate changes in crop productivity at different temperature levels using the latest GTAP database version 9, base year 2011. We obtain the data of South Asian countries from Roson and Sartori (2016).

IPCC (2014) reveals that increasing global temperature also raises the sea level, affecting the land through erosion. This phenomenon is generated by glaciers' melting and many other factors. The IPCC (2014) indicates a positive relationship between the SLR and rising global mean surface temperature. We use the data of the loss of productive land endowments provided by Roson and Sartori (2016) for a 1°C increase in temperature. Finally, the data of irrigation water, irrigation land and rainfed land are generated following Calzadilla, *et al.* (2011). We use the GTAP database version 9 for this purpose. A detailed sectoral aggregation is provided in the appendix.

Agriculture plays an important role in South Asian's economic development because of its high share in GDP (Gross Domestic Production). Our database shows that its share in the GDP is 15.1 percent in Bangladesh, 17.5 percent in India, 33.1 percent in Nepal, 25.2 percent in Pakistan and 8.3 percent in Sri Lanka. Crop structure in South Asian countries is quite different depending on the availability of irrigation water and the market demand for these crops. For instance, rice, vegetables and fruits are considered the key crops in Bangladesh; wheat, vegetables, fruits and oilseeds are main crops in India; wheat, rice, cereal crops, vegetables and fruits are cultivated mainly in Nepal; wheat, rice, oilseeds, vegetables and fruits are the key crops in Pakistan; and rice, vegetables and fruits are the main crops in Sri Lanka (Figure 4).

Fig. 4. Crop Shares in Agricultural Production

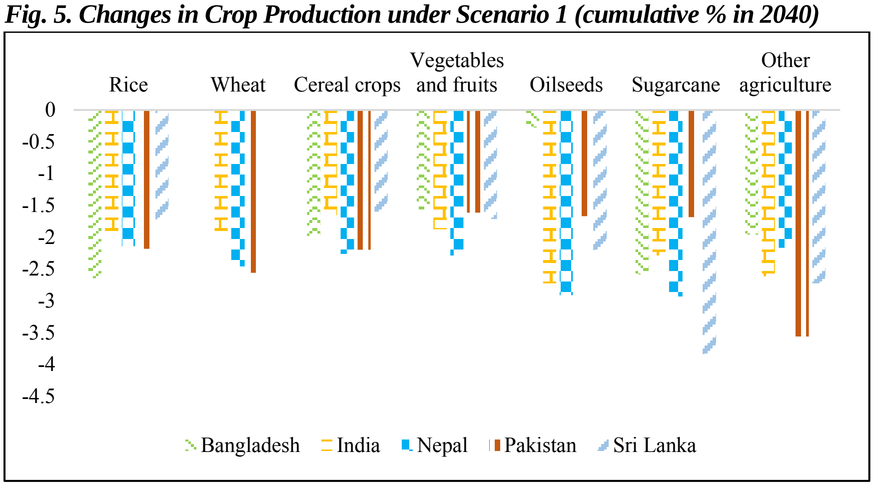


Source: GTAP Database Version 9, Base Year 2011.

5. SIMULATION RESULTS

Our simulation results show that the production of all the crops reduces after the temperature increases by 1°C in the scenario 1. In Bangladesh, production of rice and sugarcane is affected severely compared to other crops. In India, rice and oilseeds crops are more vulnerable to climate change while other crops are more resilient to such changes. In Nepal and Sri Lanka, the output of oilseeds and sugarcane reduces the most whereas rice and wheat crops are more sensitive to climate change compared to other crops in Pakistan (Figure 5).

