



INITIATIVE ON  
NEXUS Gains

# Hydro-Economic models for decision making on water optimization in Indus Basin

Examples from “Releasing water from high delta crops for other beneficial uses: Potential and Challenges seen in a computable general equilibrium (CGE) model” with extended analyses

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Stephen Davies, Iqra Akram, Moh. Tahir Ali, Mohsin Hafeez,  
and Claudia Ringler

IFPRI and IWMI

April 18, 2024

# What is a CGE model?



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## Computable

Solvable numerically



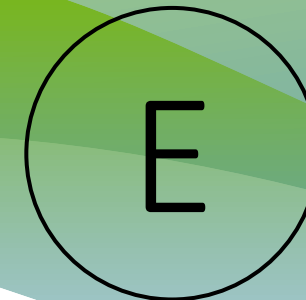
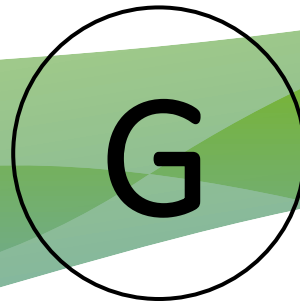
## General

Economy-wide (all production, consumption, investment, and trade that is covered by the national accounts)



## Equilibrium

- Optimizing agents have found their best solutions subject to their budget constraints.
- Quantities demanded = quantities supplied in factor and commodity markets
- Macroeconomic balance: receipts = spending for government, balance of payments, and savings-investment balance



# What is a CGE model?



## DEFINITION

An open-economy, economy-wide model with (a) flexible prices clearing most markets; (b) one or more production sectors and household groups; and (c) a government with policy tools (taxes, spending).

## MODEL

Almost all models are “real” – only relative prices matter, not the general price level.

## ECONOMY

The “economy” is typically a country but may be defined at other levels of aggregation: household, region within a country, a country, a continent ....

## REGION

Most models cover a single economy (region) but multi-region models also common (including global models).

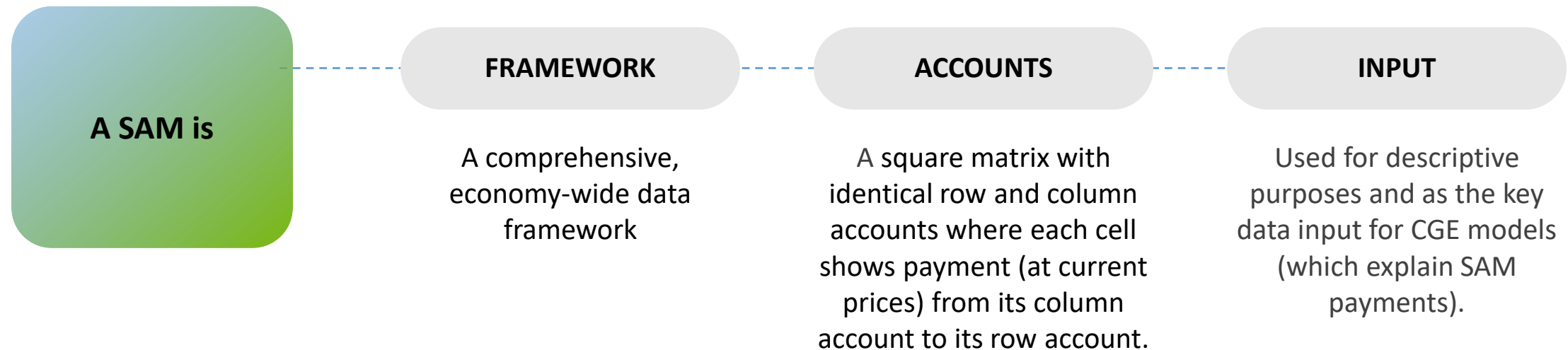
## EXAMPLE

For a model with a commonly used structure, see Lofgren et al. (2002).

# What is Social Accounting Matrix



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“Social” → often focused on incomes and spending of households of different types.



Disaggregation and classification of accounts vary widely across different SAMs.



