

Economic and Land Use Impacts of Improving Water Use Efficiency in Irrigation in South Asia

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Abstract

This paper modifies and uses an advanced computable general equilibrium model coupled with biophysical data on land and water resources by Agro-Ecological Zone (AEZ) at the river basin level to examine the economy-wide consequences of improvements in water use efficiency (WUE) in irrigation in South Asia. This is the first time the benefits of such improvements have been evaluated in an economy-wide context. It shows that such improvements increase production of food items, enhance food exports, and significantly improve food security in South Asia. Improvement in water use efficiency also leads to lower food prices, provides the opportunity to extend irrigated areas, decreases demand for cropland, and enhances reforestation. Improvement in water use efficiency in irrigation also generates important net GDP gains across the South Asia region. Investments in improved WUE of up to 40% can be economically justified in Bangladesh, India, and Sri Lanka. However, in Nepal, for an improvement of more than 20% in WUE, the economic gains are smaller than costs from the associated investments. In Pakistan and rest of South Asia, an improvement in WUE of up to 30% appears to be economically profitable.

Keywords

General Equilibrium, Water Use Efficiency, Economy Wide Impacts, Irrigation, Land Use Change, South Asia

1. Introduction

It is widely acknowledged that the economies of South Asia will face major water chal-

allenges over the coming decades [1]-[3]. Population growth coupled with economic growth will significantly extend the demand for water in these economies, in particular for irrigation where water use efficiency (WUE) is very low¹. Of course, with no further improvement in water use efficiency, these economies will also need considerable investment to expand their water supply to meet the growing demand for water². However, several studies have argued that it is possible to satisfy the growing demand for water (and land as well) by improving WUE in irrigation and other uses of water (e.g. [4]-[6]). While several papers have addressed the potential for improved WUE in South Asia [7] [8] [9] [10] [11], to the best of our knowledge, no one has yet examined the extent to which WUE could affect macro-economic outcomes, production, food security, and trade in these economies.

The share of agriculture in the Gross Domestic Product (GDP) of the South Asian countries is relatively large (e.g. 16% in Bangladesh, 19% in India, 32% in Nepal, 12% in Pakistan, and 21% in Sri Lanka in 2011). In addition, crop production in these countries relies heavily on irrigation. The share of irrigated cropland in total cropland was 40% in South Asia in 2011. The corresponding figure for the rest of the world was 17% in this year. India alone produces 18.5% of irrigated crops worldwide, while controlling 24% of the global irrigated land in 2011. The existing literature shows that the gap between actual and potential crop yields is quite large in South Asia. For example, a recent study conducted by the World Bank [6] indicated that the attainable wheat and paddy rice yields are twice their actual yields in many of India's states. Any yield improvement could help to use water and land resources more efficiently by increasing the "crop per drop" of water. In summary, any improvement in WUE or crop yield could generate significant gains in the GDP of these countries.

Although WUE can be improved in both agricultural and non-agricultural activities, improvements in irrigation have a greater potential in this region, since irrigation is massively used in South Asia. There are two ways to increase WUE in irrigation: (a) improvements in the delivery of irrigation water to the crop, and (b) improvements in the utilization of water by the plant, once it has been delivered. Both are quantitatively important. In a comprehensive study, McKinsey & Company found that WUE could be improved significantly in Asia [5]. Their study shows that the demand for water in India will be about 1498 billion cubic meters in 2030 and that about 756 billion cubic me-

¹There are two different but related concepts that refer to efficiency of water used in irrigation. The first one refers to the ratio between water that actually transpires by crops and water withdrawal for irrigation. This is the usual definition of water use efficiency (WUE). The second concept refers to crop yields per volume of water withdrawal for irrigation. This is referred to as Water Productivity (WP). These two concepts represent two sides of the same coin. Several studies have shown that WUE is low in South Asia, regardless of the method and year of estimation. For example, Seckler *et al.* [13], Rohwer *et al.* [14], and Frenken [15] estimate the overall WUE in irrigation in South Asia to be below 40% in many countries. For instance, according to Rohwer *et al.* [14] WUE in the early 2000s was 38% in Bangladesh, India and Nepal, 29% in Pakistan and 55% in Sri Lanka. Several papers also have shown that WP in South Asia compared to other regions is also low (for example, see Cai and Rosegrant [16]). Note also that the concept of WUE is subject to debate [17]. A portion of water lost in irrigation systems could flow back to the river, recharge the aquifers, or be captured and reused. So the ratio of WUE may underestimate the efficiency of irrigation systems.

²Even with additional investment, it is hard to extend water supply in many regions in South Asia where water resources are already stressed due to over exploitation.

ters of this demand can be met by saving in irrigation water at reasonable costs. In addition, in a recent policy guideline published by Ministry of Water Recourses of India [12], the Government of India has committed to the implementation of conservation policies to improve WUE across all uses 20% by 2017.

As stated above, this paper contributes to the existing literature by assessing the economy-wide implications of WUE in South Asia within an advanced computable general equilibrium (CGE) framework, linked to biophysical data on land and water resources. We organize land use by Agro-ecological zone (AEZ) in each river basin and identify water use by river basin. This allows us to examine: 1) the economy-wide consequences of improved WUE in South Asia; 2) the extent to which enhanced WUE can increase food production and improve food security in South Asia; and 3) how WUE alters demand for irrigated land and affects land use across South Asia. By employing several alternative scenarios to cover a wide range of WUE rates in irrigation under alternative assumptions on the required capital costs to improve WUE in irrigation we are able to offer insights into the relative costs and benefits of improved WUE in South Asia.

2. Model

The modeling framework used in this paper is an extension of the GTAP-E model [18] [19] which is a static model and allows substitution among energy inputs. It assumes energy and capital are substitutable inputs in economic activities, except for primary energy sectors such as gas, coal, and oil. In a series of modifications (including but not limited to Keeney and Hertel [20], Birur *et al.* [21], and Taheripour *et al.* [22]) land by AEZ, biofuels, and biofuels by-products were introduced in this model to make it suitable to study the economic and environmental impacts of biofuel production and policies. The new model has been labelled “GTAP-BIO” and is widely used to examine the consequences of biofuel production at the global scale (examples are: Hertel *et al.* [23], Tyner *et al.* [24], Taheripour *et al.* [25], and Beckman *et al.* [26]). More recently it has been modified to track supplies of, and demands for, land and water resources within a country at a spatial resolution of a river basin (RB) by AEZ level at the global scale and to take into account competition for water across its alternative uses [27] [28] [29]. The fundamental dataset in which the Input-Output tables of various countries are reconciled with international trade, tariff, domestic support, energy and agricultural datasets, is GTAP data Base, documented in Narayanan *et al.* [30]. The model developed due to this set of modifications is nicknamed GTAP-BIO-W³. This model carries all properties, characters, and validations of the GTAP standard, GTAP-E, and GTAP-BIO models and their parameters as mentioned above. It traces demand for and supply of water by country at RB-AEZ level and takes into account competition for water across agricultural and non-agricultural uses. In what follows we explain the major aspects of this model.

³Our database represents countries by river basins at the global scale. However, in this research an aggregated version of this database is used to focus on the economies of South Asia.

