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IFPRI Discussion Paper 02226

December 2023

The Economywide Impacts of Increasing Water Security through Policies on Agricultural Production

The Case of Rice and Sugarcane in Pakistan

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Increasing demand for water juxtaposed with shrinking supplies will require a transfer of water resources out of agriculture into the domestic, industrial, and ideally environmental sectors. To examine the potential of policies to facilitate a release of water from agriculture, this paper uses IFPRI's Computable General Equilibrium Model with a water extension, CGE-W, to assess the impact of commodity taxes on two highly water consumptive crops, rice and sugarcane, on water consumption and the overall economy. We find that land use grows by 1.56 million acres overall when the tax is imposed on both commodities, while 3.2-million-acre feet (MAF) of consumed water, equivalent to 6.35 MAF of water withdrawals, are released from agriculture. These outcomes are due to sugarcane's reduced use of land over two cropping seasons and significant changes in cropping patterns. The study also examined releases of water from other possible policy measures and found that an even tax rate of 30% on sugarcane, rice and cotton yields 8.73 MAF of water from agriculture. However, with a hotter, drier climate virtually all these releases of water disappear because water must stay in agriculture due to higher evaporation and less precipitation, which raises irrigation demands. The needed policies will go beyond just taxation and might include changing cropping patterns and irrigation practices, as well as development of drought resistant varieties. Other approaches, such as buying tubewells from farmers, and developing markets for nonagricultural purchases of water, may have a role. The role of international trade in sugar and rice is shown to be significant and should be considered further in these analyses.

Keywords: Water savings, water reallocation, sectoral water demand, agricultural land taxation, climate change, CGE-W modeling

Acknowledgments

This work was carried out under the CGIAR Initiative on NEXUS Gains, which is grateful for the support of CGIAR Trust Fund contributors: www.cgiar.org/funders. The CGIAR Initiative on NEXUS Gains (https://www.cgiar.org/initiative/nexus-gains/) works at the critical intersection of food, energy, and water security while preserving the ecosystems underlying food systems in selected transboundary river basins.

Acronyms

AF	Acre Feet
AW	Applied Water
BCM	Billion Cubic Meters
CGE-W	Computerized General Equilibrium- Water
CU	Consumptive Use
ETa	Evapotranspiration
Extshk	External Shock
FSAV	Foreign Saving
GCMs	General Circulation Models
GDP	Gross Domestic Product
GST	General Sales Tax
GW	Ground Water
HDCL	Hot and Dry Climate Change (lower inflows, precipitation, higher evaporation)
IBMR	Indus Basin Model Revised
IFPRI	International Food Policy Research Institute
IPPC	Intergovernmental Panel on Climate Change
IRRI	Irrigated
IRS	Indus River System
IWMI	International Water Management Institute
Km^3	Cubic Kilometers
LFPHE	Low Flow Precipitation High Evaporation
m^3	Cubic Meters
MAF	Million Acre Feet
Mm	Millimeters
MoWR	Ministry of Water Resources (of Pakistan)
MPS	Marginal Propensity to Save
NHDCL	Climate Change with historical inflows, precipitation, and evaporation
OP	Other Province
PKR	Pakistan Rupee
RFNP	Rural Farm Non-Poor
RFP	Rural Farm Poor
RNFNP	Rural Non-Farm Non-Poor
RNFP	Rural Non-Farm Poor
ROW	Rest of World
SAM	Social Accounting Matrix
SC	Sugarcane
SW	Surface Water
UNDP	United Nations Development Program
UNP	Urban Non-Poor
UP	Urban Poor

1. Introduction

Amidst growing scarcity and increasing demands, water use in Pakistan is often considered as wasteful and not optimally used. Population growth, urbanization and industrialization have given rise to mounting demand for water resources. Cities like Karachi and Lahore have experienced rapid expansion, putting considerable pressure on existing water supply systems. Pakistan's population, estimated at approximately 235.82 million people in 2022 (World Bank, 2022[1]) might well reach 250 million by 2025 (Ishaque et al., 2023), and will be 52% urban (UNDP, 2019; Janjua et., 2021). Due to this exponential increase, water demand for agriculture and non-agriculture usage like industrial and domestic uses are expected to increase by a further 8 percent by 2025 (Parry, 2016). With fixed supply, the per capita availability of water is continuously decreasing. Pakistan had a per capita availability of 5,000 m^3 in 1951, which fell to 1,100 m^3 in 2005, and by 2025, it is expected to fall to 800 m^3 (Shaheen, 2010; Qureshi & Ashraf, 2019). Additionally, Pakistan's overall water demand is increasing at an average yearly rate of 10 percent, suggesting an overall increase of demand to 338 square kilometers by 2025, while water availability will remain at 240 to 258 square kilometers (Ishaque et al., 2023). With glaciers accounting for 28 percent of Indus flows rapidly melting, future water supply might well be lower (Latif et al., 2020). Changes in monsoon rains will further affect precipitation levels and will negatively affect food production and water security, as witnessed during recent extreme heat and flood events.

Pakistan's National Water Policy of 2018[2] has the objective to conserve the nation's water resources, increase water productivity, and shift to crops with less water consumption suitable to agro-climatic and economic conditions of the area. Moreover, the Water Policy and subsequent provincial water acts have placed a significant emphasis on water accounting, and efficient water allocation within and between sectors. The Ministry of Water Resources (MoWR) is particularly interested in assessing how the reallocation of crop areas and water resources to different end uses might impact the national economy under various scenarios.

Most of the country's water resources are used in agriculture. However, 80 percent of water is used to irrigate commodities that account for just 4-5 percent of GDP. In response to this, there is a growing consensus to reallocate scarce water resources towards more profitable and less water-intensive crops (Maqbool, M., 2022). The suggestion has therefore been that around 10 million acre feet (MAF) of water will need to be transferred out of agriculture over the next several decades (Davies and Young,2021, Young et. al., 2019). Notably, sugarcane and rice stand out to be the highest water deltas, calculated by

[1] Worldbank. Population, total—Pakistan | data. The World Bank Population Data. Available at: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=PK . Accessed on 30th October 2023
[2] Available at: https://mowr.gov.pk/SiteImage/Misc/files/National%20Water%20Policy.pdf

multiplying the number of irrigations required (from sowing to harvest) with the volume of water applied per irrigation. Sugarcane also has the protection through a support price to uphold the competitiveness in the global market. Given Pakistan's heavy reliance on commodity-based rice and cotton-based textile exports for revenue, there's a contention that the country is effectively involved in the virtual export of water (Business Recorder, 2019).

As a result of the interest by MoWR and other stakeholders, this study provides an in-depth analysis of the consequences of reducing the area and water allocated to two major water-intensive crops using an economy-wide modeling framework, the Computable General Equilibrium – Water (CGE-W) model. This paper specifically looks at the agricultural production, water and land use and economy-wide implications of restricting rice and sugarcane acreage by 15 percent separately, and jointly as a third simulation. Several alternative approaches to taxation are compared at the end of the paper. The major focus is on the quantity of water that might be released from agriculture for the other, more highly-valued uses.

The remainder of the paper is as follows. A section describing the agricultural setting in Pakistan is immediately below, which is followed by a discussion of the analytical model used in this analysis, IFPRI's computable general equilibrium model - water (CGE-W). The specific policy measures, a commodity-specific tax on sugarcane and rice to disincentivize water-intensive crops, is described. The specific characteristics of the CGE-W's incorporation of water and land use, salinity and climate change are presented to show what the simulations will be based on. The results section presents changes in land and water use as well as key economic and food security outcomes. The paper concludes with a series of discussions and conclusions regarding how well various policies perform in reducing water from agriculture.

2. Overview of Pakistan's Crop Agriculture and Water Resources

Pakistan heavily depends on the Indus River System (IRS) as the primary water source for irrigation, supporting approximately 80 percent of agricultural land and spanning 21.5 million hectares (Ishaque et al., 2023). The Indus Basin contributes substantially to Pakistan's economy, contributing 22 percent of Pakistan's GDP. The IRS provides water resources to nearly 90 percent of Pakistan's crop production, which accounts for about five percent of the country's GDP (Yaqoob et al., 2021; Young et. al. 2019). The livestock sub-sector is the primary contributor to agricultural GDP with a 58 percent share, followed by the four major crops (wheat, rice, sugarcane, cotton) with the combined share of 37 percent.

Pakistan's water use increased over time from both surface and groundwater sources, but the IRS's reliance on groundwater increased particularly rapidly, by a factor of 17 since 1961. While data are imperfect, the Indus basin is seen to have a large alluvial aquifer, but with a recent characterization of the period from 2000 as having an expanding extraction via a growing number of tubewells, along with a declining water table and lower water quality, all of which is challenging for the future (Lytton, et. al., 2021). The following tables 1 & 2 show both the important crops grown as well as changes over time in surface and groundwater resources.

Table 1. Harvested Area of Major Crops 1991-2018

Year	**Area Harvested in '000' Hectare**				**Share in Total Harvested Area**			
Year	Wheat	Sugarcane	Rice	Cotton	Wheat	Sugarcane	Rice	Cotton
1991	7911	884	2097	2836	0.421	0.047	0.112	0.151
2001	8181	961	2114	3116	0.419	0.049	0.108	0.160
2011	8901	988	2571	2835	0.422	0.047	0.122	0.134
2014	9199	1140	2890	2961	0.424	0.052	0.133	0.124
2018	8797	1102	2810	2373	0.416	0.052	0.133	0.112
Annual percent Chg. 1991 to 2018	0.39	0.82	1.08	-0.66				

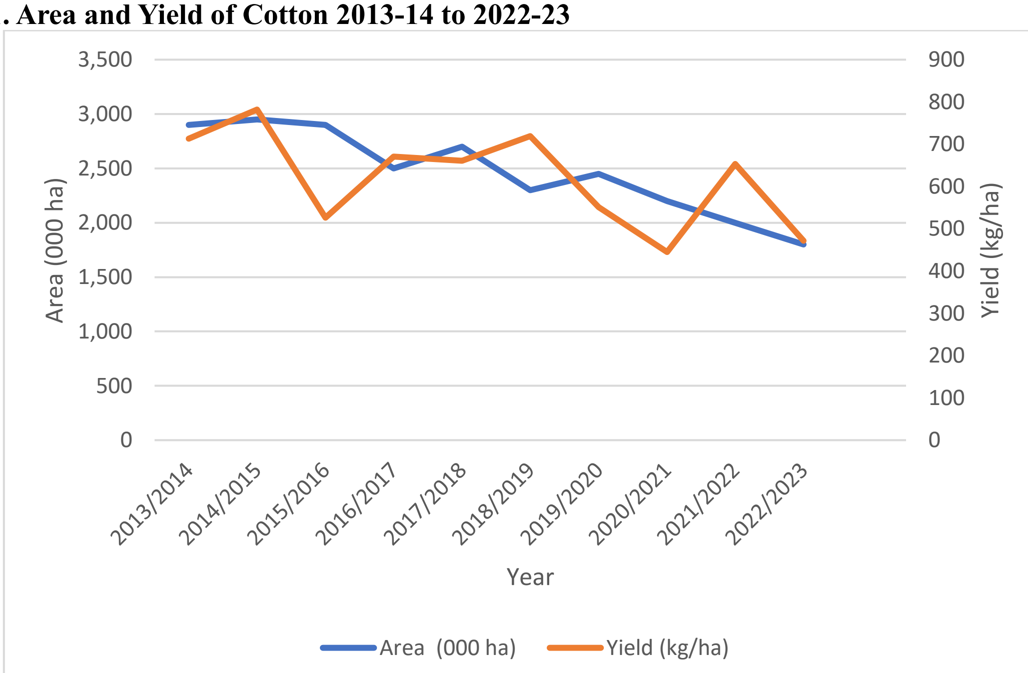
Source: Authors' calculation from FAOSTAT and MNFSR agriculture statistic data

Table 1 shows the change in cultivated areas of four major crops since 1991. While harvested area increased for both rice and sugarcane from 1991 to 2018, at 1.08 percent per year and 0.82 percent per year, respectively, wheat area expanded more slowly, and area planted to cotton contracted after 2014.

We give more detail on the cotton crop because it is a major beneficiary when taxes are put on rice and sugarcane in the simulations described in Section 4 below. In effect, the outcome of our simulations benefit cotton, so we want it to be clear that this is a deviation from the recent trend that we will need to revisit. However, even with a declining trend a major change in the economics of sugarcane and rice is likely to lead to positive responses for cotton. Thus, we give the following sketch.