Column totals = row totals

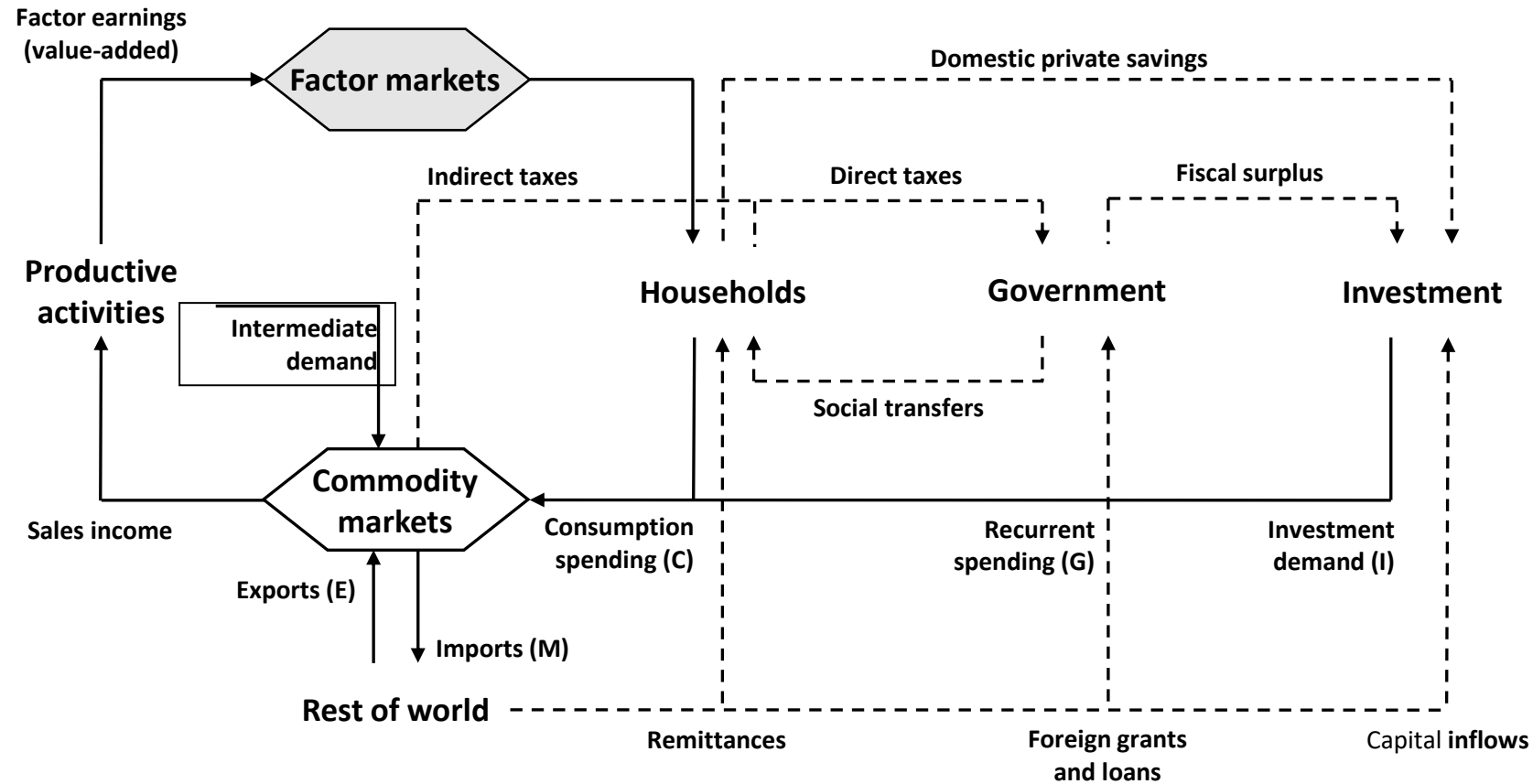


First SAM developed for the UK in 1962 by Richard Stone, Nobel laureate for development of national income accounting.

# Circular flow diagram of the economy



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**Table 1: Standard Nexus Macro SAM**

	Activities	Commodities	Factors	Enterprises	Households	Government	Taxes	Investment	Rest of the World	Total
Activities		Marketed outputs			Private non-marketed consumption					Activity income
Commodities	Intermediate demand	Transaction costs			Private marketed consumption	Government consumption		Gross capital formation	Exports	Total demand
Factors	Value-added								Foreign transfers to factors	Factor income
Enterprises			Factor income to enterprises			Government transfers to enterprises			Foreign transfers to enterprises	Enterprise income
Households			Factor income to households	Enterprise transfers to households		Government transfers to households			Foreign transfers to households	Household income
Government				Enterprise transfers to government	Household transfers to government		Taxes paid to government		Foreign transfers to government	Government income
Taxes	Taxes on producers	Taxes on products	Factor taxes	Corporate taxes	Household taxes					Tax income
Savings				Enterprise savings	Household savings	Government savings			Foreign savings	Savings
Rest of the World		Imports	Factor payments abroad	Enterprise payments abroad	Household payments abroad	Government payments abroad				Foreign exchange outflow
Total	Activity expenditures	Total supply	Factor expenditures	Enterprise expenditures	Household expenditures	Government expenditures	Tax payments	Investment	Foreign exchange inflow	

# Household Expenditures -- Revised



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Codes	Description	Notes
HHD-R1	Rural - quintile 1	Rural households separated into national per capita consumption expenditure quintiles
HHD-R2	Rural - quintile 2	
HHD-R3	Rural - quintile 3	
HHD-R4	Rural - quintile 4	
HHD-R5	Rural - quintile 5	
HHD-U1	Urban - quintile 1	Urban households separated into national per capita consumption expenditure quintiles
HHD-U2	Urban - quintile 2	
HHD-U3	Urban - quintile 3	
HHD-U4	Urban - quintile 4	
HHD-U5	Urban - quintile 5	

Per Capita Monthly Consumption Expenditure (PKR)