Figure 1 represents the GTAP-BIO-W approach in allocating primary inputs including labor, capital, resources, land and water. In this model competition for labor, capital, and resources takes place at the national level. This means that firms compete for these primary inputs only at that level.

In **Figure 1** the competition for these endowments occurs within the green box which represents a national economy including several river basins. Sectors take labor, capital, and resources from the national pool. Labor and capital are, as usual, mobile inputs. This means that these endowments move freely across uses. Following the standard GTAP model, land, water, and other resources are modeled as sluggish endowments. This means that they cannot move easily across sectors.

Competition for water takes place at the RB level. As shown **Figure 1**, a given national economy may have several river basins. In each river basin water has two main uses. A portion goes for irrigation and the rest goes for other purposes. As shown in **Figure 1** each river basin may serve several AEZs. So AEZs within each RB compete for irrigation (see the blue box). The GTAP-BIO-W model also represents available managed

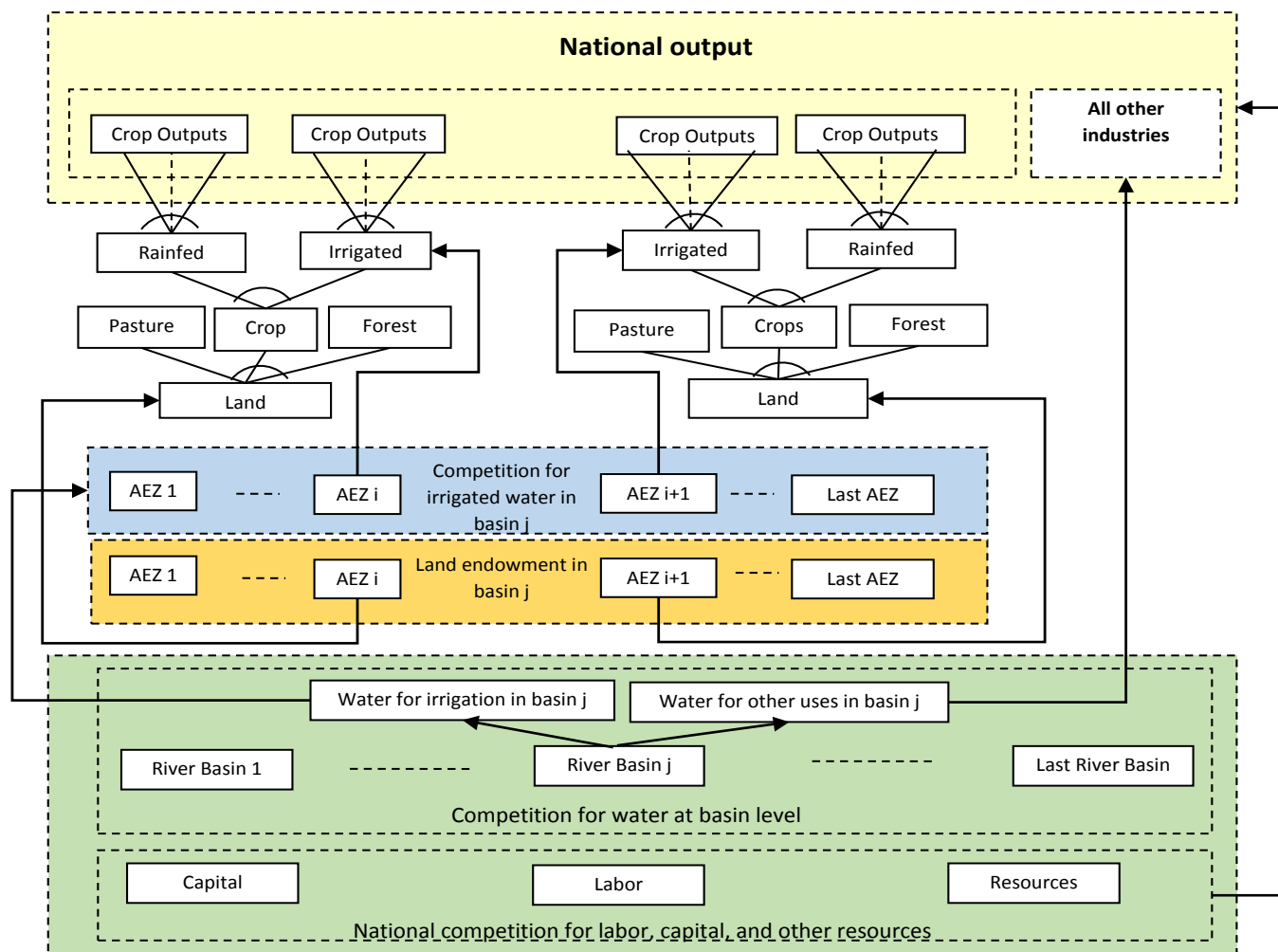


Figure 1. Structure of the GTAP-BIO-W static model.

land at the RB-AEZ level. In each RB-AEZ the area of available managed land is divided between forest, pasture and cropland, as shown in **Figure 1**. Then irrigated and rainfed crops compete for cropland. Land, of course, cannot move across RB-AEZs. The irrigated crop producers compete for managed water in each RB at the AEZ level. This means that competition for water for irrigation also takes place at the spatial resolution of RB-AEZ. Finally irrigated crops compete for irrigated cropland and rainfed crops compete for rainfed cropland. In this model water can move from one AEZ to another one in a river basin. A constant elasticity of transformation governs the movement of water across the AEZs of a river basin.

3. Experiments Undertaken

Using the GTAP-BIO-W model we conducted several experiments to examine the extent to which changes in WUE in irrigation affects economies of South Asia. Given the uncertainty in the extent to which the economies of South Asia can actually improve WUE in irrigation, four different levels of efficiency gains are considered: 10%, 20%, 30%, and 40%. Improvements in WUE were examined under two alternative cost assumptions. We first assumed that improvement in WUE is costless. While clearly unrealistic, this is useful in giving an upper bound on the value of the efficiency gains. Then, we developed four experiments which take into account the fact that improvements in WUE will require additional investment. There are several alternative methods for improving WUE, including: reduction in over-irrigation, no-till farming, optimizing fertilizer application rates, using systems of rice intensification, investing in improvements to the existing systems for water collection and conveyance, alternative wet and drying practices in rice production, using micro irrigation technologies (sprinkler and drip irrigation), along with a number of other options. Some of these methods (e.g. reduction in over irrigation, no till farming, optimizing fertilizer application rates) improve WUE at no or low costs. These are often termed “no-regrets options” as they appear to be beneficial in any case. However, the extent to which these no-regrets options policies contribute to WUE is limited. To save more water in irrigation higher cost technologies such as micro irrigation, advanced rice cultivation and irrigation methods, or improvement in water infrastructure are required.

Many papers have examined the costs, returns, and rate of improvement in WUE for a range of water saving technologies at the farm level ([7] [8] [9] [10] [11]). However, limited information at the national level is available in this area. McKinsey [5] has developed a stepwise water availability supply curve for India. This supply curve covers a wide range of alternative methods which can be implemented to save consumption of water or extend its supply. It shows that water supply (including saving in consumption of water) can be expanded in India by 756 billion cubic meters with a modest investment of \$5.9 billion-less than 0.8 cents per cubic meter saved. Given that the extent to which low costs methods could reduce water consumption is limited and that the advanced irrigation and cultivation methods are expensive, this figure seems very small. According to Palanisami *et al.* [10], the average costs of saving in water consumption

with sprinkler and drip irrigation systems were about 14 cents and 16 cents per cubic meter saved, respectively, for those farmers who installed these systems in 7 states of India prior to 2010. The corresponding cost in the McKinsey curve is less than 3 cents per cubic meter saved.