The area under cotton declined due to changes in climate, poor farm management practices, and pest attacks which resulted in a significant shift from cotton to sugarcane in the former cotton belt (Abbas, 2020; Razzaq et al., 2021). Since sugarcane is a highly water intensive crop, the shift from cotton to sugarcane resulted in increased water use in agriculture. The area planted to cotton also decreased from 2950 thousand hectares in 2014-15 to 1800 thousand hectares in 2022-23, while yields declined from 782 kg/ha in 2014-15 to 472 kg/ha in 2022-23 shown in figure 1. The other factors contributing to the demise of cotton in Pakistan are lack of enough support from the government to compensate the crop loss, lack of incentives for farmers (better support price), timely policy interventions including new climate resilient varieties and crop insurance, inefficient fertilization, and poor seed technologies (Afzal et al., 2019; Ahmad & Raza, 2014).

Figure 1. Area and Yield of Cotton 2013-14 to 2022-23



Source: U.S Department of Agriculture; Agricultural Marketing Information Services, Pakistan

To understand the magnitudes impacted by a tax on water-intensive crops, it is useful to describe their relative economic importance. The Social Accounting Matrix (SAM) used in this analysis includes the total value added for disaggregated commodities (or GDP at factor cost, which is the sum of labor and capital payments). In 2014, the total GDP for crop agriculture was PKR 2,544 billion, while GDP for all agriculture was PKR 5,793 billion. Sugarcane and rice each contributed around PKR 250 billion or slightly less than 10 percent of crop agriculture's GDP each, and together the two crops accounted for 8.6 percent of all agricultural value added. If cotton and wheat, with value added of PKR 397 and PKR 776 billion, respectively, are added, the four crops together account for 66 percent of total crop GDP, and 29 percent of total agricultural GDP. The simulations of a 15 percent reduction in area planted to rice and sugarcane leads to a 2.8 percent reduction in total area, ***before*** substitution into alternative crops, which are shown below to be large. Given these magnitudes, the effects are likely small compared to aggregate income, production, and other economic economywide effects. However, the question asked in this analysis is whether these policies can release helpful amounts of water for non-agricultural uses.

Table 2. Water Withdrawal and Area Irrigated 1991-2018

Year	Water withdrawals	Surface Water	Ground Water	Irrigated Area
	Billion m^3	Billion m^3	Billion m^3	Hectares (1000)
1991	147.55	93.30	54.25	16750
2001	164.40	102.84	61.56	17820
2011	167.58	105.65	61.93	20200
2014	170.88	111.70	53.27	17026
2018	164.55	100.41	53.66	20200
Annual percent change. 1991-2018*	0.40	0.27	-0.04	0.69

Source: Authors' calculations from FAOSTAT and FBS data.

Pakistan's water resources. Pakistan's water supply from both surface and groundwater sources has increased over time, (and groundwater abstraction increased more than 17 times from 1961) However, since 2001, both surface and groundwater levels have been relatively constant, with groundwater abstraction reaching unsustainable levels in parts of the country. Table 2 presents water supply to agriculture over time from both sources and irrigated area.

3. Structure And Methods of IFPRI's Computable General Equilibrium (CGE-W) Model

The CGE-W is a whole economy model, with consumers, producers and government entities tied together through production, consumption, trade, and taxes. The model includes a Social Accounting Matrix (SAM) that brings together financial flows between all actors for the base year of 2013-14, with 64 activities including 17 in agriculture, 34 in industry and 13 in services (for a detailed description see Saeed, 2017). The agricultural sector includes twelve crops (rainfed wheat, irrigated wheat, basmati rice, Irri or coarse rice, cotton, sugarcane, other field crops and vegetables/horticulture) in three regions (Sindh province; Punjab province; and the Other Pakistan (called OP hereafter) which includes both Balochistan and Khyber-Pakhtunkhwa). Rainfed agriculture is only included for Punjab and only for wheat. Industrial activities include eight food processing activities, such as meat, dairy, oils & fats, grain milling of wheat and rice, and sugar refining among others. Raw cotton production is transformed into cotton lint, yarn, cloth, knitwear, garments, and other textiles, all of which are sold domestically and abroad, and have been the mainstay of exports from Pakistan.

These production activities use land and labor inputs, with land limited to the agricultural production sector. Land is categorized into small, medium, and large rainfed parcels, growing only wheat, and into small, medium, and large irrigated farms. Labor is also disaggregated: farm workers are separately identified by size of farm and across regions, but they are proportionally fixed within production activities as they are assumed to be less mobile. The model also has agricultural wage workers and non-agricultural unskilled and skilled workers.

The model uses 18 household groups. Farm household cohorts are defined by size of farm and location, while non-farm households are split into income quartiles. Farm households are represented as small, medium, or large holders for Punjab province, and as a group for all other provinces (yielding six farm cohorts). Non-farm households include rural landless agricultural households, rural nonfarm households, and urban households, with income quartiles for each category (twelve cohorts).

Several macroeconomic balances and factor markets are tied together through specific closures modelled in the CGE-W. The international market, or the rest of the world (ROW), is summarized in a current account resulting from trade and financial flows. In the base year SAM, a deficit in the current account is covered by foreign savings (FSAV). In our Pakistan model, FSAV is fixed, so a flexible exchange rate fluctuates to balance any disequilibrium in the current account. Similarly, the factor markets (for land, labor, and capital) equilibrate using perfectly flexible factor prices to balance supply and demand of the factor.

Additionally, savings and investment must be balanced, as must government expenditures and tax revenues. Both government expenditures and investment demand are tied proportionally to total absorption in the economy (i.e., domestic production plus imports). Thus, as the economy grows, investment and government expenditures will expand to stay at the same relative size in the economy. The direct taxes on businesses and households vary endogenously to generate revenues that support government expenditures. In a similar fashion, the marginal propensity to save (MPS) varies endogenously to provide savings to support investment. However, as FSAV is fixed, both government and non-government savings need to be combined to support investment expenditures. Also, as is often the case, government savings is negative so household and business savings must be higher to offset those deficits. Thus, the endogenous behavior of MPS and government taxes in the CGE-W jointly provide savings and closures for government and investment[3].

The commodity taxes used to force reductions in acreage in this analysis are indirect taxes and therefore are set exogenously for a given simulation. However, as rice is an important export crop, and raw sugar sees varying exports and imports as well as policy dimensions, reducing these acreages will have a larger impact on trade and the exchange rate than the crops' contribution to GDP.

The CGE-W also uses a series of water modules that have been developed based on the Indus Basin Model Revised (IBMR), and most recently summarized by Yang et. al (2013) and Yu et. al (2013). Further details can be found in Appendix D in Young et. al. (2019).

Commodity Taxes in the CGE-W

The database for the IFPRI CGE model of Pakistan, based on a 2010-11 SAM developed by IFPRI (2015), was updated to 2013-14 to give solutions that trace direct and indirect effects of various scenarios through production and consumption linkages, deriving distributional effects through the disaggregated labor and household categories. Details of the IFPRI standard CGE model can be found in Löfgren, Harris and Robinson (2002).

Commodity taxes are included as a set of indirect taxes specified in the social accounting matrix (SAM). These can be imposed on the supply of a given commodity and include general sales taxes on domestic production and imports (GST), excise taxes, and surcharges. The first two are usually the largest and have

3In IFPRI's CGE models, a range of closure options are provided that can be alternatives to the closures used here. So, for instance, FSAV can be flexible instead of the exchange rate. Löfgren, Harris and Robinson (2002).)

been used the most often. For the purposes of this analysis, these are included in a group called COMTAX, and are added together to create a base tax rate ($tq_0(C)$) using the following formula.

$$tq_{0}(C) = SUM\ (COMTAX_{C})/(PQ_{0}(C)*QQ_{0}(C))$$

The tax rate tq_0 varies by commodity C and is the ratio of the sum of the relevant commodity taxes divided by the total supply value of a given commodity in the SAM. These provide the base rates, which can be adjusted to create alternative simulations.

Sales tax rates play a role in tying total demand and supply together for a given commodity via the following price equations. This value must equal the total value demanded for domestic products (QD) and imports (QM). A series of related equations link the price behavior of price of good (PQ), demand price for commodity produced & sold domestically (PDD), and price of imports (PM), as well as other relevant prices. Naturally, a higher tax will lower the supply on the left side of the equation below, which requires that total demand drop to equilibrate the equation.

$$PQ(C)*(1 - tq(c))*QQ(C) =E= PDD(C)*QD(C) + PM(C)*QM(C)$$

The values of *tq* were adjusted for the two largest water-consuming crops, sugarcane, and rice, to induce changes in their acreages[4].

From the Base simulation, we applied changes to *tq* to simulate the required fifteen percent acreage reductions, with specific values found in Table 3 for the three simulations discussed below (for rice and sugarcane separately and as a joint tax). To achieve the intended reductions in acreage, the tax for rice was set at 33 percent for basmati rice and 31 percent for IRRI (or coarse) rice. To achieve a 15-percent decline in the area planted to sugarcane, a commodity tax of 44 percent was included. For comparison, the general sales taxes (GST) is 17.5 percent, so while our simulation figures are high, the general GST tax rate is also high. Also, this is an elasticity of 0.26 which is not excessively low.

[4] Initial simulations led to substantial reductions in sugarcane and rice areas. Rather than experimenting with many demand and supply side parameters, we used the commodity taxes and international prices to create a more level production to use to examine tax effects. For rice, international prices were raised by 0.75 percent per year for both basmati rice and Irri rice. These shifts in international prices were retained throughout the simulation exercises. The international prices were not effective for sugarcane and so a commodity tax of -18 percent was used in the base. This was removed in the sugarcane simulations but its presence or absence did not affect 2030 values.

Table 3. Commodity Tax changes used in the CGE-W Base Run and acreage reduction scenarios, (in percent)

		Tax to decrease acreage by 15 percent in:		
	Base Calibration	Rice	Sugarcane	Sugarcane and rice
Basmati rice*		33		36
Irri Rice*		31		34
Sugarcane	-18		44	47
Refined Sugar			44	47

Source: Authors' estimations.
Note: International prices are raised as an exogenous input for basmati rice by 0.75 percent per year for both Irri rice and basmati rice for all simulations.

Commodity Trade in the CGE-W

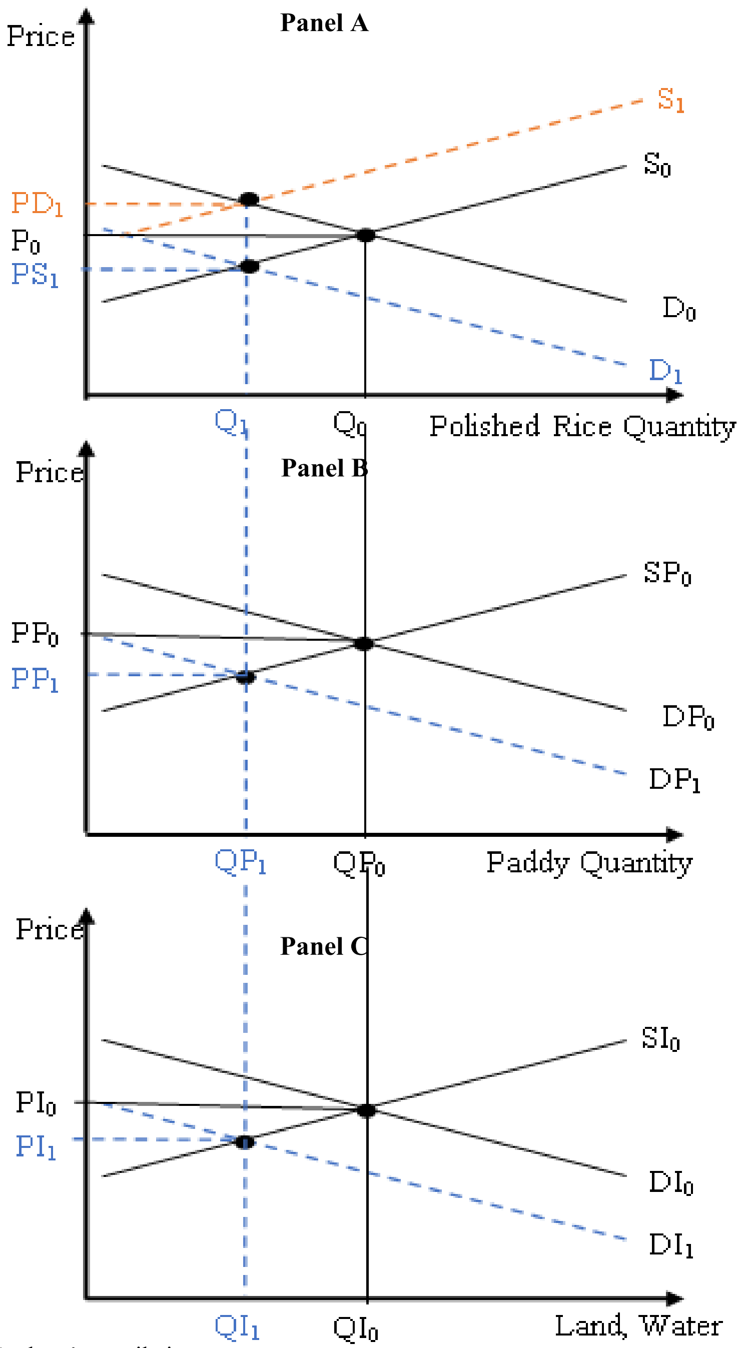
Regions constructed in CGE models are frequently assumed to be small, open economies that are incapable of influencing import and export prices. CGE models frequently try to avoid "all or nothing" specialization effects, which are inconsistent with actual evidence and may overstate the effects of policy (RTI, I., 2003). The standard CGE model also includes analyses of trade flows that showcase the interplay between changes in commodity production and the ripple effects on domestic production, exports, and imports of commodities. In this modeling framework, commodities, inputs, and factors of production are interconnected through supply and demand relationships. To elucidate the domestic side of the CGE structure, consider figure 2. Comments on the trade side are made at the end of this section.