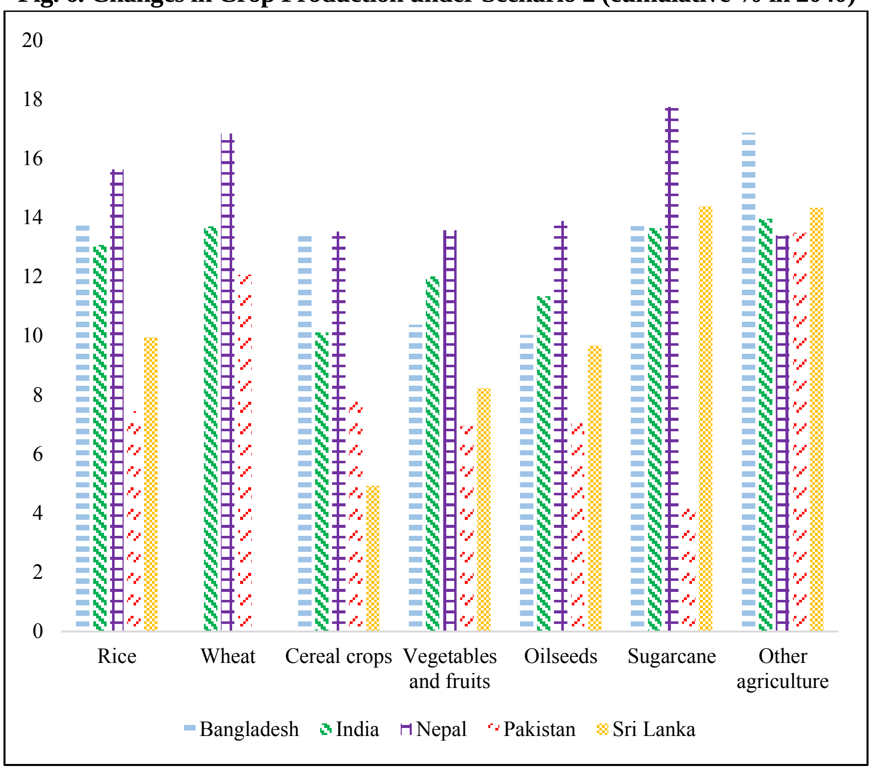
Fig. 5. Changes in Crop Production under Scenario 1 (cumulative % in 2040)



Source: Authors' calculations.

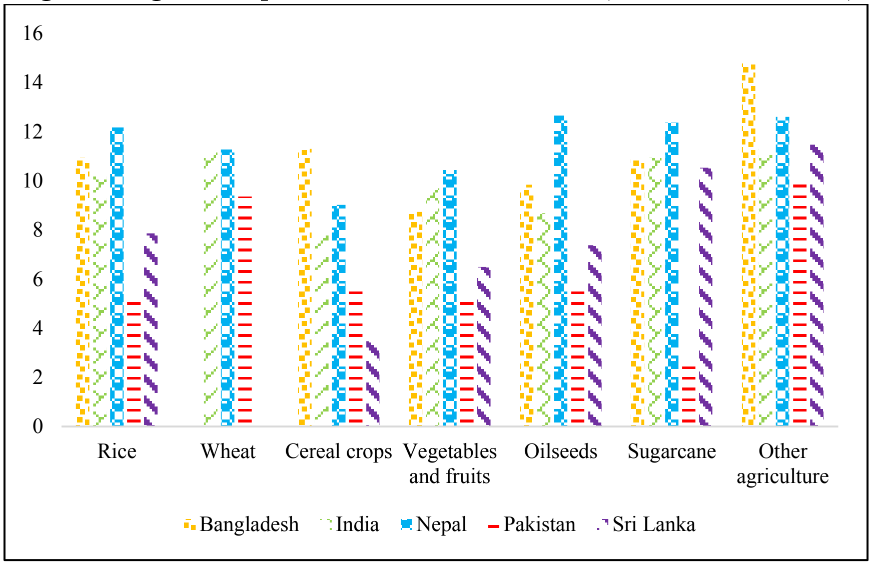
Although the impact of climate change is negative on all the crops, however, its harmful effects can be reduced through an effective adaptation strategy. We implement our adaptation strategy in the scenario 2 where the irrigation efficiency increases by 50 percent till 2040. This policy compensates for the negative production losses originating from rising temperature. The yield of all the crops goes up as a result of this policy shock (Figure 6). Our simulation results reveal that Nepal takes most of the benefits from such an adaptation strategy to climate change as its produce of rice, wheat, cereal crops, vegetables, fruits, oilseeds, and sugarcane grows the most compared to other South Asian countries. In Bangladesh and India, the crop production of rice and sugarcane rises more than other crops. Output of wheat and rice cops upswings in Pakistan while the crop yield of rice and sugarcane grows in Sri Lanka more than other crops. Finally, crop production falls down slightly under the scenario 3 compared to the scenario 2 but it still remains positive (Figure 7). It indicates that our adaptation policy can effectively encounter the negative effects of climate change. However, we argue that the impact of such policy varies by country.