	HHD-R1	HHD-R2	HHD-R3	HHD-R4	HHD-R5	HHD-U1	HHD-U2	HHD-U3	HHD-U4	HHD-U5
<b>Flour</b>	215	242	252	239	255	202	215	229	193	215
<b>RICE</b>	67	88	136	136	145	42	67	94	101	137
<b>POTATO</b>	24	27	31	35	37	26	26	28	29	36
<b>VEGE</b>	134	171	199	219	274	142	175	178	204	249
<b>FRUIT</b>	59	69	103	145	303	42	104	144	217	404
<b>MILK</b>	353	578	670	917	1043	409	503	541	818	1088
<b>MEAT</b>	11	31	56	62	312	30	17	30	112	379
<b>POULTRY</b>	49	73	124	131	150	46	114	136	147	196
<b>REFINED SUGAR</b>	50	61	81	79	84	42	53	54	57	69
<b>OCROPS</b>	38	40	52	53	51	39	43	41	51	55

# Data beyond the SAM



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## OTHER DATA COMPONENTS

- In addition to a SAM, the core data for CGE models often include:
  - elasticities (trade, consumption, and production)
  - labor employment by sector
  - stocks (factors; foreign and domestic debts)



## DATA IMPORTANCE

- Non-practitioners may not always be able to see
  - that all data pieces are not equally important
  - in a consistent system with market and budget constraints (like a CGE model), qualitative insights tend to be insensitive to many elasticities



## IMPORTANCE OF SENSITIVITY ANALYSIS

- Important to test sensitivity of results to changes in parameter values (including elasticities).

# Structure of Country CGE Model



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- Model written as a set of simultaneous equations.
- Many equations represent first-order conditions to producer and consumer optimization problems; others cover:
  - a) payments from factors to institutions and between institutions
  - b) Definitions
  - c) budget constraints
  - d) market equilibrium conditions.

Models may be

- Static (used for comparative static analysis)
- Dynamic (recursive or intertemporal with perfect foresight)

In the dynamic case, growth in output and other variables is driven by:

- Growth in factor stocks (endogenous or exogenous)
- Growth in factor productivity (endogenous or exogenous)

# Structure of Country CGE Model



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“Closure” = rule on the basis of which a market (quantity demanded = quantity supplied)

Or

a macro balance (receipts = payments) clears.



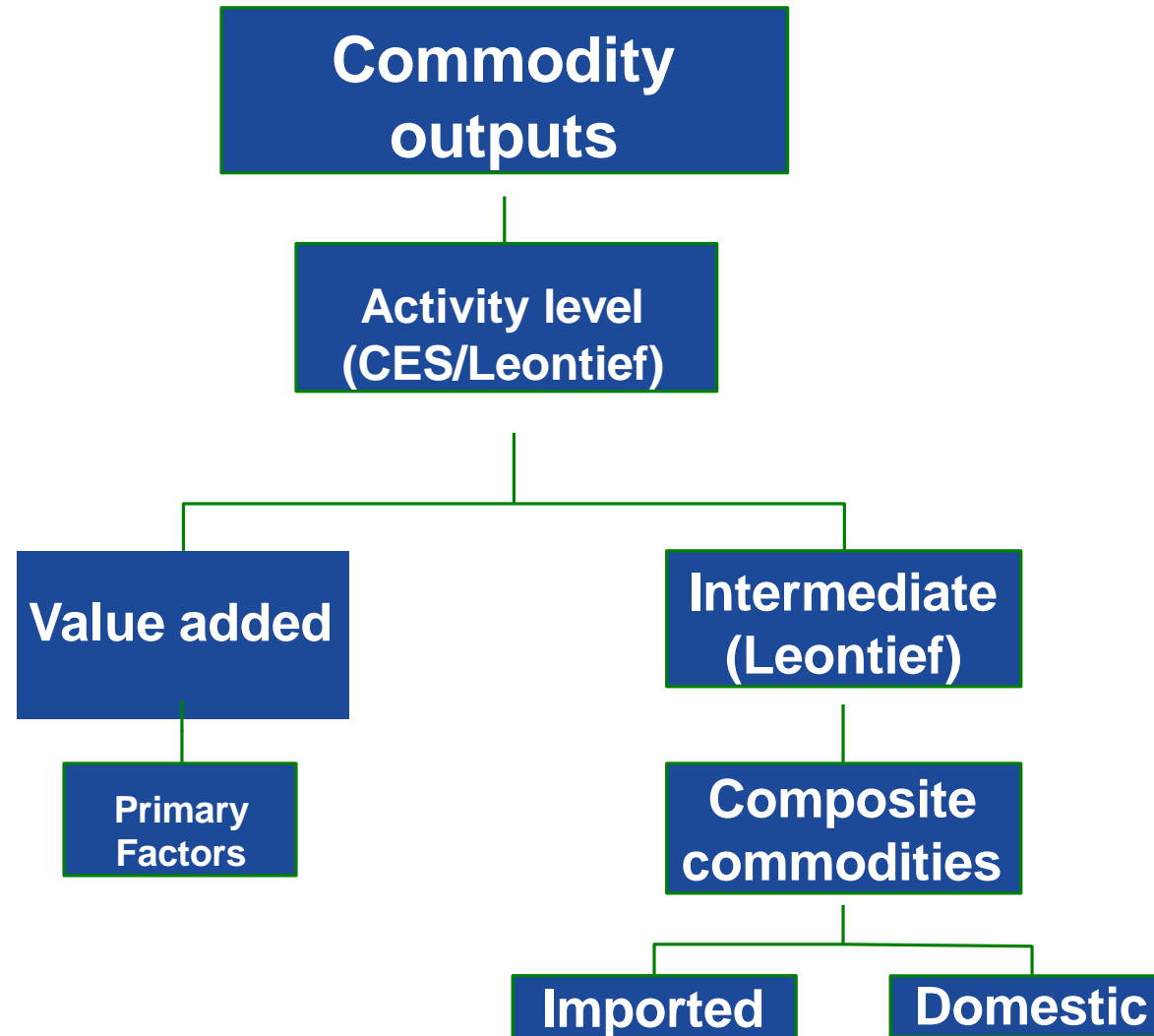
Common options:

- Domestic factor and commodity markets. Prices (wages, rents) clear; for factors with or without endogenous unemployment.
- Foreign markets. Exchange rate clears (leading to adjustments in export demand and import supply at exogenous world prices).
- Government. Adjustment of one or more receipt or spending items.
- Balance of payments. Adjustment of the real exchange rate or of a non-trade foreign exchange flow.
- Savings-investment balance. Investment clears (investment is savings driven) or one or more savings flows adjust (savings is investment)

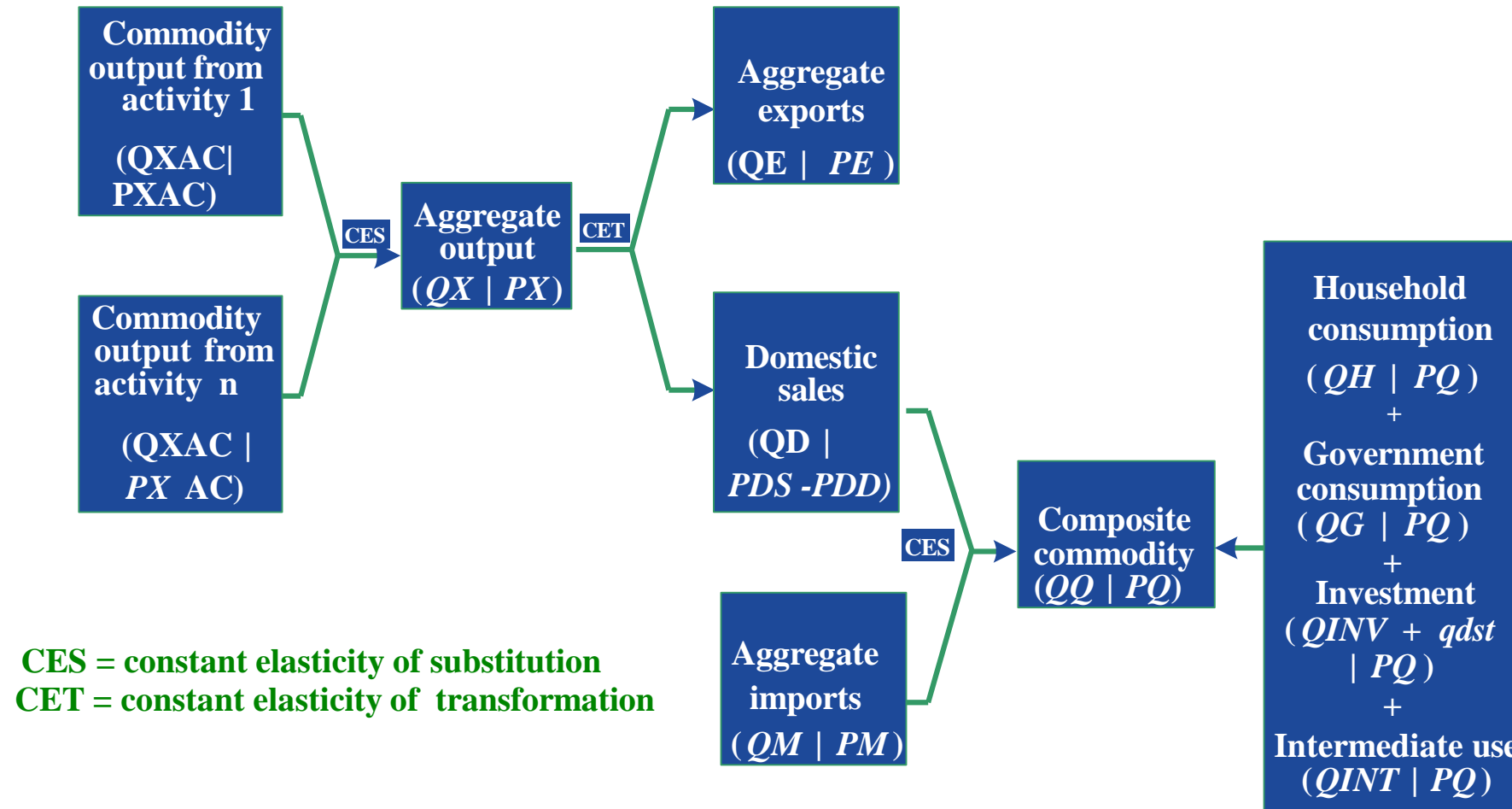
# Figure. Production technology



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# Figure. Commodity flows



# GAMS and other software for CGE models



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Major computational achievement to solve applied CGE models – large number of simultaneous, non-linear equations; methods developed since late 1960s.