In a new research undertaken at the Massachusetts Institute of Technology, Winchester *et al.* [31] developed a set of stepwise irrigated land supply functions for major river basins across the world. These functions were introduced into a CGE model (EPPA) to examine the impact of water scarcity on food, bioenergy and deforestation at global scale. These supply functions show the costs of expansion in irrigated cropland due to water saving activities. Using the results of this research we developed a set of stepwise investment schedules which show required investment for four levels of 10%, 20%, 30%, and 40% improvement in WUE by country for South Asian economies (top panel of **Table 1**). For example, this table shows that on average WUE in irrigation can be improved by 10% in India at a cost of \$27 per hectare of irrigated cropland. To attain a 20%, 30%, and 40% improvement in WUE the average investment costs grow to \$63, \$142, and \$289 per hectare of irrigated land. These figures show that the average investment costs grow with an increasing rate as the level of improvement in WUE expands. The higher the level of improvement in WUE the higher the average investment costs per hectare. As shown in the top panel of **Table 1**, the investment costs per hectare vary across regions. India and Pakistan represent the lowest and highest cost schedules, respectively. We used these cost schedules and irrigated areas of each country to evaluate the capital requirements for each level of improvement in WUE at 2011 prices (bottom panel of **Table 1**).

This table indicates that the capital requirement for an improvement in WUE by 10% in Bangladesh, India, Nepal, Pakistan, Sri Lanka, and rest of South Asia are about \$212 million, \$2000 million, \$49 million, \$608 million, \$36 million, \$62 million. The size of capital requirement grows as desired improvement in WUE grows in each country and it depends on the size of the irrigated agricultural land and the required water saving technology. The largest capital requirements belong to India and the smallest to Sri

Table 1. Costs of improvement in water use efficiencies in South Asia by country at 2011 prices.

Description	Level of improvement in WUE	Bangladesh	India	Nepal	Pakistan	Sri Lanka	Rest of South Asia
Average costs for each level of improvement in WUE (\$/ha)	10%	31	27	33	35	41	35
	20%	74	63	78	83	96	83
	30%	167	142	176	186	216	186
	40%	340	289	358	380	440	380
Capital requirement for each level of improvement in WUE (million \$)	10%	212	2000	49	608	36	63
	20%	503	4735	116	1441	86	149
	30%	1132	10667	260	3245	193	336
	40%	2307	21736	531	6612	393	685

Lanka at each level of WUE, since these two countries hold the largest and smallest irrigated areas in South Asia.

We create, within the CGE model, a mechanism to finance these investment costs. In this mechanism, the public sector pays for the investment costs by reducing the existing electricity subsidy rates. In South Asia, consumption of electricity is highly subsidized. For instance, the electricity subsidies paid in Bangladesh, India, Pakistan, and Sri-Lanka were about 2.63%, 0.32%, 1.31%, and 0.47% of their respective total GDPs in 2011 [32]. Among all electricity users, agriculture usually pays the lowest tariff rates and receives the highest subsidy rates. The agricultural electricity tariff rates in Bangladesh, India, Nepal, Pakistan, and Sri Lanka were about 2.6 cents, 3.5 cents, 5 cents, 6.2, and 13.6 cents per kWh in 2011, respectively. The corresponding industrial tariff rates were about 5.4 cents, 11.3 cents, 9.5 cents, 10.3 cents, and 9.1 cents in 2011 [33]⁴. We estimate that the agricultural electricity subsidy rates⁵ in Bangladesh, India, Nepal, Pakistan, and Sri-Lanka were about 55%, 41%, 29%, 23%, and 11% in 2011. It is frequently argued that these subsidies encourage over consumption of electricity and water in agriculture. In our simulations it is assumed that the overall investment costs of improvement in WUE will be financed by a public loan (at a 5% annual interest rate) and the loan will be paid off in 15 years using the fiscal savings from reduced electricity subsidies paid to all electricity users⁶ during this time period.

The experiments introduced in this section are examined in a comparative static framework. In each experiment we impose the desired rate of improvement in WUE as an exogenous shock to the current economy. Then we compare the simulation results with the status quo conditions.

4. Results

4.1. Simulation Results If Improvement in WUE Is Costless

4.1.1. Impacts on Food Production and Imports

Food production goes up significantly in South Asia even with a 10 percent improvement in WUE, and it grows as efficiency improves (Table 2). With a 10 percent improvement in WUE, food production would increase annually by \$739 million (1.4%), \$7,887 million (1.2%), \$46 million (0.6%), \$1847 million (1.3%), \$81 million (0.3%), and \$214 million (2.2%) at 2011 constant prices in Bangladesh, India, Nepal, Pakistan, Sri Lanka, and rest of South Asia, respectively (Table 2).

With a 40 percent improvement in WUE, the corresponding figures would grow to \$2717 million (5%), \$26,426 million (4%), \$111 million (1.4%), \$6,102 million (4.4%), \$212 million (0.9%), and \$611 million (6.3) respectively (Table 2).

Now consider the impacts of improvements in WUE on the production of individual crops (Figure 2). Bangladesh, Pakistan, and rest of South Asia experience larger

⁴According to Jamil [33] this reference, the electricity tariff for agriculture where higher than the tariff for industry in Sri Lanka in 2000-2011.

⁵The subsidy rate is defined as the ratios of tariff paid by the final user over the production and distribution costs.

⁶It is assumed that the life time of installed equipment is also 15 years. If the equipment last more than 15 years, then there will some gains with no corresponding costs.

Table 2. Impacts of improvement in WUE on food production at constant 2011 prices (million \$).

Rate of Improvement in WUE	Food Item	Bangladesh	India	Nepal	Pakistan	Sri Lanka	Rest of South Asia
10%	Crops	453	4495	24	1512	20	111
	Livestock Products	57	827	7	11	4	20
	Processed food	229	2565	15	324	58	83
	Total	739	7887	46	1847	81	214
	% change over 2011	1.4	1.2	0.6	1.3	0.3	2.2
20%	Crops	891	8534	40	2919	30	205
	Livestock Products	111	1554	12	8	7	33
	Processed food	435	4731	27	539	101	147
	Total	1438	14819	79	3466	138	385
	% change over 2011	2.7	2.2	1.0	2.5	0.6	4.0
30%	Crops	1314	12180	48	4208	36	285
	Livestock Products	164	2199	15	-4	9	41
	Processed food	620	6583	36	689	134	194
	Total	2097	20961	100	4893	180	520
	% change over 2011	3.9	3.2	1.3	3.6	0.8	5.3
40%	Crops	1720	15479	52	5334	40	341
	Livestock Products	214	2774	18	-23	11	47
	Processed food	783	8174	41	791	161	223
	Total	2717	26426	111	6102	212	611
	% change over 2011	5.0	4.0	1.4	4.4	0.9	6.3