Fig. 6. Changes in Crop Production under Scenario 2 (cumulative % in 2040)



Source: Authors' calculations.

Fig. 7. Changes in Crop Production under Scenario 3 (cumulative % in 2040)



Source: Authors' calculations.

Climate change has the potential to affect the non-agricultural sectors of an economy as well. Our simulation results demonstrate that escalating temperature under the scenario 1 lessens the output of most of the non-agricultural sectors in the South Asian countries (Table 1). The rising temperature shrinks the production in the livestock, energy (coal, oil, gas, oil products) and energy intensive industry in most of the countries under analysis. However, growing gas production in Bangladesh and Nepal indicate that dependence on gas is increasing in these countries. Further, the output of meat products increases in Bangladesh, Pakistan, and Sri Lanka showing that the meat market is growing bigger than the agricultural crop market.

After implementing the adaptation policy under scenario 2, we discover that production of most of the non-agricultural sectors turns positive (Table 2). In fact, agricultural and non-agricultural sectors are strongly connected through the backward and forward linkages, and this connection affects their productivity simultaneously. In addition, water savings through efficient irrigation system can provide extra water to non-agricultural sectors boosting their productivity.

The scenario 3 highlights that some of the benefits of our adaptation policy to climate change are reduced because of the simultaneous increase in temperature (Table 3). Our simulation results show that output of many sectors slightly diminishes in the scenario 3 compared to the scenario 2. Nonetheless, it confirms that the adaptation policy can encounter the negative production losses emerging form the rising temperature.

Table 1

Changes in Non-agricultural Production under Scenario 1 (cumulative % in 2040)

Sector/Country	Bangladesh	India	Nepal	Pakistan	Sri Lanka
Animals	–2.33	–2.50	–2.37	–5.46	–0.75
Meat products	6.74	–1.11	–1.79	0.63	12.26
Processed food	–2.97	–2.70	–3.25	–2.92	–3.33
Forestry	–0.67	–0.13	–0.18	–0.44	–0.16
Fishing	–1.29	–0.48	–3.86	–0.18	–0.37
Coal	–7.21	–5.21	–0.63	–4.43	–3.39
Oil	–0.01	0.09	0.33	–0.06	–0.11
Gas	2.58	–0.04	0.01	–0.06	0.00
Oil products	–3.12	–3.40	–4.87	–1.91	–2.04
Electricity	–3.34	–4.77	–2.30	–1.91	–2.24
Water	–2.40	0.10	–1.13	–1.82	–0.46
Energy intensive industry	–1.66	–4.21	–1.24	–2.68	–6.30
Other industries	–13.27	–6.35	–2.99	–9.44	–2.68
Market services	–2.64	–4.32	–1.54	–2.63	–1.45
Non-market services	1.89	2.55	–2.34	0.29	–0.05

Source: Authors' calculations

Table 2

Changes in Non-agricultural Production under Scenario 2 (cumulative % in 2040)