Figure 2, Panel A describes the impact of commodity taxes on interconnected markets with implications for land and water inputs in a multistage production function based on Alston (1991). The first diagram focuses on the market for polished rice. Initially, the equilibrium point (Q_0) is established with a corresponding demand curve (D_0) and supply curve (S_0). Upon the imposition of the tariff, the supply curve shifts upwards to S_1, indicating an increase in the cost of production and a reduction in the quantity supplied at each price level. This results in a new market price, denoted as PD_1, which is higher than the original equilibrium price. Therefore, the quantity demanded for polished Rice decreases to Q_1, as consumers react to the increased price by reducing their purchases. A shift in the demand curve (D_1) is also included in the figure, mostly to make the point that the tax could be imposed on consumers and would lead to similar outcomes. We chose a supply slide representation, but specific policy approaches could use either structure.

Figure 2, Panel B illustrates the effects of changes in the polished rice market on the interconnected paddy market. The decrease in the quantity demanded for polished rice, from Q_0 to Q_1, leads to a reduction in the demand for paddy. This shift is denoted by the change from QP_0 to QP_1, as represented by the demand curve for paddy in the diagram. The reduction in the demand for paddy signifies that paddy producers will experience a decrease in output and prices due to the lower quantity demanded by rice producers.

Figure 2, Panel C illustrates the effect on a key input, water, which is essential for paddy production and thus polished rice supply. The decline in paddy production (QI_0 to QI_1) is accompanied by a reduced demand for water inputs (and this holds for other inputs like land as well). This reduction in demand not only affects the input markets but also has implications for the overall acreage under production. Thus, this interdependence between the polished rice, paddy production and inputs (such as land and water), highlights the broader consequences of commodity taxation on the agricultural landscape.

Figure 2. Imposition of a Commodity Tax in Vertically Related Markets



Source: Authors' compilation.

In the CGE-W, the specifications are more elaborate and tie markets together through both demand and supply functions. On the demand side, household expenditures on commodities are determined through a linear expenditure system that compares prices of alternative goods and grows with family income. Thus, commodity markets are tied together via these functions. The demand shifts in the top panel cause effects in other markets, as illustrated by the demand curve D_1. On the supply side, the first order conditions related to production functions are affected by prices of labor and capital, as well as by external parameters for productivity growth. Because labor and land must be pulled from other uses, supply curves are affected by multiple markets through economy-wide input competition.

The figure shows no links to international markets, but typical regional trade models accommodate a domestic (or autarky) equilibrium at P_0 and Q_0, along with an external world price. If the world price is above the equilibrium price, the country is an exporter in that commodity, with an excess supply curve created, while if the world price is below the autarchy price, the country is an importer. If the country is an exporter, it faces a demand curve for its exports which, depending on the nature of the international market can be nearly infinitely elastic or less so if the exporter is a large country. The CGE-W allows for a wide range of elasticities to structure these relationships. The commodities of most interest in this study are sugarcane and rice, where rice is a clear export commodity, while sugarcane has been variable over time and is subject to numerous tariff variations and domestic objectives (USDA 2014). We explain the behavior of trade in the simulation results in section 5.1.4.

Finally, taxing a broader set of commodities, such as adding cotton, would allow individual rates to be lower or would create more water savings. Other possibilities include taxes on inputs such as fertilizer or water or using quotas on acreage. Some examples of these are presented at the end of the paper.

4. Simulations and CGE-W Base Data

The objective of the economic modelling in this study is to induce acreage reductions in two water-intensive crops by imposing commodity taxes. With these simulations, we can examine economic as well as land and water use outcomes. The focus of the analysis is on broad reactions across provinces with the main objective to evaluate the releases of water from agriculture. Three simulations are examined:

1. A 15 percent decrease in national rice acreage that is evaluated for the three regions in the country (Punjab, Sindh, and OP (Other Provinces consisting of Khyber Pakhtunkhwa and Balochistan).
2. A 15 percent decrease in national sugarcane acreage that is evaluated for the three regions in the country.
3. A 15 percent decrease in national acreage of both rice and sugarcane together.

The taxes are imposed on a Base of 2013-14, and the 15 percent acreage reduction is assessed in 2030 as the full effect of any policy changes take time in CGE modelling. Other standard assumptions linked to CGE modeling are described in Appendix D in Young et. al (2019). Given the focus on water quantities, there are several distinct assumptions and characteristics of the CGE-W model and its data that need to be spelled out.

Characteristics of land and water in the Base CGE-W model. Because the SAM uses data aggregated at the provincial level, additional insights into water-intensive crops can be described beyond those in Tables 5and 10. Total land use in agriculture in 2014 was 58 million acres, with 42.4 million acres or 73 percent of the total area in Punjab. The totals in Sindh and the OP were approximately equal, in the range of 7-8 million acres. Among the crops, the area was largest for irri wheat in Punjab, accounting for 36 percent of total area. This was followed by the two rice crops, with 11 percent. Together, wheat, the two rice crops plus sugarcane accounted for 51.7 percent of agricultural land use. In Sindh, again wheat is the dominant crop, and accounted 31 percent of agricultural land use. Nearly 20 percent of land was in Irri (or coarse) rice, while 9 percent was in sugarcane. Thus, the total acreage in these crops was more than three fifths of Sindh's agricultural acreage. In the OP, Irri rice and sugarcane were most important, but had lower acreage levels, so together sugarcane and rice accounted for less than 13 percent of the total in those two provinces. If cotton is added as to the group under consideration, the total acreage rises 23.3% in Punjab and nearly- one quarter in Sindh given the importance of that crop.

Table 4. Base CGE-W Land and Water Use by Rice, Sugarcane, and Cotton, 2013-14

Panel A: Land Use

	Total Land	Wheat	Basmati Rice	IRRI Rice	Sugarcane	Cotton	percent of total w/o cotton	percent of total with cotton
				Millions of Acres				
Punjab	42.4	15.34	3.0	1.6	2.0	5.1	51.7	63.8
Sindh	8.5	2.64	0.1	1.8	0.8	1.3	62.8	78.1
Other	7.2	1.70	0.1	0.5	0.3	0.1	36.1	37.5
Total Acres	**58.2**	**19.68**	**3.3**	**3.8**	**3.0**	**6.5**	**51.2**	**62.3**

Panel B: Water Use

	Total Water	Wheat	Basmati Rice	IRRI Rice	Sugarcane	Cotton	Percent of total wo cotton	Percent of total with cotton
Province					Mill Acre Feet consumed			
Punjab	50.2	10.75	6.44	3.63	5.65	11.58	52.7	75.8
Sindh	14.1	2.46	0.43	4.46	2.59	2.39	70.5	87.4
Other	3.3	0.38	0.24	1.2	0.80	0	79.4	79.4
Total MAF	**67.6**	**13.59**	**7.1**	**9.3**	**9.0**	**14.0**	**57.7**	**78.4**

Source. Authors' estimation from the CGE-W database

Total water use would of course tend to follow land use in the various crops, but varying water intensity can change the proportions. Panel B in Table 4 shows the distribution of water use in the three regions and crops considered. Over 50 MAF or 74 percent of irrigation water was used in Punjab while 21 percent was consumed in Sindh. Thus, compared to land use, Punjab accounted for about the same percent, and Sindh was about 5 percent higher. The OP accounted for a smaller percent in water.

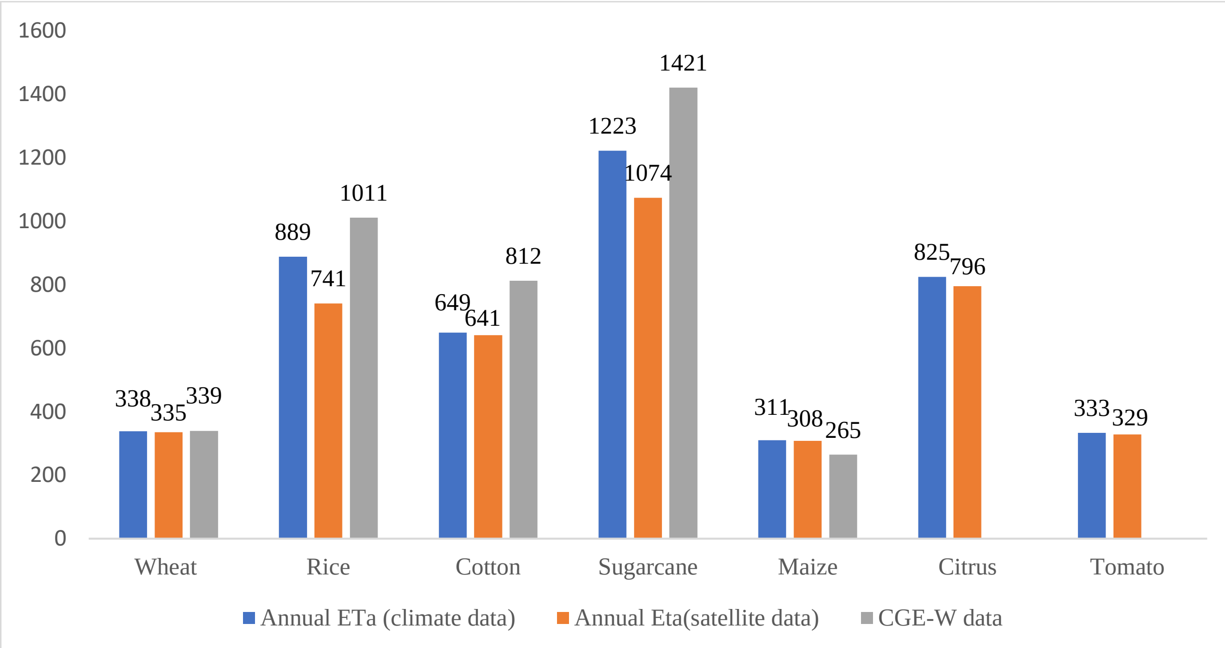
The total water use without cotton in the three provinces was more than one third of all agriculture uses but reached almost 60 percent when cotton is included. The uses by crop ranged from 7.0 to 14.0 MAF, when summed across the three regions, so they all account for significant proportions of use. In Punjab, basmati rice accounted for most water use (excluding cotton), while Irri rice used the most water in Sindh and in the OP.

The two panels can be combined to show water use per acre (AF). The average water use is about 2.4 acre feet (AF) per acre for both rice crops, while it is more than a half-acre foot higher in sugarcane, at 2.94 AF per acre. In contrast, cotton uses just one third less per acre than sugarcane, at 2.04 AF per acre. Of course, given the objectives of the study, the crops chosen for the tax have higher water use requirements than the average, which can be derived from Table 4 as 1.10 AF per acre.

Water resources in the CGE-W. Surface and groundwater resources in Pakistan (and elsewhere) are closely interlinked as described in Young et. al (2019) and Lytton et. al. (2021), among others. In the CGE W, water supply and demand are balanced in 12 agro-ecological zones, where irrigation demand is tied to supply from both sources, and total availability is specified at the zonal level. Groundwater, in addition to being limited by zone, also has a maximum volume of extraction in the CGE-W that cannot be exceeded in any given year. For our study, we set the limit at 45 MAF, which is below the observed level identified in Young et. al. (2019) of 50 MAF, but it is consistent with our measurement of adequate water availability for all crops. With the limit set at 45 0 MAF, there is very little water stress found. Some of this occurs because there are several optimization processes in water allocation, so water tends to be used perhaps more efficiently than in reality.