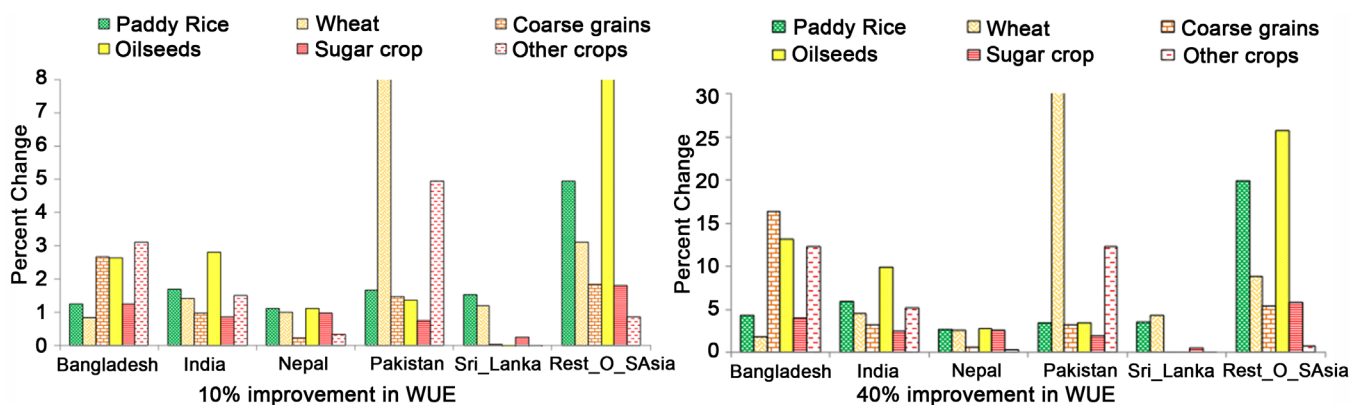


Figure 2. Impacts of improvement in water use efficiency on crop outputs in South Asia.

percentage changes in their crop outputs compared to India, Nepal and Sri Lanka. Outputs of all crops and in particular coarse grains, oilseeds, and other crops rise in Bangladesh. In India rice and oilseeds go up more than others. In Nepal, changes in crop outputs remain small, even at 40% improvement in WUE. Outputs of wheat and other crops are most responsive in Pakistan. In Sri Lanka only outputs of rice and wheat grow due to improvement in WUE. Finally, outputs of rice, wheat and oilseeds grow in rest of South Asia as shown by **Figure 2**.

The gap between the irrigated and rainfed crop yields helps to explain the observed variations in the regional impacts of WUE on crop outputs. An improvement in WUE saves water on existing irrigated land and that provides an opportunity to use a portion of the saved water to convert existing rainfed cropland to irrigated cropland. In these circumstances, the gain in crop production depends on the difference between the irrigated and rainfed crop yields. If the difference is not large, the expansion in crop production will be limited. However, if the difference is large, then crop production can grow significantly. In India, for example, the difference between the rainfed and irrigated yields are not large, on average. Hence, an improvement in WUE in this country generates moderate gains in crops outputs. However, in Bangladesh, Pakistan, and rest of South Asia where irrigation contributes more to crop yields, an improvement in WUE, generates larger changes in crops outputs. Notice that in areas where the gap between the rainfed and irrigated yields are large, water requirement is also large.

Expansion in crop supply due to improvements in WUE directly enhances the food security of South Asian countries, which is assumed to be a function of total supply of food, its reliability, and its price. However, improvement in WUE indirectly advances the food security of South Asia as well. As mentioned above improvement in WUE provides an opportunity to convert rainfed cropland to irrigated cropland. Given that irrigated crops are less vulnerable to the extreme weather conditions, expansion in irrigated crops enhances food security. The extent to which improvement in WUE enhances production of irrigated crop is shown in **Figure 3**, which represents changes in the market share of rainfed in total production of each crop due to improvement in WUE at 10% and 40% levels. For example, a 40% improvement in WUE decreases the market share of rainfed wheat in total production of wheat by 7.8%, 2.7%, 1.5%, 1.7%, 4%, and 19.2% in Bangladesh, India, Nepal, Pakistan, Sri Lanka, and rest of South Asia, respectively. The corresponding reductions for oilseeds are 8.2%, 14.6%, 6.2%, 23%, 0.01%, and 14.7%. One can see similar patterns for other crops as well. This line of enhancement in food security will be discussed in the next section when we analyze induced land use changes of improvement in WUE.

The expansion in food production due to improvement in WUE increases the net exports of food products (crops, livestock products, and processed food) from South Asia (**Table 3**). Improvement in WUE extends the net exports of food products of South Asian countries except for Sri Lanka. The net exports of food products of this country drops slightly at all levels of improvement in WUE. With a 10 percent improvement

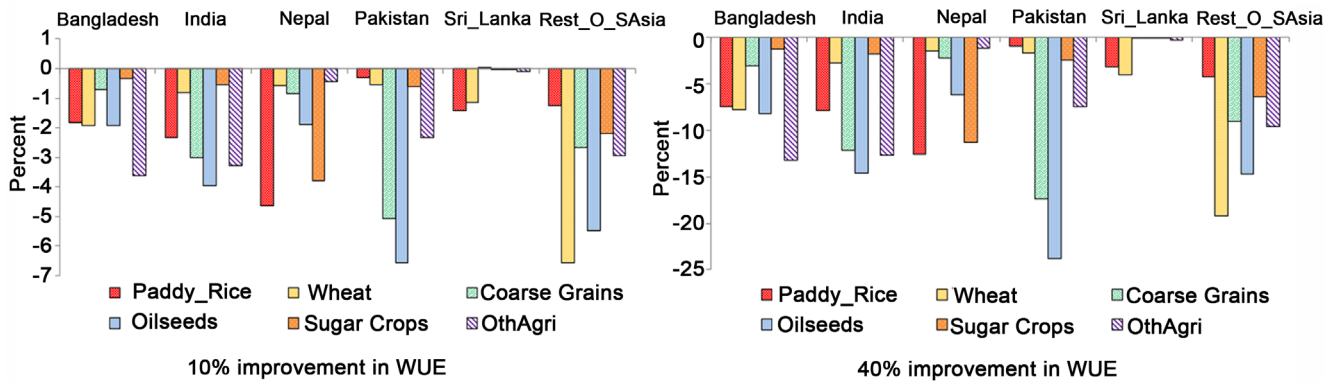


Figure 3. Reduction in the market shares of rainfed crops due to improvement in WUE.

Table 3. Impacts of improvement in WUE on net exports of food products at constant 2011 prices (million \$).