Sector/Country	Bangladesh	India	Nepal	Pakistan	Sri Lanka
Animals	11.38	13.95	10.93	17.20	2.95
Meat products	–15.39	6.93	9.14	–6.47	–30.79
Processed food	14.32	14.27	18.28	9.87	12.76
Forestry	1.79	0.14	–0.47	0.88	0.63
Fishing	3.06	0.61	21.21	0.46	0.51
Coal	19.12	13.54	–3.07	10.93	5.98
Oil	0.03	–0.77	–1.88	0.09	0.17
Gas	–11.67	–0.63	–0.01	0.13	0.00
Oil products	12.27	13.67	21.85	6.16	5.52
Electricity	11.81	15.67	4.03	6.49	5.36
Water	8.34	0.68	6.60	5.05	1.38
Energy intensive industry	5.49	8.74	–10.20	7.05	18.49
Other industries	42.52	15.81	–2.37	29.75	1.48
Market services	9.22	16.37	6.25	7.18	3.05
Non-market services	–7.25	–6.53	12.30	–1.41	–0.07

Source: Authors' calculations.

Table 3

Changes in Non-agricultural Production under Scenario 3
(cumulative % in 2040)

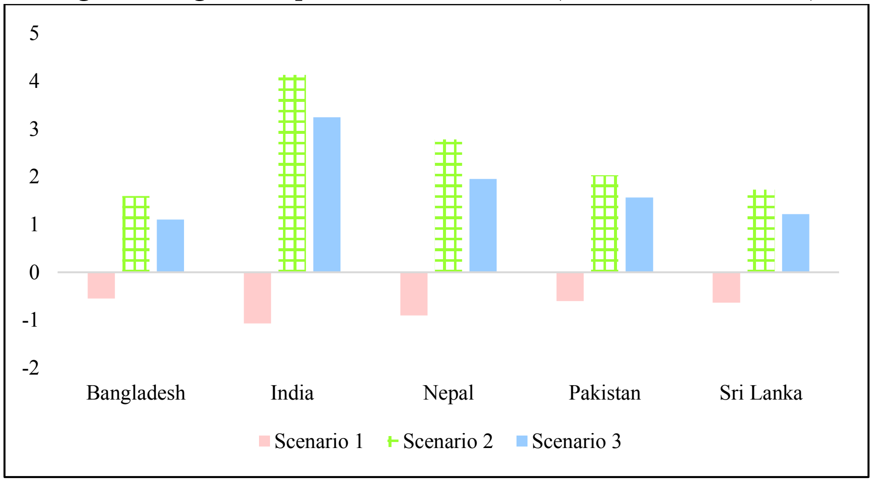
Sector/Country	Bangladesh	India	Nepal	Pakistan	Sri Lanka
Animals	9.06	11.41	7.81	11.29	2.05
Meat products	–10.36	4.72	7.34	–5.36	–23.41
Processed food	11.02	10.89	13.73	6.68	9.01
Forestry	1.24	–0.06	–0.26	0.62	0.24
Fishing	2.14	0.12	12.82	0.28	0.20
Coal	18.79	9.48	–1.30	6.71	3.60
Oil	0.02	–0.65	–1.42	0.05	0.09
Gas	–8.51	–0.55	–0.01	0.08	0.00
Oil products	9.01	10.12	13.97	4.17	3.88
Electricity	8.23	11.48	2.79	4.38	3.56
Water	5.90	0.14	3.88	3.03	0.70
Energy intensive industry	4.14	5.88	–5.60	4.47	12.46
Other industries	27.16	11.09	1.16	19.37	0.08
Market services	6.48	12.06	3.67	4.49	1.90
Non-market services	–5.22	–5.24	6.38	–1.66	–0.11

Source: Authors' calculations.

Higher investment level is an indicator of economic development and vice versa. There are many channels through which investment can move globally and there is a dire need to identify such channels to boost the investment level in South Asian. Insufficient investment is a bigger challenge for the South Asian countries as this region has the potential for huge climate-related investment projects.