The primary focus of this paper is on consumptive use of water by crops. Estimates for such values generally agree on which crops use most water but they differ in absolute values. Figure 3 shows consumptive water use data by crop from the earlier estimates in the CGE-W, from an IWMI climate change analysis, and from remote sensing estimates. The highest values are already in the CGE-W for rice and sugarcane They exceed the medium results by 14 percent for rice and 16 percent for sugarcane, and the lowest values, taken from remote sensing estimates, by nearly one third. We chose to use the highest crop water requirements, which are those currently in the CGE-W. This raises the water required within agriculture and should make the level of releases outside the sector more conservative. However, with higher taxes, more water will be available from rice and sugarcane for other uses in agriculture or otherwise.

Figure 3. Annual Crop Water Requirement (mm/year)

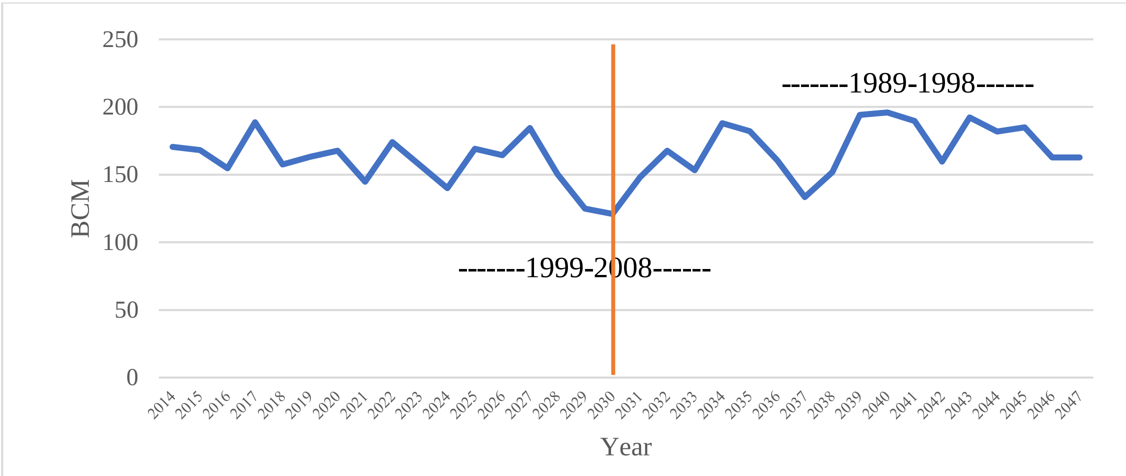


Source. Authors' estimation

Surface water availability varies based on inflows at the rim stations, which are based on historically observed data from 1975 to 2008, which are shifted forward to represent future inflows. Figure 4 shows the series as developed for a longer run analysis, of which the current analysis is a subperiod (Davies and Young (2021)). Figure 4 has one change in the historical sequence: the worst drought on record (years 2000–2014) was placed in the middle of the simulation to avoid having the final period in Davies and Young (2021) coincide with an extreme climate event.

The vertical orange line in the figure shows the ending date for the current analysis, and it points out that the final year in this research has the lowest flows in the entire sequence. However, we assessed the level of water stress using a variable (ExtShk) that shifts a crop's production function down based on the percentage of stress observed. In our simulations, there is little evidence of significant water stress even with our ending year showing low flows. This is likely the case because the CGE-W model uses water efficiently in that it optimizes water use at several stages of a simulation, and, when needed, water can be drawn from resources that otherwise go to the Indus delta without a penalty under the current configuration of the model.

Figure 4. Projected Rim Station Inflows for Simulations, 2014-47



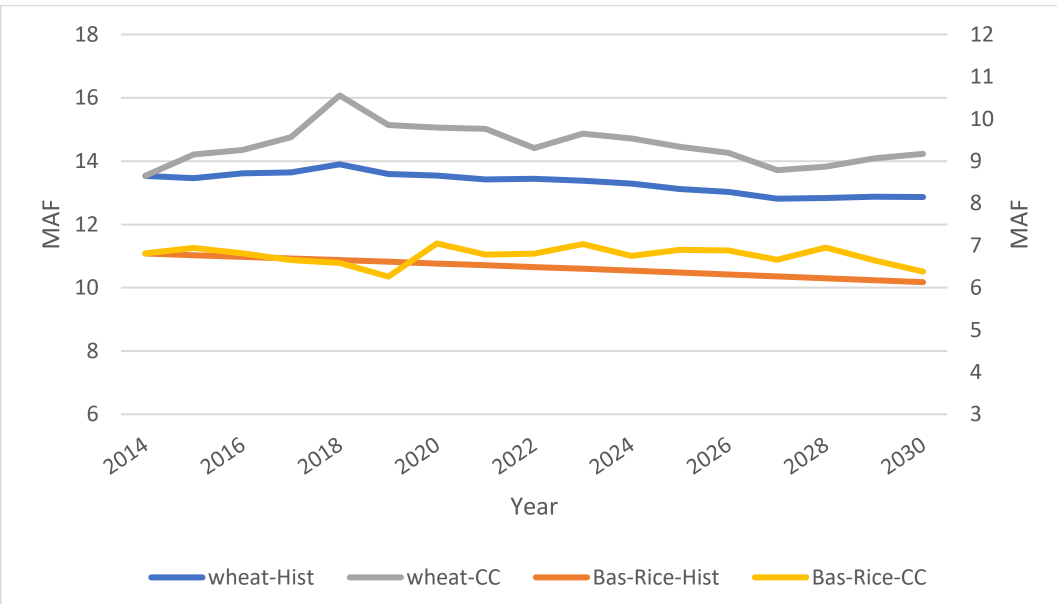
Source. Authors' estimation

Groundwater, salinity and tubewell distribution. In the CGE W model, groundwater is allocated to different canals with associated land having either fresh or saline groundwater. For the analyses, land is aggregated into 12 agroecological zones across the three regions of the country. The maximum extraction of each tubewell is fixed, as is the maximum extraction for a given year. For Punjab, almost 80% of the canal commands have fresh versus saline water, while it's only 26 percent in Sindh. In OP, all groundwater is fresh. The number of acres supported by each tube well runs from a low of 25 acres per tubewell in Punjab to 818 in Sindh and many thousands in OP. Thus, the ability to use water when demanded and the dependence on tubewells is highest in Punjab.

Clearly salinity is a potentially large and growing issue. For instance, Briscoe et al., (2005) calculated a salt accounting balance through the Indus Basin which is similar to the water accounting in Young et. al (2019). In that assessment, they show that about 15 million tonnes of salt is stored somewhere in the Basin each year, about one tonne per hectare of irrigated land. However, this focus has not been central for the CGE-W to date. At present, the salinity proportions in the acreage categories within various canal commands do not change during a simulation. Also, the initial yields per acre are higher in Sindh for most crops and changes in total factor productivity by crop do not reflect differences in salinity levels. This may be leaving out such dynamics that Briscoe et al., 2005 identified but this is reserved for later work.

Climate Change in CGE-W: To examine impacts of climate change on water resources, the CGE-W model employs the LFPHE (Low Flow, Precipitation and High Evaporation) scenario from Young et. al. (2019). The combination of low flows from snow and glacial melt, less precipitation and high evaporation represents a scenario, where there is reduced water input and increased water loss (due to evaporation and evapotranspiration). This dry and hot condition has significant implications for water availability, especially in agriculture, which heavily relies on adequate and reliable water sources. The CGE-W currently uses older General Circulation Models (GCMs) to assess the outlook for precipitation, temperature and inflows from snowmelt in the Northern Areas, which was derived using 17 GCM runs of IPCC-AR4 in Yu et. al. (2013). They estimated that by the 2050s, temperatures could rise by about 3ºC and precipitation might increase even more. Specifically, over the forecast, our analysis assumed that flows would drop by about 8 percent overall with climate change, and 10 percent during high flow months from June to September. Evaporation was simulated to rise by 6.5 percent across the year, while rainfall is expected to drop by 3 percent. The higher evaporation and lower precipitation raises demand for irrigation water for crops, while supply drops from reduced inflows from the northern areas.

Figure 6: Irrigation Water Requirements for Wheat and Basmati Rice, with and without Climate Change



Source. Authors' estimation

An example of these changes is shown in figure 6 above, which gives the irrigation water requirements for two crops, wheat and basmati rice, under a higher climate change scenario compared to the lower historical scenario. For wheat, the water requirements are higher for all years with climate change and reach a maximum in 2019 of 4.2 MAF. There is less variation in rice but still water requirements run higher and more variable with climate change. The maximum difference in that series was 0.8 MAF in 2028.

Household food consumption. Given the importance of food security and household consumption, the baseline projections reflect a steady production of major crops and consumption of food, but with a partial transition toward a healthy diet consistent with the Eat Lancet distribution of calories (Pauw et. al. (2021)). By manipulating demand elasticities and productivity growth for selected commodities, a transition in caloric consumption was achieved (by 2050), including a decline in cereals from over 50 percent to about 41 percent of total calories, complemented with an increase in meat and pulses consumption, from 4 percent to nearly 10 percent. These changes are implemented gradually to 2050, while the tax on water-intensive crops is assessed for 2030. While most of the healthy diets effects are not fully reflected in 2030, some changes in fruits and vegetable results are likely due to this additional change.

5. Results

The results are summarized in two main sections. The first section below looks at the changes in land and water use across regions and different simulations. The basic objective is to see what possible releases of water from agriculture may come from the set of policies evaluated. Secondly, we provide a synthesis of major effects on economic and food security outcomes and add a section on how outcomes differ when a hotter, drier climate is assumed. These include changes in production by province, income growth, illustrating effects on poverty, changes in calories consumed and the effects of climate change on water releases from agriculture.

5.1. Acreage and Water Use Impacts of Rice and Sugarcane Reduction

In the following sections, we focus on a detailed assessment of changes in acreage and water consumption across provinces and crop categories.

5.1.1. Change in Acreage by Province

Tables 5 to 7 present a summary of provincial outcomes for agricultural land use in the Base simulation and in three scenarios reducing acreage in rice and sugarcane. The scenarios decrease rice and sugarcane acreage by 15 percent separately, and jointly in the third scenario. Province-level results can vary from the 15 percent reduction, however.

Punjab. In the Base simulation, overall acreage in Punjab is expected to increase by 1.93 million acres, a 0.28 percent annual growth versus the observed average from 1991 to 2018 of 0.39 percent. This slowing growth in area expansion is reasonable but disguises many shifts across commodities during this period. First, the vegetable and fruit areas are projected by 2030 to expand dramatically by 1.39 and 1.35 million acres, respectively. Other Crops, consisting mainly of fodder and pulses, and Irri rice, see about 6.1 percent growth over the period simulated, followed by cotton area, growing by 5.0 percent. Conversely, wheat acreage is expected to see a pronounced decline, with an estimated reduction of 1.68 million acres by 2030. These shifts, especially for vegetables and fruit, are driven partly by assumptions driving a transition in consumption to a more balanced and healthy diet by 2050, which are discussed in Table 12 below.

With a 15-percent decrease in rice acreage, equivalent to a decline of 430 thousand acres from the commodity tax, overall acreage ***rises*** by 200 thousand acres (0.20 million acres) relative to Base outcomes. Among other crops, there is a significant increase in cotton acreage in the kharif season, at 170 thousand acres, and wheat in the rabi season, with 190 thousand more acres. The growth in higher valued crops adds 180 thousand acres above the Base results (vegetables, fruit, and other crops). Thus, as in the Base simulations, more substitution effects than net total changes are seen.

If national sugarcane acreage decreases by 15 percent, total crop area rises by a small amount (80 thousand acres). In contrast to rice, where all commodities see positive effects, the outcomes for sugarcane are more varied. Acreage expands for wheat, cotton, and fruit, where wheat and fruit use acreage mostly in rabi season, while cotton is primarily in kharif. The expansion in wheat and fruit takes acreage from Other Crops in rabi season, while cotton takes some acreage from basmati rice in khatif season. At the end, these interactions lead to just small increases in acreage. If both sugarcane and rice land decline, a similar pattern to the sugarcane simulation alone exists, where the decline in Other Crops is significant and the expansions in wheat, cotton, and fruit are similar to, but larger than, the outcomes in the single simulation. The land use expansion in vegetables is relatively high compared to the other simulations, while fruit acreage does not expand as rapidly as in the other simulations.