Rate of Improvement in WUE	Food Item	Bangladesh	India	Nepal	Pakistan	Sri Lanka	Rest of South Asia
10%	Crops	239	1144	9	1040	-24	47
	Livestock Products	-2	59	3	-37	-1	15
	Processed food	53	987	13	-206	12	74
	Total	290	2189	25	797	-13	136
20%	Crops	459	2179	14	1992	-41	85
	Livestock Products	-4	107	6	-67	-1	26
	Processed food	101	1808	23	-388	21	128
	Total	556	4094	43	1538	-21	239
30%	Crops	662	3118	16	2843	-54	118
	Livestock Products	-6	147	7	-91	-1	34
	Processed food	142	2500	29	-544	29	166
	Total	798	5765	53	2208	-26	317
40%	Crops	848	3974	17	3567	-64	140
	Livestock Products	-8	181	8	-110	-1	39
	Processed food	176	3087	34	-672	36	189
	Total	1017	7242	59	2784	-30	368

in WUE, the net exports of food products of Bangladesh, India, Nepal, Pakistan, and the rest of South Asia will increase by \$290 million, \$2189 million, \$25 million, \$797 million, and \$136 million at 2011 constant prices, respectively. The corresponding figures with a 40 percent improvement in WUE will be about \$1017 million, \$7242 million, \$59 million, \$2784 million, and \$368 million, respectively. These figures show that India, Pakistan, and Bangladesh could gain significantly in trade of food products, if

they use their water resources more efficiently. Of course expansion in food production and exports could positively affect rural income and living conditions in these regions.

4.1.2. Price Impacts

Improvement in WUE reduces the prices of food products in South Asia considerably. However, the price impact varies by region and food product⁷. For example, other factors being the same, a 40 percent improvement in WUE could reduce the price index of crops by 18.9% in Bangladesh, 12.4% in India, 11.1% in Nepal, 16.6% in Pakistan, 4.5% in Sri Lanka, and 17.3% in rest of South Asia (Figure 4). The rate of reduction in the price index of livestock products is smaller than the rate reduction in the crop price index in each region. With a 40% improvement in WUE the price index of livestock products drops by 11.4%, 5%, 7.7%, 1% and 8% in Bangladesh, India, Nepal, Sri Lanka, and Rest of South Asia, respectively. Unlike these countries, in Pakistan the price index of livestock goes up slightly by 2.3%. Improvement in WUE in irrigation encourages farmers to convert some pastureland to crop production in Pakistan and that negatively affect output of livestock industries, which leads to an increase in the price of livestock products. Finally, with 40% improvement in WUE the price index of processed food decreases by 5.2%, 6.1%, 10.4%, 2.9%, and 12% in Bangladesh, India, Nepal, Sri Lanka, and Rest of South Asia, respectively. The price index of processed food goes up slightly by 1.6% in Pakistan.

In conclusion, the positive impacts of improvements in WUE on food production plus its potential to lower food prices jointly contributed to improve food security in South Asia.

4.1.3. Land Use Impacts

As mentioned, improvement in WUE in irrigation reduces the rainfed harvested areas and increases irrigated areas. For example, a 10 percent improvement in WUE increases the areas of irrigated cropland by 3.9% (or 268 thousand hectares), 7.3% (or 5503 thousand hectares), 5.9% (or 87 thousand hectares), 3.1% (or 544 thousand hectares), 2.3% (or 20 thousand hectares), and 7% (or 126 thousand hectares) in Bangladesh, India, Nepal, Sri Lanka, and Rest of South Asia, respectively.

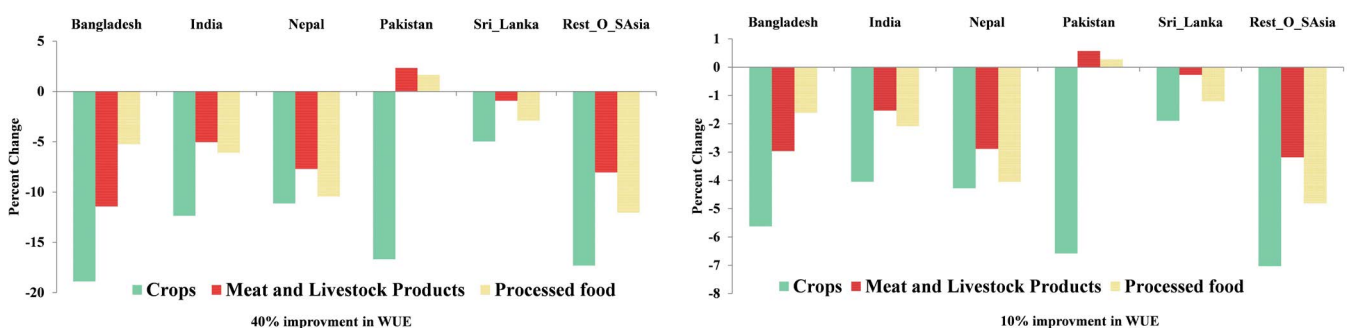


Figure 4. Impacts of improvement in water use efficiency on prices of food items in South Asia.

⁷The price index of primary factors is the numeraire in each region. Therefore all price changes are relative to this numeraire.

Nepal, Pakistan, Sri Lanka, and rest of South Asia (**Table 4**). The corresponding figures for 40% improvement in WUE are 16% (or 1086 thousand hectares), 28.5% (or 21,444 thousand hectares), 14.2% (or 210 thousand hectares), 12% (or 2085 thousand hectares), 5.1% (or 46 thousand hectares), and 24% (or 435 thousand hectares). These large expansions in irrigated areas could meaningfully improve the food security of South Asia against climate change.

Since irrigated areas are usually more productive than their rainfed counterpart, an improvement in WUE reduces demand for cropland and that generates some incentives for reforestation (expansions in forest and natural pasture land) across South Asia except for Pakistan (**Table 5**). For example, a 40% increase in WUE reduces demand

Table 4. Changes in irrigated and rainfed harvested areas due to improvement in WUE (1000 hectares).

Rate of Improvement in WUE	Irrigation Type	Bangladesh	India	Nepal	Pakistan	Sri Lanka	Rest of South Asia
10%	Irrigated area	267.6	5502.7	87.2	544.0	20.3	125.7
	Rainfed area	-326.2	-6193.1	-92.0	-556.0	-20.7	-138.0
	Total	-58.7	-690.4	-4.8	-11.9	-0.4	-12.3
20%	Irrigated area	533.2	11030.8	163.8	1083.3	32.8	250.1
	Rainfed area	-651.9	-12374.3	-171.5	-1084.3	-33.6	-270.9
	Total	-118.7	-1343.5	-7.7	-1.1	-0.8	-20.8
30%	Irrigated area	800.7	16363.4	203.9	1608.6	40.7	364.0
	Rainfed area	-981.1	-18325.0	-213.5	-1576.4	-41.8	-389.2
	Total	-180.4	-1961.6	-9.6	32.1	-1.1	-25.2
40%	Irrigated area	1085.8	21443.5	210.2	2084.7	45.9	434.7
	Rainfed area	-1330.0	-23988.8	-221.6	-1990.1	-47.2	-461.5
	Total	-244.2	-2545.3	-11.4	94.6	-1.3	-26.8

Table 5. Changes in land cover due to improvement in WUE (1000 hectares).