GAMS (General Algebraic Modeling System) and GEMPACK (developed at Monash University) are the two major software for CGE modeling.

A text editor is needed to program in GAMS (GAMSIDE included with the software).

In GAMS, the model and its database are represented in a format that is very similar to a mathematical statement.

GAMS may exchange data with many other software (including Excel).

In GAMS, the model and its database are represented in a format that is very similar to a mathematical statement.

The key building blocks (which are reserved words) in GAMS: SET, PARAMETER, VARIABLE, EQUATION, MODEL, SOLVE.

# Sample GAMS code excerpt from simple CGE model



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```
SETS
  a  activities
  /a-agr  agriculture
   a-nagr non-agriculture/

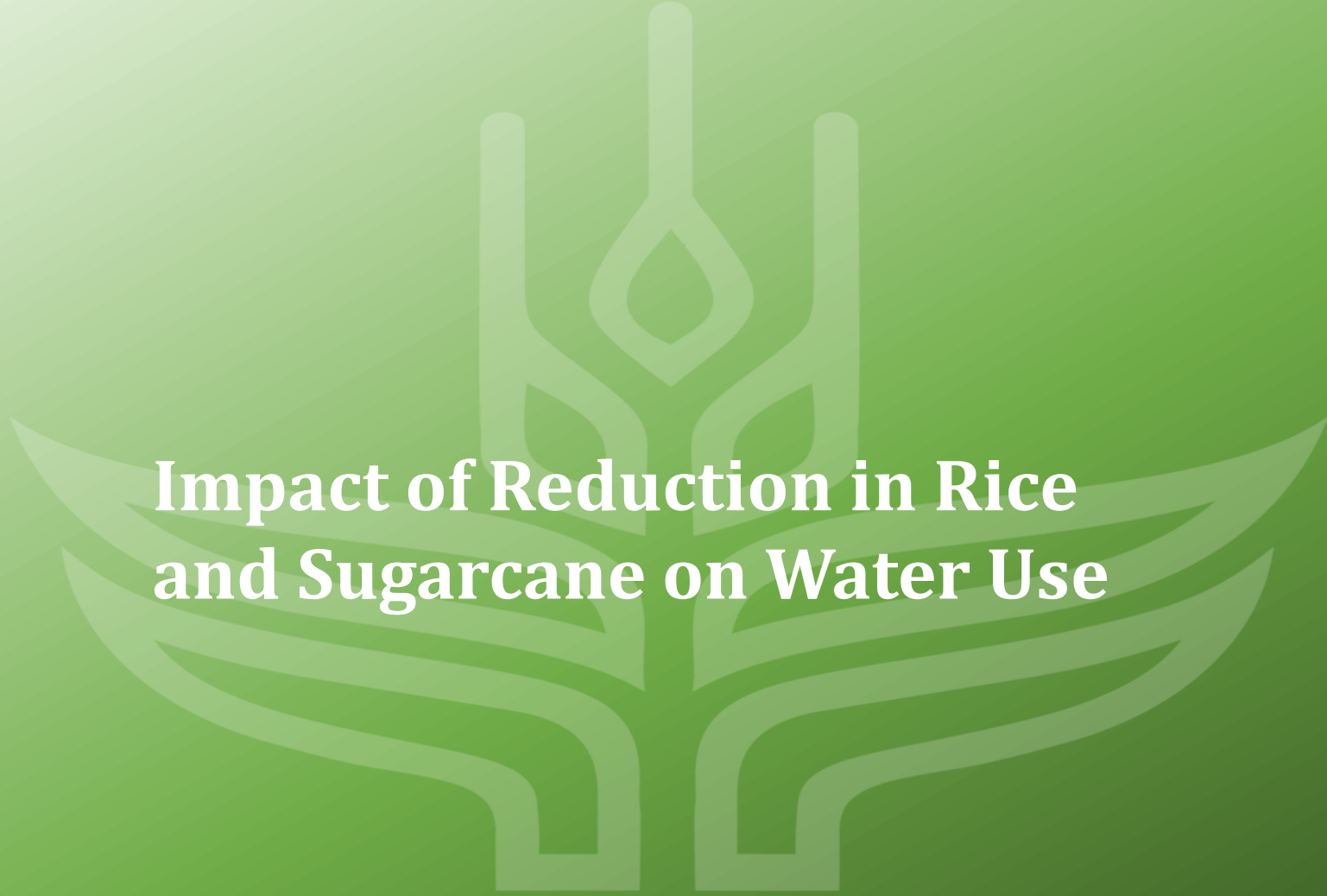
  f  factors
  /f-lab  labor
   f-cap  capital/
;
VARIABLES
  QA(a)    level of activity a
  QF(f,a)  quantity demanded of factor f from activity a
;
PARAMETERS
  ad(a)    efficiency parameter in the production fn for a
  alpha(f,a) share of value-added to factor f in activity a
;
EQUATION
  PRODFN(a)    Cobb-Douglas production function for activity a
;