Table 5. Changes in Land Use in Punjab to 2030 based on the Historical Scenario and Three Scenarios (Million Acres)

Crops	**Base**			**15 percent 🡻 in Rice**		**15 percent 🡻 in Sugarcane**		**15 percent 🡻 in Rice & Sugarcane**	
	2014	2030	Change	2030 Level	Diff*	2030 Level	Diff	2030 Level	Diff
Wheat	17.10	15.42	-1.68	15.61	0.19	15.70	0.28	15.99	0.58
Irri Rice	1.39	1.48	0.08	1.41	-0.07	1.55	0.07	1.42	-0.06
Basmati	2.63	2.54	-0.09	2.25	-0.29	2.43	-0.11	2.22	-0.32
Cotton	5.67	5.95	0.28	6.13	0.17	6.15	0.20	6.39	0.44
Sugarcane	1.58	1.59	0.01	1.61	0.02	1.36	-0.23	1.39	-0.20
Maize	1.75	1.78	0.03	1.79	0.01	1.80	0.02	1.81	0.02
Other Crops	8.77	9.30	0.54	9.31	0.01	8.71	-0.60	8.52	-0.78
Vegetables	2.41	3.80	1.39	3.92	0.12	3.90	0.10	4.03	0.23
Fruit	1.57	2.92	1.35	2.97	0.05	3.29	0.36	3.33	0.41
Total	**42.87**	**44.80**	**1.93**	**45.00**	**0.20**	**44.88**	**0.08**	**45.10**	**0.31**

Source: Authors' estimation. IFPRI CGE-W model runs
Note: *The Diff columns show the differences in the change to 2030 in the Base versus each of the scenarios.

Sindh. In the Base simulation in Sindh, found in Table 6, magnitudes are less than in Punjab, but the patterns of change are similar. Like in Punjab, the projected expansions in the Base simulation for vegetables, fruit and Other Crops were large, with 950 thousand acres added in that group by 2030. Cotton also saw some growth in both provinces.   Wheat saw the largest decline in Punjab while rice and wheat had similar losses of acreage in Sindh. Sugarcane was stable in both provinces.

Simulations of reduced rice and sugarcane of 15 percent were ***determined for the whole country***, so individual provincial results were not exactly at 15 percent. In Sindh's case, the reductions are far more than double the 15% percent rate (at 38% percent) while in Punjab it was less than 10 percent. For sugarcane, it is greater in Punjab (at 24 percent) versus just about the 15 percent expected in Sindh, so the differences were narrower and in the opposite direction from rice. For rice, the absolute values are similar in both provinces despite a much larger crop in Punjab. Part of this likely reflects better productivity in Punjab, so with a negative demand shock due to taxes, Sindh absorbs a greater portion of the reduced demand. The 32 percent reduction in rice acreage in Sindh leads to small positive shifts in all other related commodities and a reduction in land use of 200 thousand acres.

The decline of 350,000 acres in the sugarcane simulation is the result of reduced acreage in most crops. Overall, the outcomes in Sindh appeared to mirror the results in Punjab. The three higher valued products all lose acreage relative to the Base simulation, and the significant expansions in wheat and cotton found in Punjab are insignificant in Sindh. Given the large acreage reductions with the 15 percent acreage declines in sugarcane and rice together, the group of higher valued crops has a 380 thousand acreage decline relative to the Base simulation, while wheat and cotton acreage growth remains insignificant in the combined simulation in Sindh.

Table 6. Changes in Land Use in Sindh to 2030 based on Historical Base and Three Scenarios (Million Acres)

Crops	Base			15% ↓ in Rice		15% ↓ in Sugarcane		15% ↓ in Rice & Sugarcane	
	2014	2030	Change	2030 Level	Diff*	2030 Level	Diff*	2030 Level	Diff*
Wheat	2.82	2.52	-0.30	2.55	0.03	2.51	-0.01	2.53	0.01
Irri Rice	0.75	0.46	-0.29	0.15	-0.31	0.39	-0.07	0.13	-0.33
Basmati	0.13	0.12	-0.01	0.10	-0.02	0.12	0.00	0.10	-0.02
Cotton	1.48	1.57	0.10	1.63	0.05	1.61	0.03	1.62	0.05
Sugarcane	0.63	0.61	-0.02	0.59	-0.02	0.51	-0.10	0.51	-0.10
Maize									
Other Crops	0.75	0.85	0.10	0.87	0.01	0.85	-0.01	0.85	0.00
Vegetables	0.68	1.05	0.37	1.06	0.01	0.91	-0.14	0.79	-0.26
Fruit	0.56	1.04	0.48	1.08	0.04	0.98	-0.06	0.92	-0.12
Total	**7.80**	**8.23**	**0.44**	**8.03**	**-0.20**	**7.88**	**-0.35**	**7.47**	**-0.76**

Source: Authors' estimation. IFPRI CGE-W model runs
Note: *The Diff columns show the differences in the change to 2030 in the Base versus each of the scenarios.

OP. In the Base simulation, overall acreage declined by 11.9 percent in OP versus growth in the larger provinces, with declines in all crops except vegetables and fruit (Table 7). Wheat saw the largest reduction in absolute terms, at half a million acres, while proportionally, sugarcane had the largest decline at 41 percent. Fruit had an increase of 27 percent from 2014 to 2030. A main difference is that far fewer substitution effects into other crops occurred in OP compared to Punjab and Sindh, so that the reduction in rice of 140 thousand acres led to an overall drop in land used of 130 thousand acres. In the sugarcane simulation, a reduction of 70 thousand acres occurred in sugarcane, but that reduction did not lead to land being released from agriculture, as growth in wheat and basmati acreage was offset by surprising reductions in irri rice, vegetables, and fruit. The combined simulation appears to be close to a sum of the two individual ones. The results in this region demonstrate very clearly that large reductions are possible when substitution effects are low.

Table 7. Changes in Land Use in Other Provinces in 2030 based on Historical Scenario and Three Scenarios (Million Acres)

Crops	Base			15 percent ↓ in Rice		15 percent ↓ in Sugarcane		15 percent ↓ in Rice & Sugarcane	
	2014	2030	Change	2030 Level	diff	2030 Level	Diff	2030 Level	Diff
Wheat	2.67	2.15	-0.50	2.17	0.02	2.25	0.10	2.27	0.12
Irri Rice	0.39	0.32	-0.10	0.22	-0.10	0.08	-0.25	0.24	-0.08
Basmati	0.1	0.07	-0.03	0.03	-0.04	0.36	0.28	0.04	-0.03
Cotton	0.09	0.08	-0.02	0.08	0.00	0.08	0.00	0.08	0.01
Sugarcane	0.22	0.15	-0.09	0.16	0.01	0.08	-0.07	0.07	-0.08
Maize	1.12	0.84	-0.28	0.84	0.00	0.87	0.03	0.87	0.03
Other Crops	0.74	0.57	-0.15	0.57	0.01	0.59	0.02	0.60	0.03
Vegetables	0.62	0.75	0.11	0.74	-0.02	0.67	-0.08	0.63	-0.12
Fruit	0.92	1.19	0.25	1.18	-0.01	1.14	-0.05	1.14	-0.06
Total	**6.87**	**6.13**	**-0.82**	**6.00**	**-0.13**	**6.12**	**-0.01**	**5.94**	**-0.19**

Source: Authors' estimation. IFPRI CGE-W model runs
Note: *The Diff columns show the differences in the change to 2030 in the Base versus each of the scenarios.

Summary. The growth rate in total land use shown earlier in Table 2 indicated an average of 0.39 percent growth from 1991 to 2018. The Base scenario shows slower growth, of 0.16 percent, perhaps logically given these are projections into a future where land and water are increasingly scarce. The total effects of each simulation are shown at the bottom of the three Tables, and in all simulations in Punjab net acreage changes were positive while in Sindh and OP, they lost acreage. This is still the case even though total acreage can rise with the reduction in sugarcane acreage frees land in two seasons. Thus, the penalty of lower demand and higher costs from commodity taxes is most pronounced in Sindh and OP, which appear to be in the position of meeting the residual demand after Punjab has expanded.

The results also show that there is extensive substitution across crops in agriculture and across seasons. A second pattern is found in differences between tax effects in the two crops. When rice is taxed, land is released and goes to a broad range of all other crops. Those in kharif season benefit directly from the released land, but growth also occurs in the rabi (winter) season. This may come more from the release of water than land, but a clear positive effect exists. This is more complicated in the sugarcane case. Due to land use expansion in both seasons by sugarcane, basmati rice, with a longer growing season, grows significantly while Irri rice drops. Wheat acreage expands has become available in winter season, so other rabi crops such as Other Crops, vegetables, and fruit decline in these simulations.

5.1.2. Changes in Water Use by Province

Tables 8 to 10 present a summary of provincial outcomes for agricultural water use in the Base simulation and three scenarios reducing acreage in rice and sugarcane. The scenarios decrease ***national*** rice and sugarcane acreage by 15 percent, and then in both crops together. The values in this section are for consumptive use based on the crop water requirements shown for the CGE-W in Figure 4. Together, the three regions use about 68 MAF (or 83 billion cubic meters) which is broadly consistent with the values in Figure ES.1 in Young et. al. (2019). These values have losses added back to give applied water quantities at the rim stations at the end of this section.

Punjab. In the Base simulation, overall water use in Punjab is expected to increase by 2.93 million acre feet (MAF), or by 5.8 percent over sixteen years, a result greater than land use growth of 4.8 percent, but below the rate from 1991 to 2014 of 0.9 percent per year shown in Table 3. The growth in water use by 2030 is fastest in vegetables, fruits and Other Crops, with a total increase in that group of 2.05 MAF. More than half of this growth comes from fruit, which expands by 1.07 MAF alone. Sugarcane follows these crops with a 1.39 MAF expansion and rice grows by 0 83 MAF. Wheat water use is expected to decline by 1.25 MAF in 2030. These shifts are driven in part by the assumptions creating a transition in consumption to a more balanced and healthy diet by 2050.

When rice acreage decreases in the individual tax scenario, water use declines by a very large by 2.20 MAF in those crops. This water goes most into cotton (0.88 MAF) and then into the higher valued crops, which add 0.74 MAF, with similar additions in fruit, vegetables, and other crops. In summary, this result shows that taxing rice leads to a significant reduction in water use within agriculture relative to the base scenario and shifts its use to higher valued and non-food commodities. For the movements within agriculture to occur, the IRS must be able to shift these quantities into the rabi season, as wheat and many of the higher valued crops use water in that season.

Of additional interest is that the total water use, as with acreage, rises with a reduction in sugarcane acres. In that simulation, acreage is added in two seasons, leading to a net growth in water demand of about 1.08 MAF. In the rice and combined simulations, water is released from crop agriculture relative to the Base expansion, with the combined reduction providing 0.64 MAF to other uses. From another perspective, the total water released in the combined policies frees 6.15 MAF, but 2.42 MAF shifts into cotton and 2.60 MAF into higher valued crops, leaving just 0.64 MAF to be released from agriculture. Additionally, when rice decreases via the commodity tax, sugarcane's water use only rises slightly, but rice responds positively and strongly when sugarcane acreages decrease via the commodity tax.

Table 8. Changes in Water Use in Punjab to 2030 based on Historical Scenario and Three Scenarios (MAF)

Crops	Base			15 percent ↓ in Rice		15 percent ↓ in Sugarcane		15 percent ↓ in Rice & Sugarcane	
	2014	2030	Change	2030 Level	Diff	2030 Level	Diff	2030 Level	Diff
Wheat	10.75	9.50	-1.25	9.61	0.11	9.73	0.24	9.89	0.39
Irri Rice	3.63	4.23	0.60	2.82	-1.41	4.85	0.63	2.92	-1.30
Basmati	6.44	6.67	0.23	4.88	-1.79	7.39	0.72	4.93	-1.74
Cotton	11.58	11.51	-0.07	12.39	0.88	12.55	1.04	13.93	2.42
Sugarcane	5.65	7.04	1.39	7.17	0.13	3.86	-3.18	3.93	-3.11
Maize	0.70	0.68	-0.02	0.70	0.02	0.73	0.05	0.76	0.08
Other Crops	6.19	6.34	0.15	6.59	0.25	6.87	0.52	7.21	0.86
Vegetables	3.03	3.86	0.83	4.11	0.25	4.29	0.43	4.64	0.77
Fruit	2.26	3.33	1.07	3.57	0.24	3.96	0.63	4.30	0.97
Total	**50.22**	**53.15**	**2.93**	**51.84**	**-1.31**	**54.23**	**1.08**	**52.51**	**-0.64**

Source: Authors' estimation. IFPRI CGE-W model runs
Note: *The Diff columns show the differences in the change to 2030 in the Base versus each of the scenarios.