Rate of Improvement in WUE	Land Type	Bangladesh	India	Nepal	Pakistan	Sri Lanka	Rest of South Asia
10%	Forest	43.0	332.3	2.1	-0.2	-0.2	0.0
	Cropland	-58.7	-690.4	-4.8	-11.9	-0.4	-12.3
	Pasture	15.6	358.1	2.7	12.1	0.7	12.3
20%	Forest	87.0	647.9	3.6	-0.3	-0.4	0.0
	Cropland	-118.7	-1343.5	-7.7	-1.1	-0.8	-20.8
	Pasture	31.7	695.7	4.2	1.4	1.2	20.8
30%	Forest	132.2	947.3	4.6	-0.1	-0.6	0.0
	Cropland	-180.4	-1961.6	-9.6	32.2	-1.1	-25.2
	Pasture	48.2	1014.3	5.0	-32.0	1.6	25.2
40%	Forest	267.6	5502.7	87.2	544.0	20.3	125.7
	Cropland	-326.2	-6193.1	-92.0	-556.0	-20.7	-138.0
	Pasture	-58.7	-690.4	-4.8	-11.9	-0.4	-12.3

for cropland by 2.5% (or 244 thousand hectares), 1.5% (or 2545 thousand hectares), 0.4% (or 11 thousand hectares), 0.1% (or 1.3 thousand hectares), and 0.3% (or 27 thousand hectares) in Bangladesh, India, Nepal, Sri Lanka, and rest of South Asia. In Pakistan at this level of improvement in WUE harvested area of irrigated land extends more than the reduction in rainfed areas and therefore total harvested area increases by 0.4% (or 95 thousand hectares) and therefore we observe some land conversion from forest and pasture to cropland. Therefore, in general, an improvement in WUE generates reforestation in South Asia as well.

Land and water endowments in India, unlike other countries in South Asia, are scattered across many river basins and different agro ecological zones representing different climate conditions and length of growing periods. Since an improvement in WUE could generate different land use patterns across the country, here we study the land use impacts of improved WUE in India by river basin and AEZ, limiting analyses to the case of 20 percent improvement in WUE. The left panel of **Figure 5** shows changes in cropland, forest, and pastureland areas by river basin. This figure indicates that with a 20 percent improvement in WUE, the area of cropland shrinks across all river basins, with major reductions in Ganges (by 349,000 hectares), Krishna (142,000 hectares), Brahmani (141,300 hectares), Indus (137,000 hectares), and Mahi-Tahi (125,000 hectares). In return, the areas of forest and pastureland grow across all river basins.

The right panel of **Figure 5** shows changes in cropland, forest, and pastureland areas by AEZ. This figure shows that, with a 20 percent improvement in WUE, areas of cropland in India shrink across several AEZs, with major reductions in AEZ3 (by 598,000 hectares), AEZ4 (192,000 hectares), AEZ2 (138,800 hectares), AEZ8 (115,000 hectares), and AEZ9 (111,000 hectares). Again, in return the areas of forest and pastureland grow across these AEZs.

The left panel of **Figure 6** represents changes in the mix of irrigated and rainfed croplands by river basin with a 20 percent improvement in WUE. Irrigated area grows most in the Ganges (by 4.2 million hectares), Indus (2 million hectares), Krishna (1.2 million hectares), and Godavari (1 million hectares) river basins. Finally, the right panel of **Figure 6** shows changes in the mix of irrigated and rain-fed croplands by AEZ with a

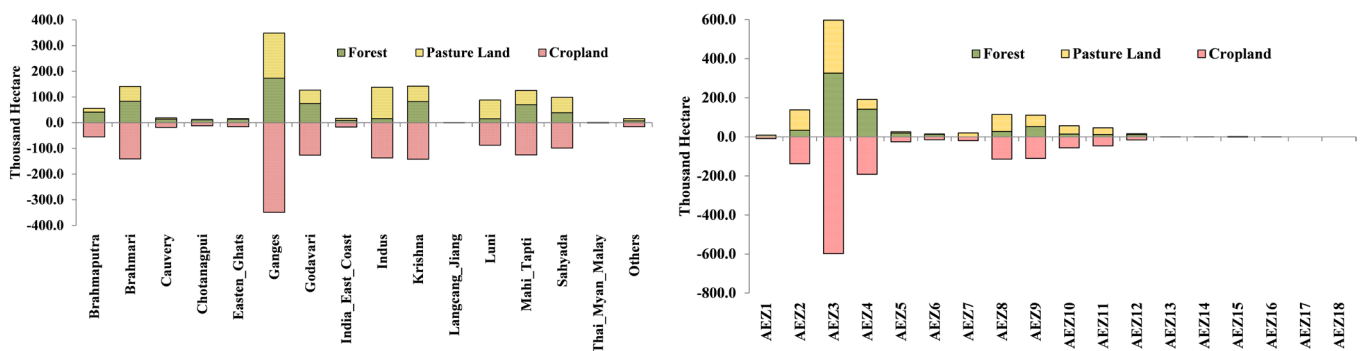


Figure 5. Land use changes in India by river basin (left panel) and by AEZ (right panel) due to 20% improvement in water use efficiency.

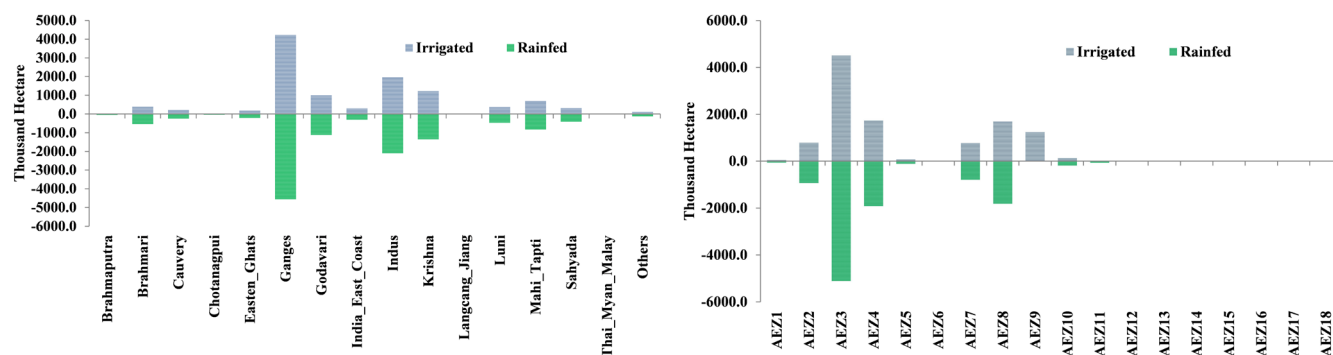


Figure 6. Changes in rainfed and irrigated cropland in India by river basin (left panel) and by AEZ (right panel) due to 20% improvement in water use efficiency.

20 percent improvement in WUE. As shown in this figure, irrigated area grows largely in AEZ3 (5.1 million hectares), AEZ4 (1.9 million hectares), AEZ8 (1.8 million hectares), and AEZ9 (1.4 million hectares).

4.1.4. Impacts on Outputs of Non-Agricultural Sectors

Improvements in WUE could affect outputs of non-agricultural activities through two main channels. First, as discussed, it extends agricultural activities and that could generate indirect demand for other goods and services through the forward and backward linkages between agricultural and non-agricultural activities. Second, a portion of water saved by improvements in WUE could move to non-agricultural activities and that helps these sectors to grow as well. For example, a 40% improvement in water use efficiency increases the share of non-agricultural activities in water withdrawal of: Bangladesh from 15.1% to 15.8%; India from 16.8% to 19%; Nepal from 3.3% to 4.5%; Pakistan from 8.8% to 9%; Sri Lanka from 48.7% to 59.2%; and rest of South Asia from 4% to 5%. For this level of improvement in WUE the overall output of non-agricultural sectors changes by 1.8%, 1.4%, 0.9%, -0.2%, 0.7%, and 0.2%. These figures indicate that, except for Pakistan, an improvement in WUE increases the share of non-agricultural activities in water withdrawal and that helps these sectors to grow in South Asia.