  PRODFN(a)..  QA(a) =E= ad(a)*PROD(f, QF(f,a)**alpha(f,a));
```

# Resources on CGE modeling and/or GAMS



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- The following websites provide plenty of materials and links:
  - [www.gams.com](http://www.gams.com)
  - [www.gtap.agecon.purdue.edu](http://www.gtap.agecon.purdue.edu)
  - [/www.agrodep.org/model/gams-training-toolbox](http://www.agrodep.org/model/gams-training-toolbox)



# Impact of Reduction in Rice and Sugarcane on Water Use

# Overview and Objectives



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## Overview



- Amidst growing scarcity and increasing demands, it has been estimated that 10 MAF of water in Pakistan is not optimally used and could go to higher valued uses outside agriculture .
- Population growth, urbanization and industrialization create mounting demand for water resources, while climate change and better diets can affect water requirements in agriculture.

## Study Objective



Reflecting recent interest from MoWR and other stakeholders, we use IFPRI's Computable General Equilibrium –Water model (CGE-W) to assess how much reducing sugarcane and rice acreage can release water resources for other agricultural uses

## Discussion paper is published



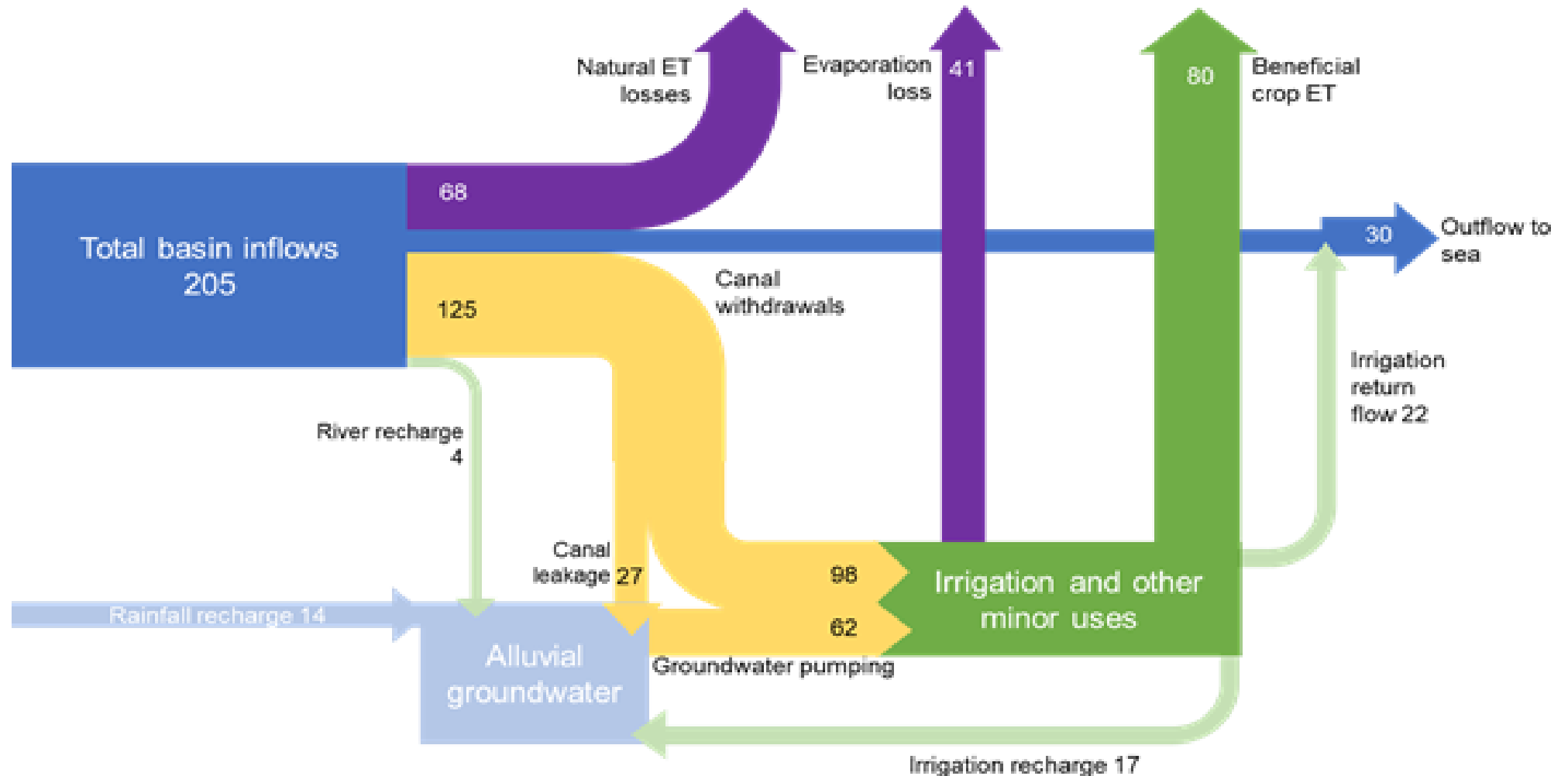
Davies, S., Akram, I., Ali, M. T., Hafeez, M., & Ringler, C. (2024). *The economywide impacts of increasing water security through policies on agricultural production: The case of rice and sugarcane in Pakistan*. Intl Food Policy Res Inst.

DOI: <https://doi.org/10.2499/p15738coll2.137073>

# Indus Basin Water Balance (Young et. al 2019)



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# Changes in Water Use in Punjab to 2030 for a Base and Three Scenarios (MAF)



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

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



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## Tax to decrease acreage by 15 percent in:

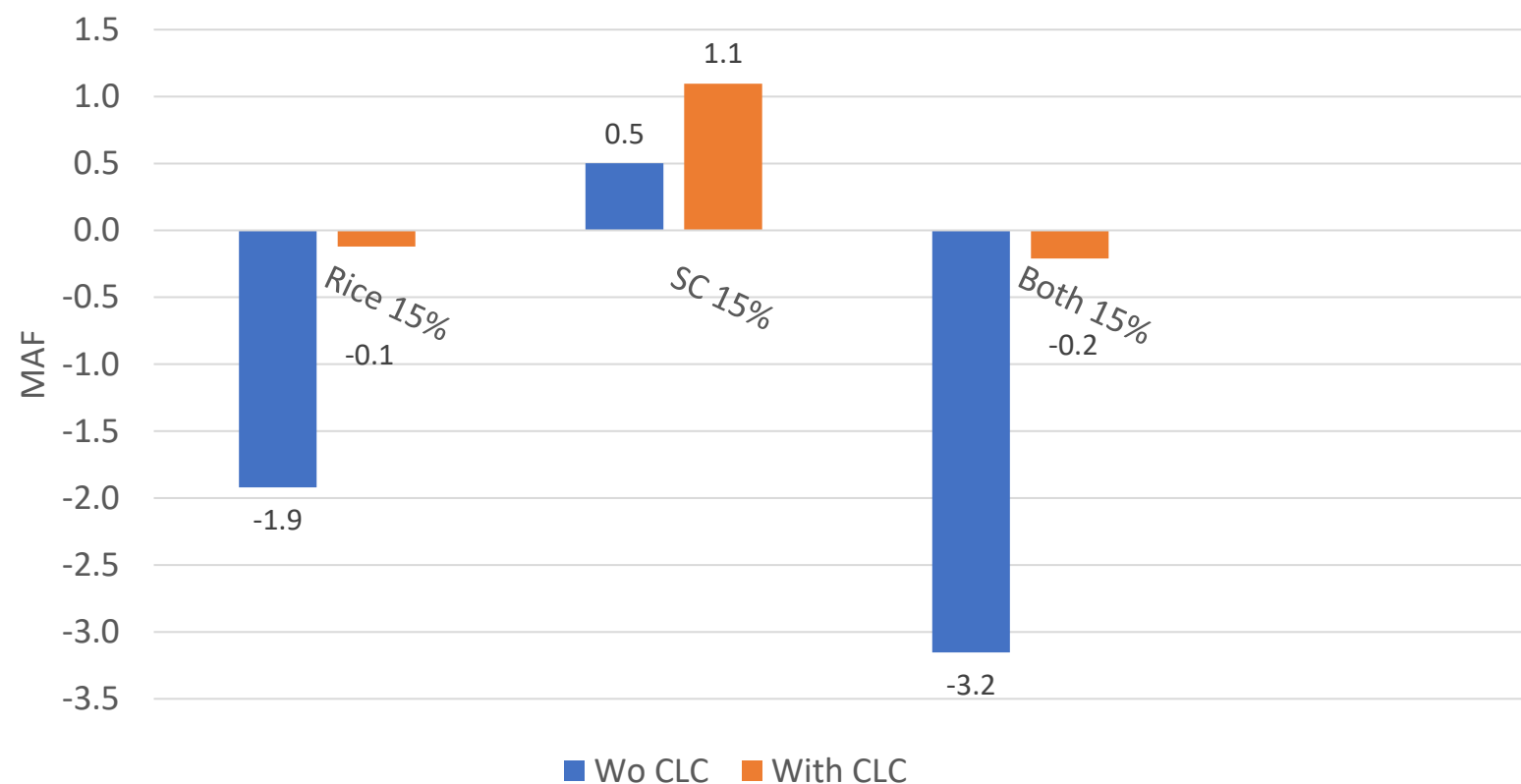
	Base Calibration	Rice	Sugarcane	Sugarcane and rice
Basmati rice*		33		36
Irrigated Rice*		31		34
Sugarcane	-18		44	47
Refined Sugar			44	47

# Annual Water Releases from Tax policy, with and without climate change



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## Water Releases from agriculture due to Taxes on Rice and Sugarcane, with and without Climate Change

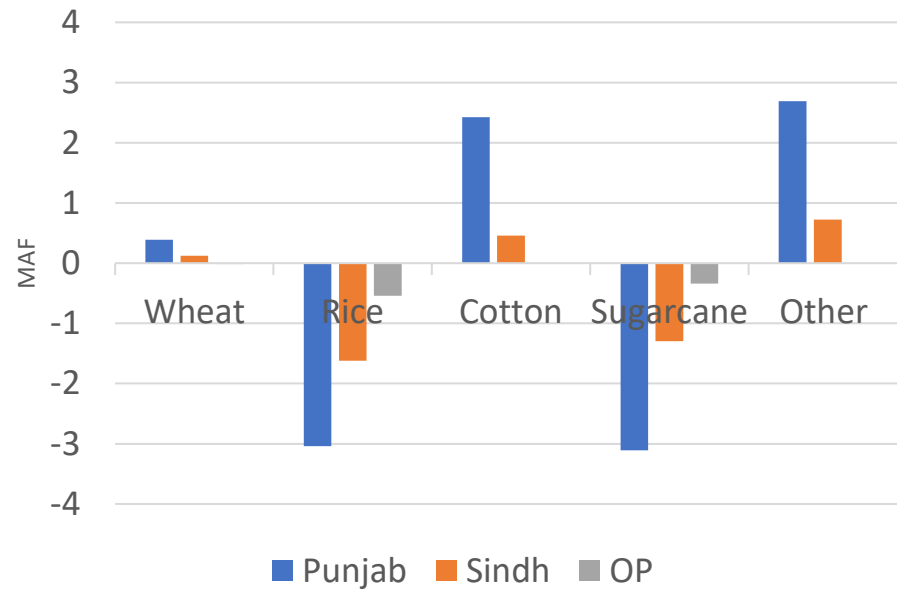