Level of investment and expected rate of return are positively related in any economy. A higher expected rate of return is an indicator of the higher level of investment as investors would prefer such a country which promises them a higher return on their investments. Our simulation results reveal that the expected rate of return falls down in the South Asian countries under scenario 1. It reduces the most in India by 1.06 percent while it decreases by 0.54 percent in Bangladesh, 0.9 percent in Nepal, 0.59 percent in Pakistan and 0.62 percent in Sri Lanka (Figure 8). In contrast, it surges to the highest level in India (4.1 percent) among the South Asian countries under scenario 2. In addition, the expected rate of return increases by 1.5 percent in Bangladesh, 2.7 percent in Nepal, 2.0 percent in Pakistan and 1.7 percent in Sri Lanka. It remains positive under the scenario 3 but with a small drop in its value compared to scenario 2 indicating the positive significance of the adaptation policy to climate change.

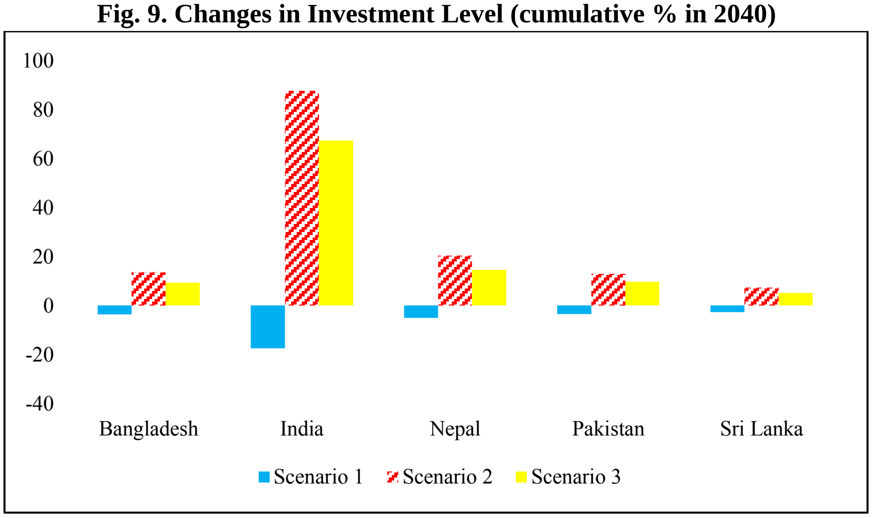
Fig. 8. Changes in Expected Rate of Return (cumulative % in 2040)



Source: Authors' calculations.

When investors notice that expected rate of return is turning down under the scenario 1, the level of investment also reduces in all the South Asian countries (Figure 9). This situation might persist if a country ignores a policy response in such a situation. However, after introducing the adaptation policy, the investment starts coming back to all the South Asian countries under scenario 2 and scenario 3. The scenario 3 reveals that the level of investment rises by 67.3 percent in India, 14.5 percent in Nepal, 9.7 percent in Pakistan, 9.3 percent in Bangladesh and 5 percent in Sri Lanka till 2040 compared to the base year 2011.

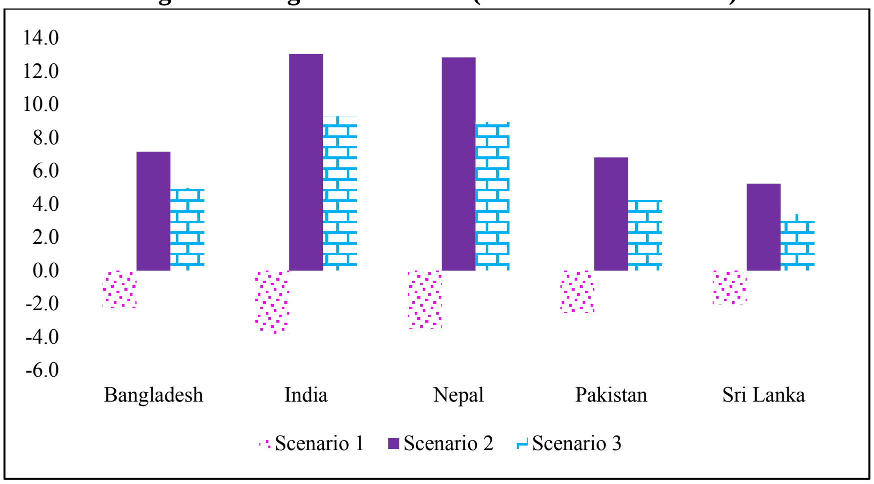
Fig. 9. Changes in Investment Level (cumulative % in 2040)