4.1.5. Economy-Wide Impacts

WUE improvements also positively affect the real GDP of South Asian countries and the impact grows with the rate of the WUE improvement (Figure 7). For example, a 10 percent improvement in WUE increases the real GDP of Bangladesh, India, Nepal, Pakistan, Sri Lanka, and rest of South Asia by 1.1 percent, 0.5 percent, 0.2 percent, 0.6 percent, 0.2 percent, and 0.5, respectively. The corresponding annual monetary value of these increases at 2011 constant prices are \$1216 million for Bangladesh, \$8696 million India, \$34 million for Nepal, \$1160 million for Pakistan, \$146 million for Sri Lanka, and \$100 million for rest of South Asia (Figure 7). With a 40 percent improvement in WUE, GDP grows by 3.8 percent, 1.5 percent, 0.5 percent, 1.7 percent, 0.7 percent, and 1.2 percent in Bangladesh, India, Nepal, Pakistan, Sri Lanka, and the rest of South Asia, respectively. The corresponding annual monetary gains of these increases at 2011 constant prices are \$4178 million for Bangladesh, \$27,715 million India, \$87 million for

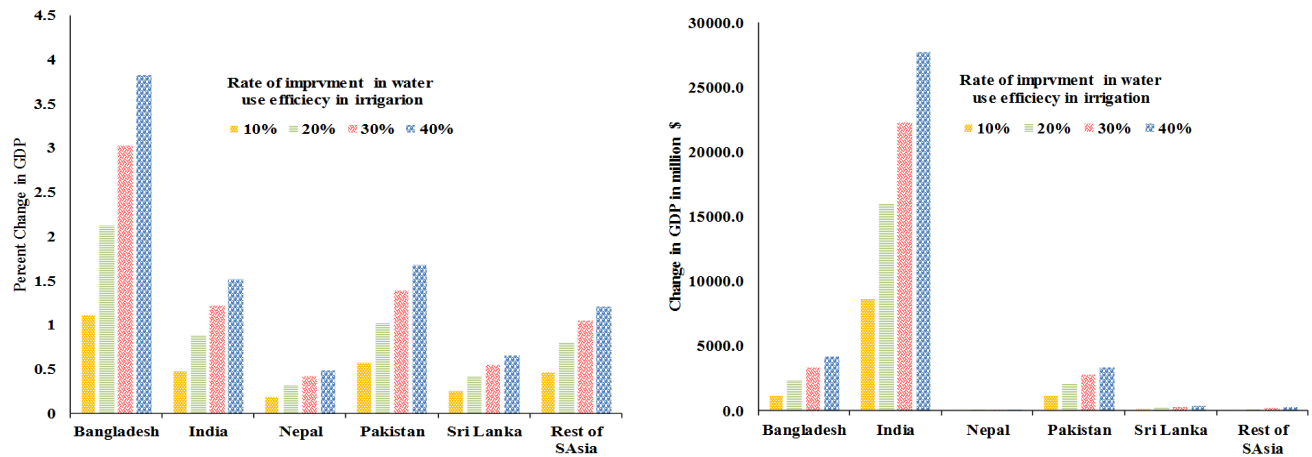


Figure 7. Percent changes in GDP (left panel) and their monetary values at 2011 constant prices (right panel) due to improvement in water use efficiency in irrigation in South Asia: Improvement in water use efficiency is costless.

Nepal, \$3357 million for Pakistan, \$380 million for Sri Lanka, and \$260 million for rest of South Asia.

An improvement in WUE in irrigation enhances GDP through several channels. First, it extends crop production, which boosts agricultural output (including livestock and forestry). Since the share of agriculture in GDP is relatively high in South Asia, this significantly increases GDP through the backward linkages among the agricultural and non-agricultural activities. As mentioned before, improvement in WUE releases some water and that allows non-agricultural sectors to grow as well. This enhances employment in South Asia, where the rate of unemployment is usually high.

It is important to note that our static simulations show that GDP grows with a decreasing margin as the level of improvement in WUE increases (Figure 8). The decreasing rate of marginal contribution of improvement in WUE matches with the economic principle of decreasing marginal product of an increasing input in a static framework. In long run when economies of South Asia grow over time any additional drop of saved water could generate growing marginal outputs when water scarcity hit these economies.

4.2. Simulation Results When Improvement in WUE Needs Additional Investment

4.2.1. Impacts on Outputs, Net Exports, and Price of Food Products and Land Use Implications

The agricultural impacts of improved WUE in the presence of additional investment charges are only slightly different from the costless cases, regardless of the level improvement in WUE. Two factors explain this observation. First, the share of electricity in the cost structures of irrigated crops in South Asia is small. Second, the public sector pays the costs of improvement in WUE with a uniform reduction in electricity subsidies across all users. So farmers only pay a small portion of the costs of improvements in WUE. Since the new results are not very different from the corresponding results of the costless cases, we do not present them in here.

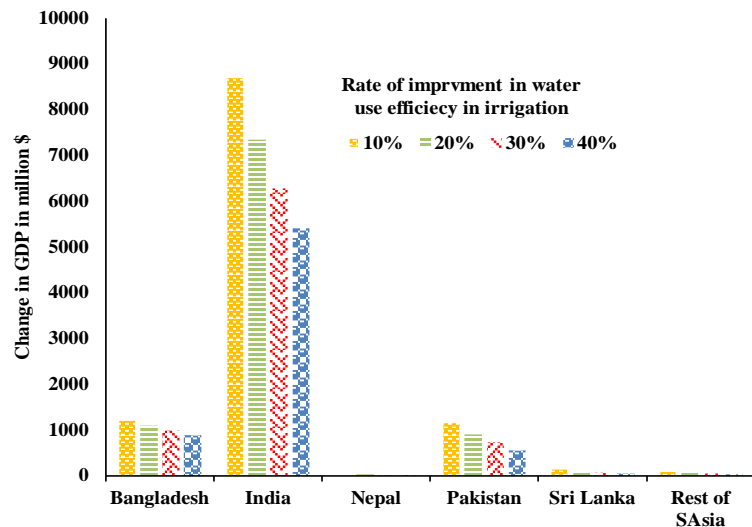


Figure 8. Marginal impacts of different levels of improvement in water use efficiency on GDP of South Asian economies: Improvement in water use efficiency is costless.

4.2.2. Impacts on Production and Price of Electricity

Since electricity subsidies are reduced to finance the improvements in WUE, this policy affects the production and price of electricity across South Asia. To examine these impacts, the changes in the production and price of electricity are compared for a 40% improvement in WUE under the two cases of with and without investment costs. With no investment costs for improvement in WUE, the production of electricity changes by -1%, 2.6%, 0.5%, 2.6%, 1%, and 1.5% in Bangladesh, India, Nepal, Pakistan, Sri Lanka, and rest of South Asia, respectively. The corresponding changes for the case with investment costs are -2.6%, 1.5%, -0.5%, 0.5%, 0.1%, and -1.5%. These figures show that production of electricity drops in the second case by 1% to 2% in the main countries of the region, when electricity subsidies are reduced to finance the investment costs of improvement in WUE. The reduction in electricity subsidy increases the consumer price of electricity as well. With no investment costs for improvement in WUE, consumer price of electricity changes by 5.9%, 0.7%, -1.2%, 4.4%, 0.4%, and -0.9% in Bangladesh, India, Nepal, Pakistan, Sri Lanka, and rest of South Asia, respectively. The corresponding changes for the case of with investment costs are 11.8%, 5.3%, 6.7%, 11.7%, 3.5%, and 25%. These figures are significantly higher than their corresponding figure for the costless case.