Water use in Sindh province. In the Base simulation, overall water use in Sindh is expected to increase by 0.94 MAF, or by 6.7 percent over sixteen years, a higher growth than in Punjab. The growth in water use by 2030 is fastest in sugarcane, fruit, and Irri rice, with a total increase of 1.16 MAF in those crops. All other crops have only small changes except for wheat, which uses 0.30 MAF less in the Base simulation.

Looking across simulations, the total released water is greatest in the combined simulation, at 1.61 MAF. The individual simulations released far less than the combined scenario because substitution into and out of rice and sugarcane is restricted in the latter simulation, as both crops must reduce water. A 15 percent decrease in acreage of rice leads to a 0.13 MAF decline in rice's water use, most of which comes from Irri rice, as basmati is a marginal crop. This reduction goes predominantly into fruit and small amounts into wheat, sugarcane, and Other Crops. In contrast to most other simulations, cotton declines. The decrease nationally in sugarcane leads to a significant decrease in water use in Sindh of 1.38 MAF in that crop, but all other crops see positive changes in water use, especially Irri rice, with some to cotton and fruit. The bottom line then is just a small release from agriculture of 0.26 MAF relative to the Base simulation is made.

Table 9. Changes in Water Use in Sindh to 2030 based on Historical Base and Three Scenarios (MAF)

Crops	Base			15 percent ↓ in Rice		15 percent ↓ in Sugarcane		15 percent ↓ in Rice & Sugarcane	
	2014	**2030**	**Change**	**2030 Level**	**Diff***	**2030 Level**	**Diff***	**2030 Level**	**Diff***
Wheat	2.46	2.17	-0.30	2.24	0.03	2.19	0.03	2.29	0.12
Irri Rice	4.46	4.81	0.35	3.32	-0.35	5.38	0.57	3.30	-1.51
Basmati	0.43	0.42	-0.01	0.32	-0.06	0.45	0.03	0.31	-0.11
Cotton	2.39	2.40	0.00	2.63	-0.05	2.58	0.18	2.86	0.46
Sugarcane	2.59	3.04	0.45	3.12	0.02	1.66	-1.38	1.74	-1.30
Other Crops	0.46	0.48	0.02	0.51	0.02	0.52	0.04	0.55	0.07
Vegetables	0.53	0.60	0.07	0.68	0.06	0.68	0.08	0.80	0.21
Fruit	0.78	1.14	0.36	1.31	0.21	1.32	0.19	1.59	0.45
Total	**14.10**	**15.05**	**0.94**	**14.13**	**-0.13**	**14.79**	**-0.26**	**13.44**	**-1.61**

Source: Authors' estimation. IFPRI CGE-W model runs
Note: *The Diff columns show the differences in the change to 2030 in the Base versus each of the scenarios.

Water use in OP. In OP, the Base simulation has overall water use decline by eight percent, and as in the outcome for acreage, either declines or very small increases were seen in all crops. Naturally, following acreage, wheat saw the largest reduction in absolute terms, at 0.10 MAF, followed by sugarcane with a 0.08 MAF decrease.

The same lack of substitution effects to other crops exists in water use, suggesting that, for most crops, the translation of lower demand from higher taxes and the existence of many substitution effects in Punjab and Sindh shows up in production in OP, and that region ends up being the most penalized. From the perspective of releasing water, the OP saw both proportional and absolute levels far in excess of those in Punjab and Sindh. For the combined reduction of sugarcane and rice, 0.64 MAF was released in Punjab, 1.61 MAF became available for other uses in Sindh, while 0.90 MAF is pulled from agriculture in OP. Given the complexity of moving water outside its current infrastructure and a variable presence of groundwater, these excesses may not be that useful if they occur in OP. Thus, strategy needs to start upstream as far as possible to make the best use of released water flows.

Table 10. Changes in Water Use in Other Provinces to 2030 based on Historical Base and Three Scenarios (MAF)

Crops	Base			15 percent ↓ in Rice		15 percent ↓ in Sugarcane		15 percent ↓ in Rice & Sugarcane	
	2014	**2030**	**Change**	**2030 Level**	**diff**	**2030 Level**	**diff**	**2030 Level**	**Diff**
Wheat	0.38	0.28	-0.10	0.28	0.00	0.26	-0.01	0.26	-0.02
Irri Rice	1.20	1.16	-0.04	0.75	-0.41	1.19	0.03	0.69	-0.46
Basmati	0.24	0.20	-0.04	0.15	-0.06	0.20	0.00	0.13	-0.07
Cotton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugarcane	0.80	0.72	-0.08	0.69	-0.03	0.39	-0.33	0.38	-0.34
Maize	0.11	0.09	-0.02	0.08	0.00	0.08	0.00	0.08	-0.01
Other Crops	0.18	0.15	-0.03	0.15	0.00	0.15	0.00	0.15	-0.01
Vegetables	0.21	0.22	0.01	0.22	0.00	0.22	0.00	0.23	0.00
Fruit	0.13	0.16	0.03	0.16	0.00	0.16	0.01	0.17	0.01
Total	**3.25**	**2.98**	**-0.26**	**2.50**	**-0.48**	**2.66**	**-0.32**	**2.08**	**-0.90**

Source: Authors' estimation. IFPRI CGE-W model runs
Note: *The Diff columns show the differences in the change to 2030 in the Base versus each of the scenarios.

Summary. The historical withdrawals from 1991 to 2018 showed a growth rate of 0.69 percent annually over that period. although it appears to level off in later years. In the base simulation, the growth rate was 0.30 percent, less than half the historical growth of withdrawals. From another perspective, the total water released from rice and sugarcane in all regions with the combined tax policies frees nearly ten million acre feet (9.94 MAF), but only 3.15 MAF exits the sector. The largest shifts are into cotton (2.88 MAF), and fruit (1.43 MAF), with vegetables and Other Crops receiving about one MAF and wheat 0.49 MAF. In a food security sense, shifts into cotton can be thought of as water exiting the sector.

In all provinces, reduced water use from taxes is generally found, ranging from a negative 0.13 MAF to 1.31 MAF on sugarcane and rice separately. When rice acreage is taxed, about 1.92 MAF is released across the three regions, with most from Punjab. Due to a wider seasonal acreage use in sugarcane, water use grew in the sugarcane scenario in Punjab of 1.08 MAF was offset. The potential release of water from taxation of both commodities together is 3.15 MAF, a substantial amount, but it is consumptive use, and most estimates of water use outside agriculture will be for applied water. We return to this issue later. With these policies, water is released across both seasons, so water savings needs to be managed by season. We did not look at the effects of climate change and changes in crop water requirements, which might change this analysis substantially.

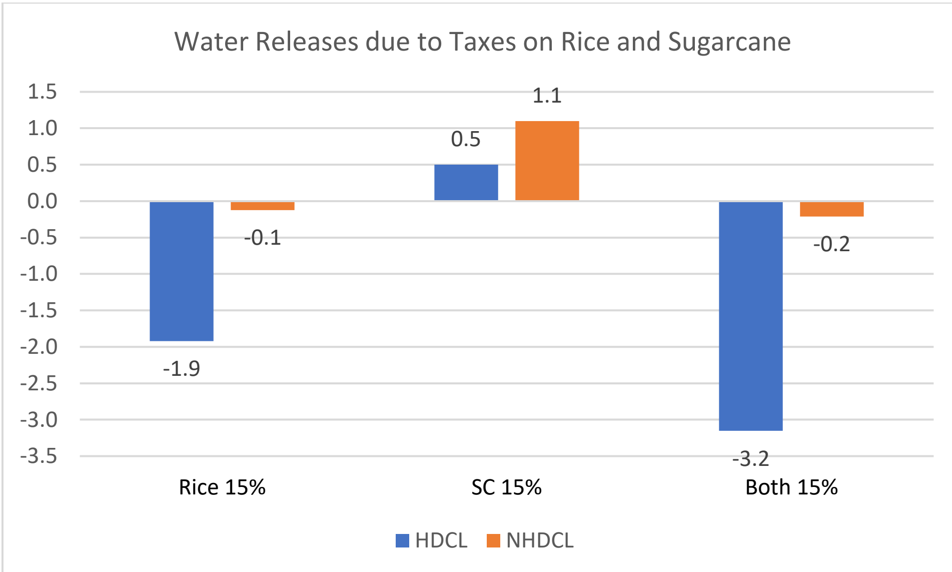
When rice acreage is taxed, about 1.92 MAF is released across the three regions, with most from Punjab. Due to a wider seasonal acreage use in sugarcane, water use grew in the sugarcane scenario in Punjab and about half of that was offset by releases in Sindh and OP. The potential release of water from taxation of both commodities in all regions together is 3.2 MAF, a substantial amount, but it is consumptive use, and most estimates of needed water use outside agriculture will be for applied water. In Appendix I, a method is developed to tie our estimated values to applied amounts, which shows that the 4.68 MAF in applied water comes out of agriculture when both crops are taxed, and 4.23 MAF is released when just rice is taxed.

5.1.3. Climate Change Effects on Crop Water Uses

Figure 5 illustrates that in the absence of climate change (NHDCL), a reduction of 15 percent in rice acreage results in the release of slightly less than 2 million acre-feet (MAF) from agriculture. By imposing taxes on both rice and sugarcane, 3.2 MAF of irrigation water is released from agriculture. However, under the climate change scenario (HDCL), characterized by lower flows from snowmelt and less precipitation, along with greater evaporation, the available water for crops diminishes significantly across all simulations. Consequently, even with the same tax structure, there is a limited water available for reallocation.

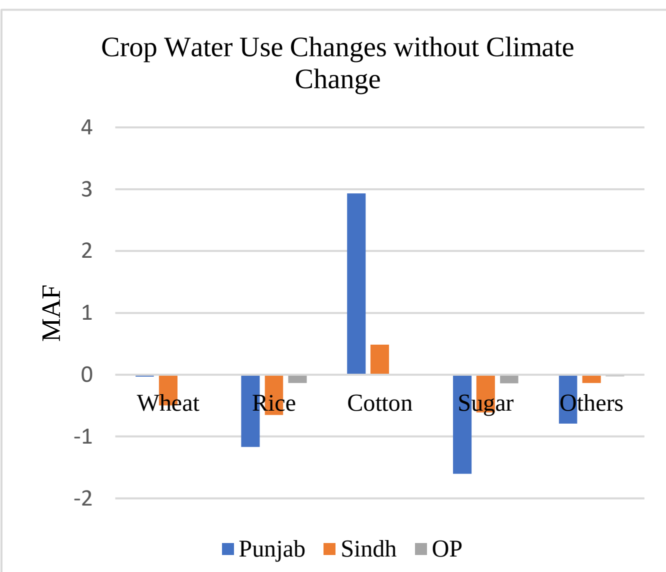
The changes in crop water use across various agricultural commodities and regions are depicted in Figure 6, which highlights water use changes with taxes on both sugarcane and rice, without and with climate change. Without climate change, wheat cultivation in Punjab releases 0.03 MAF of water, while with climate change, it shifts to an increase in water use of 0.19 MAF. In Sindh, the cultivation of wheat experienced a reduction in water releases, declining from 0.50 MAF to 0.09 MAF in the HDCL scenario. For rice, without climate change and with taxes, there is a substantial decrease in water use across all regions, particularly in Punjab (-1.17 MAF) and Sindh (-0.65 MAF). However, under climate change conditions, rice exhibits fewer reductions in water released in Punjab (-1.07 MAF), Sindh (-0.72 MAF), and other provinces (-0.17 MAF). Cotton, on the other hand, demonstrates significant increases in water use across all regions without climate change, with the highest in Punjab, i.e., 2.93 MAF. Under climate change, cotton continues to show water use increments, particularly in Punjab (3.57 MAF), which appears to come from a lack of options in kharif season with both rice and sugarcane being cut, uses of greater cotton production to offset inputs are available. The releases from other crops including fruit and vegetables essentially disappear. (For details, refer to Appendix 2).