Source: Authors' calculations.

The overall economic performance can be evaluated by examining the GDP of South Asian countries. As these countries are heavily dependent on agriculture, changes in crop production have important implications for the level of economic development in these countries. We observe that the GDP of Bangladesh, India, Nepal, Pakistan and Sri Lanka shrinks by 2.3 percent, 3.8 percent, 3.5 percent, 2.6 percent and 2.1 percent, respectively, under the scenario 1 (Figure 10). However, such negative developments can be confronted by the adaptation policy to climate change under scenario 2. The simulation results reveal that the GDP of the South Asian countries grows by 7.2 percent, 13 percent, 12.8 percent, 6.8 percent and 5.2 percent, respectively, in this scenario. This economic progress remains positive under the scenario 3 however the level of economic activity falls down in this case compared to the scenario 2.

Fig. 10. Changes in real GDP (cumulative % in 2040)



Source: Authors' calculations.

6. CONCLUSION AND DISCUSSION

The previous CGE-Water models are unable to evaluate the effectiveness of adaptation policies to climate change in a dynamic environment. Our multi-country dynamic CGE-Water model fills this gap in the literature. It portrays a new investment behaviour under a global adaptation policy scenario. Further, the previous CGE-Water models simulate adaptation strategies without considering any climate change scenarios. We also address this shortcoming in this paper.

Through our simulation results, we observe that the production of agricultural and non-agricultural sectors decreases after the temperature rises by 1 °C until 2040. This is a common phenomenon for all the South Asian countries. However, such production losses can be minimised by implementing an adaptation policy to climate change. We find that irrigation efficiency is an important adaptation policy to climate change. An improved irrigation system reduces crop production losses, attracts more investment and reduces GDP losses. However, it is important to discuss the costs associated to such irrigation efficiency.

Our irrigation cost estimates are based on Sauer, *et al*. (2010) as our dynamic CGE model does not calculate such costs directly. Sauer, *et al*. (2010) provide capital costs along with the operation and maintenance costs. The operation costs are based on energy and labour whereas the maintenance costs are fixed at 3 percent of the related capital costs for a basin irrigation system and 5 percent for any other irrigation scheme. Field application efficiency is nearly 60 percent for surface irrigation, around 75 percent for sprinkler irrigation and around 90 percent for drip irrigation. Hence, a country pays for its new and better efficient irrigation system.

The costs of our adaptation policy to climate change differ by crop type, area under cultivation and region. Such costs are high for rice, sugarcane, vegetables and fruits in Bangladesh and Sri Lanka; wheat, oilseeds, vegetables and fruits in Pakistan and India; and wheat, cereal crops, vegetables and fruits in Nepal. The total cost of increasing irrigation efficiency is USD 74.5 million for Bangladesh, 1,619.9 million for India, 37.3 million for Nepal, 18.2 million for Pakistan and 28.1 million for Sri Lanka (Table 4).

Table 4

Costs of Increasing Irrigation Efficiency (USD million in 2040)

Sector/Country	Bangladesh	India	Nepal	Pakistan	Sri Lanka
Rice	4.7	16.8	0.7	0.6	0.3
Wheat	0.7	91.6	2.4	3.7	0.0
Cereal crops	0.0	33.8	2.8	0.2	0.0
Vegetables and fruits	16.0	605.9	13.8	3.3	9.5
Oilseeds	1.8	174.3	0.7	3.6	0.0
Sugarcane	2.1	45.6	0.7	0.5	0.2
Other agriculture	49.2	651.9	16.1	6.4	18.1
Total	74.5	1,619.9	37.3	18.2	28.1

Source: Authors' calculations based on Sauer, *et al.* (2010).