4.2.3. Economy-Wide Impacts

The economy-wide gains of improvement in WUE (measured in terms of changes in real GDP) decreases when we take into account costs of improvement in WUE. For example, as mentioned before a 10 percent improvement in WUE increases real GDP of Bangladesh, India, Nepal, Pakistan, Sri Lanka, and rest of South Asia respectively by 1216 million, \$8696 million, \$34 million, \$1160 million, \$146 million, and \$100 million at 2011 constant prices when we assumed improvement in WUE is costless. The corresponding figure drops to 1146 million, \$8,175 million, \$29 million, \$986 million, \$138

million, and \$90 million when we take into account costs of improvement in WUE (Figure 9).

As was observed in the costless cases, real GDP grows with a decreasing margin as we move towards the higher levels of improvement in WUE. When we take into account the investment costs, in some countries the marginal contributions of improvement in WUE become negative at higher levels of improvement in WUE. For example, consider the case of Pakistan where the first 10% improvement in WUE increases GDP by \$1,160 million and the last 10% (from 30% to 40%) increases GDP by \$562 million when we assumed improvement in WUE is costless. The corresponding figures are about 986 million and -\$447 million when we take into account the investment costs (Table 6). This indicates that the gains of improving WUE from 30% to 40% do not cover the costs of this improvement. Three factors contribute to this observation. First as mentioned before, the marginal productivity of water is decreasing as its application rate rises. Second, the marginal costs of improvement in WUE grow as we move towards the higher levels of WUE. Third, the efficiency gains from reducing electricity subsidies disappears as the cuts increase—eventually turning into losses as subsidies become taxes. Table 6 indicates that the marginal impact of improvement in WUE on GDP becomes negative at higher levels of improvement in WUE in Nepal, and rest of South Asia as well.

Table 6. Marginal impact of each level of improvement in water use efficiency on GDP at 2011 constant prices with and without investment costs (million \$).

Cost assumption	If improvement in water use efficiency is costless				Improvement in water use efficiency needs additional investment costs				
	10%	20%	30%	40%	10%	20%	30%	40%	
Rate of improvement in WUE									
Bangladesh	1216	1098	986	878	1146	1013	835	615	
India	8696	7335	6275	5409	8175	6646	4873	2845	
Nepal	34	24	17	11	29	17	-2	-27	
Pakistan	1160	910	725	562	986	665	187	-447	
Sri Lanka	146	101	75	58	138	91	51	14	
Rest of South Asia	100	74	53	34	90	60	22	-24	

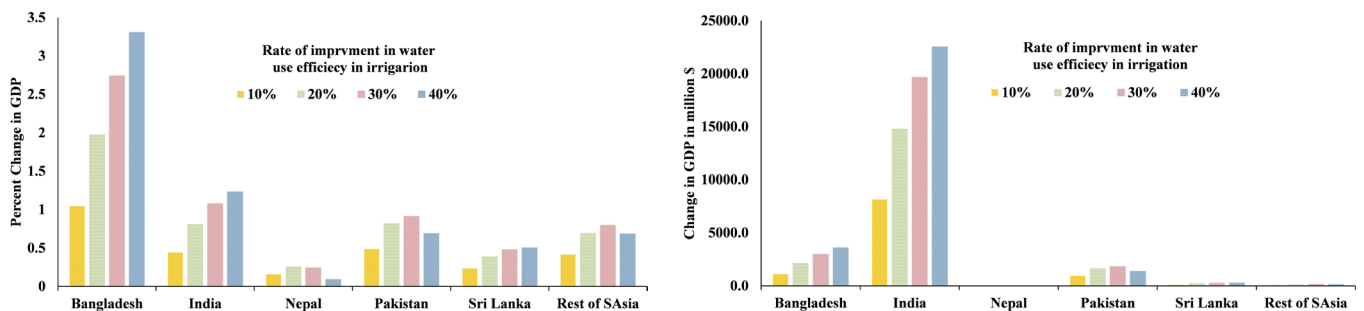


Figure 9. Percent changes in GDP (left panel) and their monetary values at 2011 constant prices (right panel) due to improvement in water use efficiency in irrigation in South Asia: Improvement in water use efficiency needs additional investment costs.

In conclusion, **Table 6** shows that improvement in WUE up to 40%, financed by a reduction in electricity subsidy, can be economically justified in Bangladesh, India, and Sri Lanka. In Nepal, after 20% improvement in WUE, the economic gains are smaller than costs. In Pakistan and rest of South Asia, an improvement in WUE over 30% may not be economically profitable.

Finally, it is important to note that the impacts of improvements in WUE on GDP could be different from its welfare impacts due to differing impacts on aggregate consumption. Our simulation results show that the welfare impacts are in general different from the GDP impacts. For instance, a 40% improvement in WUE increases the real GDP of Bangladesh, India, Nepal, Pakistan, Sri Lanka, and Rest of South Asia by \$3610 million, \$22,539 million, \$17 million, \$1392 million, \$295 million, and \$148 million at 2011 constant prices, respectively. The corresponding welfare impacts for this simulation are \$4381 million, \$19,065 million, -\$83 million, \$3130 million, \$402 million, and \$45 million. Hence, from the consumers' points of view the monetary value of improvements in WUE is higher than the gains in GDP in Bangladesh, Pakistan, and Sri Lanka and the reverse is true in India, Nepal, and Rest of South Asia.

5. Conclusions

Using an advanced computable general equilibrium model (GTAP-BIO-W), this paper shows that improvements in WUE in irrigation increase production of food items in South Asia, significantly. In addition, it has demonstrated the following beneficial impacts: a) an increase in the production of non-agricultural sectors; b) significant rises in the net food exports of South Asian economies, with an overall improvement in their trade balances; c) lower food prices, which provide the opportunity to extend irrigated areas across South Asia and lead to reforestation and more security in food production; d) notable GDP gains across south Asia.

An improvement in WUE up to 40% can be economically justified in Bangladesh, India, and Sri Lanka. In Nepal, after 20% improvement in WUE, the economic gains are smaller than costs. In Pakistan and rest of South Asia, an improvement in WUE over 30% may not be economically profitable.

Policymakers dealing with the agricultural sector and irrigation are well aware of the benefits of improvements in WUE to that sector. What they have thus far lacked are estimates of the broader benefits to the economy as a whole from such WUE improvements. This paper provides them with estimates of these benefits. Second, there has always been the question of how to finance the improvements, given the limited public resources available. Again, this paper has shown that it is possible to finance such a program through reductions in electricity subsidies, in such a way that the net benefits from some levels of investment are positive.

Further work is needed to evaluate the options that have been presented here in more detail. In particular, it is important to better understand the distributional implications of such a financing program and consider measures to address adverse effects on low income rural households.

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