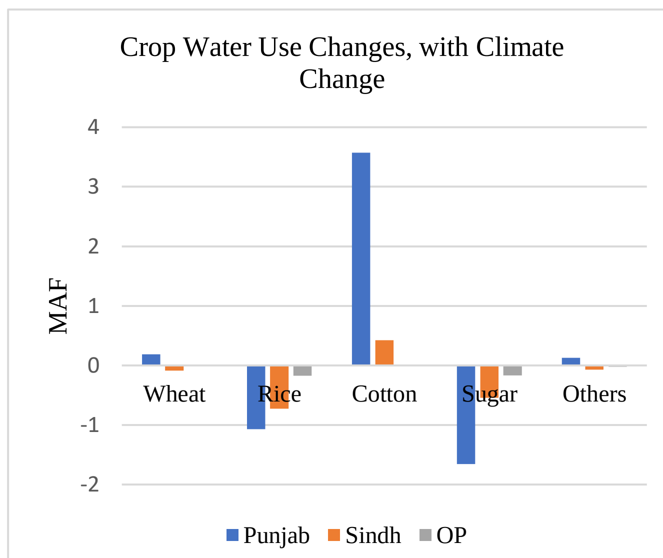
Figure 5. Annual Water Releases due to Taxes on Rice and Sugarcane, with and without Climate Change



Source: Authors' estimation from IFPRI CGE-W model runs.

Figure 6: Region wise Crop Water Use Changes with Taxes on Both Sugarcane and Rice, without and with Climate Change





Source: Authors' estimation from IFPRI CGE-W model runs.

5.1.4. Production and Trade Effects

Table 11 shows the changes in total agricultural production for each province, first for the Base scenario, and then with differences for three acreage reduction simulations. In percentage terms, these are small relative to the total agricultural economy, partly because these reductions, while large individually, are small as a proportion of all agriculture and because 15 percent is a modest cut as discussed in the section above. Also, there are substitution effects into other agricultural commodities, so the agricultural economy performs quite differently than as a simple subtraction of production in selected crops.

In the Base scenario, the growth rate was around 2.8 percent per year in Sindh and Punjab, and higher in OP at 3.6 percent. These values came from the historical scenario based on water availability at the Rim stations, which are similar to the historical pattern shown in Figure 4. The total production in Punjab was more than twice the combined amounts in the other regions, and so the overall Pakistan outcomes tend to be heavily affected by what happens in Punjab.

The largest negative effect was in Punjab, where total production drops by PKR 18.7 billion when 15 percent of the acreage is taken out of rice. The other regions also see losses in the rice simulations but at smaller levels. In contrast, there is a PKR 19.7 billion ***increase*** in production in Punjab with the sugarcane simulation, and smaller but still positive changes in the other provinces. These figures are of course small comparatively, but it is notable that the model suggests a push factor towards higher valued agricultural production for the sugarcane simulation.

Table 11: Percent Change in Production, with Hist Scenario

Provinces	**Base**			15 percent ↓ in Rice	15 percent ↓ in Sugarcane	15 percent ↓ in Rice & Sugarcane
	2014	2030	Change	**Difference**	**Difference**	**Difference**
Punjab	2,308	3,677	1,369	-18.7	19.7	-6.5
Sindh	642	1,003	360	-9.3	7.9	-8.4
OP	402	716	314	-2.9	5.5	2.4
TOTAL	**3,353**	**5,396**	**2,043**	**-30.8**	**33.1**	**-12.5**

Source: Authors' estimation. IFPRI CGE-W model runs

In contrast to expectations, where pulling a resource out of production leads to losses, there are national production gains in all regions for the sugarcane scenario, as when sugarcane acreage is decreased, agricultural production growth increases by PKR 33.1 billion. Much of this likely comes from the fact that acreage is released in both kharif and rabi seasons for that crop, so potential gains are higher and make use of the land and water resources better.

Trade Dimensions. When examining the economic implications of acreage reductions on agricultural output, an important extension is to show the role that trade plays for both sugarcane and rice. Rice has been consistently exported, and raw sugar, while generally thought of an export crop, was imported in 2014 and even in 2020/21, when the government imported 350,000 metric tonnes to cover shortages and limit consumer price increases (USDA, 2021). Final goods firms sell to domestic consumers or to international destinations by considering relative prices, while considering quality differences between the two sources.

Table 12: Percent of Production Growth, and Portions of Rice and Raw Sugar Exported or Imported, 2014-2030

	Base Percent*			15 percent ↓ in Rice		15 percent ↓ in Sugarcane		15 percent ↓ in Rice & Sugarcane	
	Output**	Trade 2014	Trade 2030	Output	Trade 2030	Output	Trade 2030	Output	Trade 2030
Irri Rice (E)	45.5	12.1	15.8 (3.7)	23.0	7.0 (-8.8)	99.0	25.7 (10)	22.0	6.0 (-9.8)
Basmati Rice (E)	37.0	16.6	22.9 (6.3)	17.0	10.2 (-12.7)	95.0	41.7 (18.8)	15.0	9.4 (-13.5)
Raw Sugar (I)	46.1	28.2	8.7 (-19.5)	62.0	21.7 (13.0)	2.0	58.9 (50.2)	-2.0	63.1 (54.4)

*Raw Sugar is imported, while both rice varieties are exported.

**The output columns show the percentage that production grows from 2014 to 2030. The Trade columns give the percentage of production exported or imported in the specified year.

Note: Figures in parentheses show the difference from base

To examine the behavior of exports and imports, Table 12 compares various growth rates in production (output) and trade as a percentage of production. In the base scenario, exports of rice grew by 3.7 percent for Irri rice, while basmati rice exports expanded 6.3 percent as percentages of Pakistan's production from 2014 to 2030. As production of Irri rice grew by 45.5 percent and exports grew as a proportion of that expansion, it can be concluded they grew faster than overall production. Imports of raw sugar dropped from 28.2 percent of Base production growth to 8.7% in 2030 so domestic output substituted for imports.

To interpret the table, consider the case of Irri rice. With a tax of 15 percent on that commodity, production growth reduced by 50 percent. Had trade stayed at the 15.8 percent proportion seen in the base analysis, the growth would have dropped by 50 percent as well. However, its proportion dropped, suggesting that it was hurt more by the tax than was domestic consumption. The same is true of basmati rice, where the tax reduces production growth by 46 percent and exports saw a reduction from their Base proportion of 12.7 percent, so both these export products saw greater decline than did production. For sugarcane, when rice is taxed, its production growth accelerated from 46 percent to 62 percent, as internal prices were raised from the shift of land into that crop, which encourages both domestic production as well as a surge in imports. If sugarcane is taxed, its production growth drops to just two percent, and imports quadruple as a percentage of production. The biggest change is the growth in production and exports of rice if sugarcane is taxed, where production growth doubles for both types of rice and exports grow to one quarter in Irri rice and over forty percent in basmati rice. The results in the combined scenario approximate a summation of the individual taxes but without the big shift from sugarcane to rice.

5.1.5. Nutrition Effects

A third important dimension for the evaluation of the policy interventions is changes in nutrition. Table 13 reports the percentage of calories consumed in the major consumption categories (aggregated as often reported in EAT Lancet nutrition analyses), where the trend in the base percentages between 2014 and 2030 is shown for those Eat Lancet categories (Pauw et. al. 2021). For perspective, the desired balance between sources of calories in the Eat Lancet reports are given in the second column, where deficiencies in consumption are clearly shown in comparisons with the estimated consumption proportions. As presented earlier, the derivation of the Base scenario was designed to create a transition towards the EAT Lancet proportions of calories by 2050. By 2030, only slight movements had been made in that direction.

Table 13. Change in Nutrition in percent of Total Calories Consumed

	EAT Lancet Reference Diet	**Base**		**15 percent 🡻 in Rice**	**15 percent 🡻 in Sugarcane**	**15 percent 🡻 in Rice & Sugarcane**
	Calorie Percent	2014	2030	diff*	diff	diff
CEREALS	34	50.77	50.09	0.69	-0.53	-0.25
MEAT/Pulses	29	4.08	5.30	-0.12	-0.09	-0.16
DAIRY	6	14.15	11.41	-0.12	-0.13	-0.39
VEGETABLES	3	3.50	1.93	0.15	0.08	0.10
FRUITS	5	2.03	1.01	0.09	0.06	0.08
OIL	18	14.61	15.06	-0.04	0.29	0.11
DISCRETIONARY (Sugar)	5	10.85	15.20	-0.64	0.31	0.52

Source: Authors' estimation. IFPRI CGE-W model runs
Note:*diff shows the difference between the Base percentage value in 2030 and a given simulation result in the same year. For cereals, a + 0.69 is added to the 50.09 in the base, yielding a positive 0.01 change from 2014 with rice decreased by 15 percent levels.

Table 13 shows that cereals are significantly over consumed, as the recommended portion of calories from that source is 34 percent, but in Pakistan about 50 percent comes from cereals. This is similar for discretionary foods (mostly sugar), which went from double the recommended amount of 5 percent to triple that level by 2030. Also, dairy and meat are consumed far from recommended amounts, with dairy over consumed and meat (with pulses) wildly under consumed, at only 6 percent of total calories versus a desired proportion of 29 percent. However, the direction of change for those two foods is correct between

2014 and 2030. Vegetables are consumed at about the right rate in the base, but percentages go in the wrong direction, despite parameters designed to encourage their demand. Fruit is too low in the base year and becomes even lower over the simulation. Remarkably, oils are approximately consumed correctly and change in the correct direction.

5.1.6. Income Effects

Households in the model are separated into categories of interest, which is done in table 14. They are divided into three broad categories, including farm, non-farm rural, and urban households, which are further divided into poor and non-poor households, giving six groups. The table summarizes the growth in total income for each household group from 2014 to 2030 in the Base simulation by presenting average annual increases in a group's income. The growth rates include both growth in the number of households as well as income per household.

Reflecting a whole series of factors in the Base simulation, the percentage income growth in farm households is highest, while urban households see the lowest growth, even though the ***levels*** of household income are greater in non-poor urban households. For example, growth rates among farm households are all over 4 percent while, except for the rural non-farm, non-poor group, are under 3 percent. However, because the number and income levels of different household categories varies significantly, urban non-poor households see the greatest expansion of household income, at PKR 5,994 billion, while poor farm households see the least growth (PKR 372 billion), even with a high percentage growth.

Table 14: Percent Change in Income, with Hist Scenario- In Millions of Rupees

Households Groups	Base			15 percent 🡻 in Rice	15 percent 🡻 in Sugarcane	15 percent 🡻 in Rice & Sugarcane
	2014	**2030**	**Change**	**Difference**	**Difference**	**Difference**
Rural Farm Poor (RFP)	379.25	752.17	4.28	-0.01	0.15	0.11
Rural Farm Non-Poor (RFNP)	5682.10	10747.01	4.29	-0.02	0.15	0.11
Rural Non-Farm Poor (RNFP)	1005.16	1575.04	2.81	-0.06	0.02	0.01
Rural Non-Farm Non-Poor (RNFNP)	1878.97	3235.15	3.40	-0.06	0.04	0.03
Urban Poor (UP)	1248.38	1851.56	2.67	-0.05	0.01	0.00
Urban Non-Poor (UNP)	11714.76	17708.51	2.58	-0.05	-0.03	-0.03

Source: Authors' estimation. IFPRI CGE-W model runs

Because households derive income from many sources, and the effects simulated here are small compared to even all agricultural sources, the changes in growth rates in the right-hand columns are very small. Despite these small effects, the directions are clear and different for the two simulations. When rice is decreased by 15 percent, all households see reductions in small percentages of growth, which are larger for non-farm households. In contrast, when sugarcane decreases, all households gain income relative to the base, with farm households seeing the largest increases of 0.15 percent in income. When both commodities are reduced, the results tend to weigh the sugarcane results more highly.

6. Alternative Policies

It is well known that taxing outputs is not the only way to influence incentives to affect crop production, or to manage government revenues and producer incomes. This section gives a brief comparison of alternatives that could be used instead of the commodity tax to compare water releases in selected alternatives. For instance, the analysis at the provincial levels above showed shifts into cotton production in most simulations, with increases in both land and water going into that commodity. Thus, we examine outcomes when cotton is taxed in addition to rice and sugarcane. We reduced the rice and sugarcane taxes to 30 percent and included cotton at the same rate. The idea to be tested is that taxes could be lower if they are broader.