Globally, 70 percent to 75 percent of fresh water is used for irrigation purpose. However, a major part of this water is lost while transporting it from canals to the fields. Low irrigation efficiency makes us unable to reach our full agricultural potential. Climatic change and with the increasing population have increased irrigation demands, generating a worldwide water stress. An efficient use of irrigation water would ease such socio-environmental burdens.

7. POLICY RECOMMENDATIONS

The short-term solution to encounter the water shortage is efficient use of water. It can be achieved by increasing the scale of high efficiency irrigation systems (HEISs), and by recovering (or increasing) the irrigation water rents (Abiana). Construction of new water reservoirs can be the long-term solution to solve the water shorting problem in a country. Country-specific policy implication are more useful than general regional policy implications. Given that many countries in South Asia face the similar issues, the policy implications for once country can be generalised for other countries under analysis. The following paragraphs discuss the short-run solutions for Pakistan in detail.

The HEISs such as drip irrigation and other related schemes are already operational in Pakistan. A notable work is the World Bank's project "Punjab irrigated-agriculture productivity improvement project (PIPIP)". It spans over a time period of 9 years (2012-13 to 2020-21), and aims to install the HEISs on 120,000 acres. The government of Pakistan is providing around 60 percent subsidy of the total amount while the remaining 40 percent of the total cost is paid by the farmers. Increasing the scale of such projects all over the country would bring the water efficiency.

Abiana rates are the highest in Balochistan province, followed by Khyber Pakhtunkhwa (KPK), Sindh and Punjab. The average Abiana collection is almost 60 percent of the total assessed amount. Further, the canal irrigation system is financially unsustainable in Pakistan as only 24 percent of the operating and management costs are recovered. The provincial governments contribute rest of the money as a subsidy to finance the gap between the rising operating and management costs and stagnated Abiana rents. Recovery of full Abiana rents can be the first step towards the efficient irrigation system. The rising Abiana price would make farmers use water efficiently.

APPENDIX

Table A 1.

Sectoral Aggregation

S. N.	Sectors	57 Sector of GTAP Database Version 9
1	Rice	Paddy rice
2	Wheat	Wheat
3	Cereal crops	Cereal grains nec
4	Vegetables and fruits	Vegetables, fruit, nuts
5	Oilseeds	Oilseeds
6	Sugarcane	Sugar cane, sugar beet
7	Other Agriculture	Plant-based fibers; Crops nec; Raw milk; Wool, silk-worm cocoons
8	Animals	Bovine cattle, sheep and goats, horses; Animal products nec
9	Forestry	Forestry
10	Fishing	Fishing
11	Coal	Coal
12	Oil	Oil
13	Gas	Gas; Gas manufacture, distribution
14	Meat	Bovine meat products; Meat products nec
15	Processed food	Vegetable oils and fats; Dairy products; Processed rice; Sugar; Food products nec; Beverages and tobacco products
16	Other industry	Textiles; Wearing apparel; Leather products; Wood products; Paper products, publishing; Manufactures nec; Machinery and equipment nec; Electronic equipment; Transport equipment nec; Metal products; Motor vehicles and parts
17	Oil products	Petroleum, coal products
18	Energy-intensive industry	Minerals nec; Chemical, rubber, plastic products; Mineral products nec; Ferrous metals; Metals nec
19	Electricity	Electricity
20	Water	Water
21	Market services	Construction; Trade; Transport nec; Water transport; Air transport; Dwellings; Defense; Education; Health; Recreational and other services; Business services nec; Insurance; Financial services nec; Communication
22	Non-market services	Public administration

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