Table 15. National Water Use with Alternative Tax Policies (MAF)

Crop	Combined SC and Rice*	SC Rice Cotton - 30 30 30	Difference (Col. 3 – 2)	Fertilizer	Difference (Col. 4 – 2)	Scaled Based on CWR	Difference (Col. 5 – 2)
Wheat	12.6	12.8	0.2	12.4	-0.2	14.7	2.1
Rice	12.4	14.1	1.6	14.2	1.8	13.7	1.3
Cotton	16.5	10.2	-6.3	11.8	-4.7	11.9	-4.6
Sugarcane	8.3	9.6	1.4	9.0	0.8	7.1	-1.2
Maize	0.8	0.8	0.0	0.8	0.0	0.9	0.1
Other crops	7.9	8.2	0.3	8.2	0.3	7.7	-0.2
Vegetables	5.7	6.5	0.8	6.3	0.6	6.6	0.9
Fruit	6.0	6.8	0.8	6.7	0.7	6.8	0.8
Total	**70.1**	**68.9**	**-1.2**	**69.5**	**-0.7**	**69.4**	**-0.7**

Source: CGE-W model runs
*This scenario released 3.2 MAF out of agriculture. The other reported simulations add varying amounts to that value.

We added two simulations that are more explicit taxation of inputs rather than outputs. First of all, we included a tax on fertilizer of 30%, which some analysts believe is simpler to implement than a tax on water and may be reasonably well correlated with water use. Additionally, in the same spirit, we scale the taxes on the outputs to be relative to their crop water requirements. In this case, we added wheat with the lowest requirements and scaled up the others proportionally and relative to a 9 percent tax on wheat. In general, this gave us an equivalent set of taxes as we originally used but are broader and scaled differently across the commodities. The results are found in Table 15.

The second column of Table 15 shows the results of the main policy examined, of taxing sugarcane and rice to get 15 percent acreage reductions. As noted, this led to a 3.2 MAF reduction in water required within agriculture. The most effective alternative policy came from taxing rice, sugarcane, and cotton at 30 percent, which leads to a further reduction of 1.2 MAF, giving a total relative to the Base of 4.25 MAF (or 8.73 MAF in applied water use). The others are not quite as powerful as this first alternative, but each further reduces the water required in agriculture by 0.7 MAF relative to the tax on both rice and sugarcane.   Regarding specific commodities, relative to taxing just sugarcane and rice there are broad gains in water use across all commodities. Rice tends to benefit the most in all scenarios, and cotton is penalized significantly. However, the latter outcome is more a result of high cotton water use in the first policy when it benefitted from the release of water and land in kharif with just rice and sugarcane being taxed.

Important dimensions of policy choice for those in Table 15 are implementation challenges. The commodity tax in this analysis is currently used as a general sales tax, and so this policy is just an extension of that structure. The taxation of a broader set of commodities or with different ratios would still be based already-used policy tools. Given the industrial structure of the fertilizer industry, it would be easy to tax that sector as well. Other options like taxing water, or imposing quotas would raise the complexity of tax administration considerably and so have not been considered. There is no question that the levels of taxation in this analysis will face political resistance, so combinations will need to be used and certainly the levels could be scaled back given the success shown in obtaining water releases.

7. Conclusions

The future demand for water resources that compete with agriculture include growing industrial and domestic uses from rising populations and income in Pakistan, as well as for environmental water flows into the Indus River delta and other habitat maintenance needs. To examine selected policies designed to facilitate this shift, this paper looked at the imposition of commodity taxes sufficient to decrease national sugarcane and rice acreage by 15 percent separately and jointly. The main purpose is to understand if significant quantities of water can be taken out of agriculture using such taxes.

Using IFPRI's CGE-W, the paper first traced the responses of land use to these taxes. In a combined simulation taxing both rice and sugarcane, land use grows by 1.56 million acres, despite losses in OP of 320 thousand acres. Thus, the penalty of lower demand and higher costs from commodity taxes is highest in OP. Total acreage rises because the reduction in sugarcane acreage frees land in two seasons, and land (and water) sees most growth in crops with rabi land use. This also leads to growth in output of PKR 33.1 billion in the agricultural sector. When rice acreage is taxed, about 1.92 MAF is released across the three regions, with most from Punjab. There are associated production losses of PKR 30.1 billion when taxing rice. Due to a wider seasonal acreage use in sugarcane, water use grew in the sugarcane scenario in Punjab by 1.08 MAF.

The total water released from rice and sugarcane in all regions with combined taxes frees nearly ten-million-acre feet (9.94 MAF), and 3.15 MAF exits the sector. The largest shifts are into cotton (2.88 MAF), and fruit (1.43 MAF), with vegetables and Other Crops receiving about one MAF each, while wheat added 0.49 MAF. In a food security sense, shifts into cotton can be thought of as water exiting the sector. Without this significant substitution into other crops, more water could be released for other uses. The results in OP clearly demonstrated that, without much substitution across crops in that region, a reduction in rice of 0.6 MAF led to an overall decline in water used of 0.85 MAF, while in sugarcane, 0.38 MAF was released, and the overall drop in water used was 0.60 MAF.

Two extended analyses were added to the above results. The first was the role of international trade, which showed that trade responded more than production in both positive and negative ways with the taxes. For instance, when rice was taxed, production growth slowed by around 50 percent, but the proportion traded declined more, so its growth rate was even lower. In that simulation, however, sugarcane (actually raw sugar is traded) responded with much higher production growth and reduced imports. The second extension was to apply a hot dry climate future in the simulations, in which water releases from agriculture virtually disappeared.

Additionally, we simulated several other policies including fertilizer taxes, a scaled commodity tax based on crop water requirements and a 30% tax on rice, sugarcane, and cotton. Using a method designed to estimate applied water levels from consumptive amounts, the combined simulation of sugarcane and rice led to 6.25 MAF in applied water use, while 3.88 MAF in applied water was released from the rice tax alone. The largest effect came from the 30% tax on rice, sugarcane, and cotton together, which permitted 8.63 MAF, over 80 percent of the often-mentioned 10 MAF that must come out of agriculture for other uses. The tax levels are high, but if there is less substitution within crops in agriculture or the transition to a more nutritious diet is slower, the rates may not be as high as estimated here.

In the end, it is clear that the potential for releasing water from agriculture for other purposes exists, and some characteristics might make this easier or harder to accomplish. First, there is a significant change in demand towards higher valued and more nutritious foods, which raises water demand within agriculture in most scenarios. Also, the level of substitution between crops within the sector is high, so water releasees tend to be small portions of total releases in taxed crops. So, if substitution among crops or the demand for nutritious food is lower, more water could be released. Nonetheless, the level of taxes required to get this accomplished is high and there will be political pressure not to pursue these policies. . Creative policies to buy out tubewell owners and other incentives to curb water use will be needed. A hot and dry climate in the future will make these releases harder to reach, even with the high taxes examined in this analysis.

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Appendices

Appendix 1: Estimates of Applied water releases from agriculture

The analysis provided in this paper used consumptive use of water to determine amounts used by different crops and the potential releases from the sector. This has been calculated in the CGE-W from crop water requirements less effective rainfall. More conventionally, figures are given as applied water in canals or at the rim stations, so consumptive use needs to add back on-farm and distribution system losses so alternative choices at the canal level can be seen easily.

Using Figure ES-1 from Young et.al. (2019), which contains a full water accounting for the Indus River System, we derive coefficients that link consumptive use back to applied use. The following equation spells out the relations in general for a system with both groundwater and surface water, and with differential losses between the two sources:

$$CU + EV = B_1*GW + B_2*SW = 0.9*GW + 0.66*SW$$

Where CU is consumptive use and EV is evaporation loss based on temperature and rainfall at the field level. These uses must be met by either groundwater (GW) or surface water (SW) resources. The coefficients B_1 and B_2 are the proportion of groundwater or surface water that gets to the field, that is after deducting losses in the distribution system. To derive B_1 and B_2 . we assumed losses in groundwater is just ten percent and so 90 percent of groundwater gets to the end of system. Given that assumption and known quantities for other values from Young et. al. 2019, we derived B_2 equal 0.66, or 1/3 of surface water is lost before getting to the field.

$$GW = 0.4*AW \qquad SW = 0.6*AW \qquad EV = 0.5*CU$$

The main objective of this exercise is to get \estimates of applied water (AW) from known values of consumptive use (CU) and other known relationships which we took from Young et. al. 2019. As expressed above, 40% of water comes from groundwater and 60% from surface water. Evaporation losses are 50% of consumptive use. Together, these yield the following equation:

$$AW = 1.5*CU/.756$$

We implement these calculations for three estimated consumptive use values:

- The combined simulation of sugarcane and rice: 3.2 CU MAF = 6.35 AW MAF,
- The rice simulation alone: 1.92 CU MAF = 3.81 AW MAF

- A 30% tax on rice, sugarcane, and cotton : 4.4 CU MAF = 8.73 AW MAF

These results make it clear that there is potential via the commodity tax to get releases from agriculture an of significant magnitudes. Particularly, a 30% tax on three large reef crops will give more than 80% of the 10 million MAF that has been suggested by some analysts.

Appendix 2: Crop Water Use Changes with Taxes on Both Sugarcane and Rice, with and without Climate Change

In Punjab, the total water release in the base scenario amounts to 2.2 MAF. Initially, 0.83 MAF of water was released from wheat without considering climate change. However, with climate change, there was a 57.8% increase in water usage for wheat in the base scenario. Following the implementation of taxation, the water released from wheat without climate change decreased to 0.8 MAF. Additionally, water use increased in hot and dry conditions, but the increase was relatively less compared to the base scenario, amounting to 0.29 MAF. For Basmati rice and maize, they contributed significantly to the total water release, accounting for 1.38 MAF. In the climate change scenario, water release decreased from 0.56 MAF to 0.35 MAF. With the introduction of taxation, water released from Basmati rice increased without climate change, while in the climate change scenario, more water was released (0.26 MAF). This suggests that the policy of taxation on both rice and sugarcane effectively encourages water release from Basmati rice.

Approximately 82.95% of the water released for all crops under taxation on sugarcane and rice is consumed by cotton without hot and dry simulation. Meanwhile, with climate change, water usage for cotton increases significantly from the base (0.13 to 3.57 MAF). In the case of fruits and vegetables, the climate change scenario, coupled with the policy intervention of taxation on sugarcane and rice, resulted in more water being released compared to scenarios without climate change.

In Sindh, in the absence of climate change, the predominant water-releasing crop is Irri rice, accounting for 85 percent of the total. With the introduction of taxation, the combined water release from wheat, Irri rice, and sugarcane becomes most significant, totaling 1.71 MAF. However, in the context of climate change, there is an increase in water consumption for cotton, amounting to 0.21 MAF. The water release under the taxation policy is reduced for wheat, Irri rice, and sugarcane—without climate change, 1.89 MAF of water was released, whereas with climate change, the released amount decreased to 1.44 MAF. Cotton in Sindh follows a similar pattern to Punjab, experiencing an increase in water consumption under hot and dry conditions.

In the context of the Other Province (OP), in the absence of any policy intervention and without climate change, the primary water-releasing crop is Irri rice, contributing to 42% of the total water release. The implementation of taxation on rice and sugarcane resulted in an increase in water release, particularly from sugarcane. Under climate change conditions and taxation, the total water released experienced an increment, reaching 0.37 MAF, compared to 0.28 MAF in the scenario with climate change but no taxation.

Table A.1. Water Use Changes- commodities and region wise

	Without Climate Change						With Climate change					
	Punjab		Sindh		OP		Punjab		Sindh		OP	
	Base	15% both	Base	15% both	Base	15% both	Base	15% both	Base	15% both	Base	15% both
Wheat	-0.83	-0.03	0.24	-0.50	-0.09	0.01	0.48	0.19	0.24	-0.09	-0.03	-0.01
Irri Rice	0.03	-0.48	-0.31	-0.60	-0.20	-0.11	0.20	-0.45	-0.15	-0.67	-0.14	-0.15
Basmati	-0.56	-0.69	-0.06	-0.05	-0.06	-0.02	-0.35	-0.61	-0.03	-0.06	-0.05	-0.02
Cotton	0.53	2.93	0.15	0.49	0.00	0.00	0.13	3.57	0.36	0.43	0.00	0.00
Sugarcane	0.74	-1.60	0.10	-0.61	-0.09	-0.14	0.89	-1.66	0.17	-0.55	-0.03	-0.17
Maize	-0.83	-0.03	0.00	0.00	-0.02	0.00	0.48	0.19	0.00	0.00	-0.02	0.00
Other Crops	0.76	-0.41	0.05	-0.05	-0.02	-0.01	-0.94	0.60	0.02	-0.02	-0.01	-0.01
Vegetables	1.22	-0.28	0.16	-0.06	0.01	-0.01	1.51	-0.60	0.24	-0.03	0.03	-0.01
Fruit	1.87	-0.07	0.69	-0.02	0.04	0.00	1.77	-0.06	0.70	-0.02	0.05	0.00

Source: Authors' estimation. IFPRI CGE-W model runs.
Note: Value are the differences in the change to 2030 in the Base versus each of the scenarios

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