# Crop Water Use Changes with Taxes on Both Sugarcane and Rice, without Climate Change

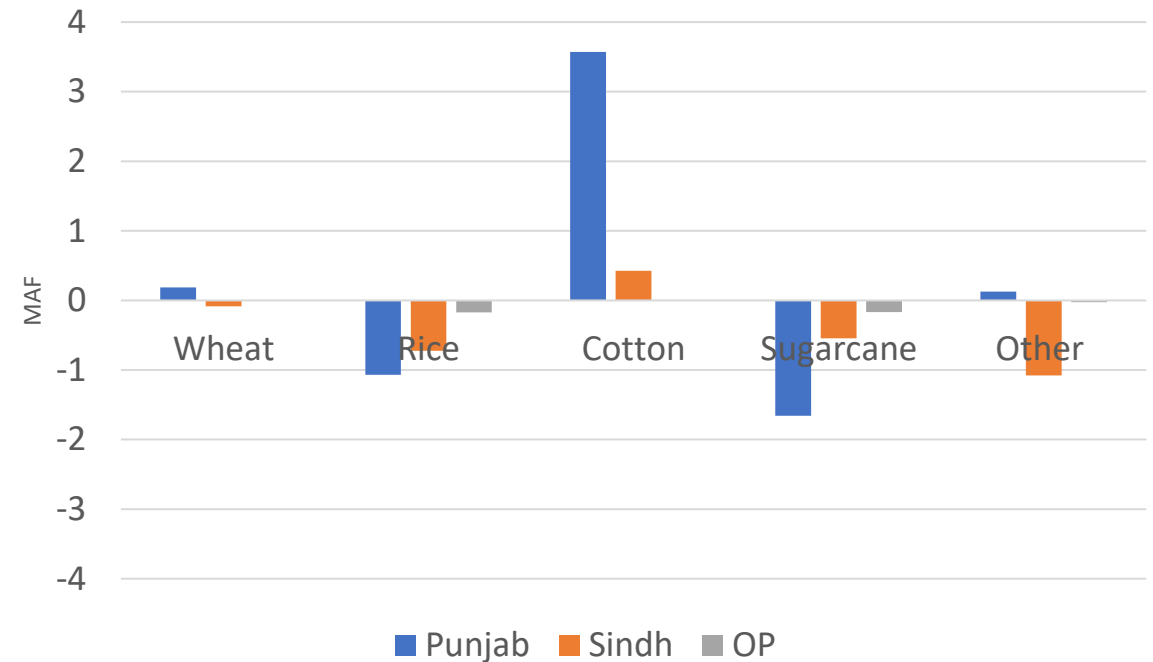


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Crop Water Use Changes without Climate Change



Crop Water Use Changes, with Climate Change





# Extensive substitution exists

## Effects across crops and taxes in Sindh:

- When Rice acreage drops 15% in Sindh: 0.41 MAF out of rice, but 0.29 MAF into fruit and 0.13 MAF is released
- When Cane acreage drops 15% in Sindh: 1.38 MAF out of cane, but 0.60 MAF goes into rice, 0.13 MAF in cotton and 0.31 MAF into HV crops, so just 0.26 is released.

## Effects across crops and taxes in Punjab:

- When Rice acreage drops 15% in Punjab: 3.20 MAF out of rice, 0.88 MAF into cotton, 0.76 MAF into HV crops and 1.31 MAF is released
- When Cane acreage drops 15% in Punjab: 3.18 MAF goes out of cane, but 1.35 MAF goes into rice, 1.04 MAF into cotton and 1.58 MAF into HV crops, and 1.08 MAF is **added**.

# Applied Water Equivalents

We derived estimates of applied water (AW) from the simulated values of consumptive use (CU) and other known relationships from Young et. al. 2019. We used 40% groundwater and 60% surface water. Estimated Evaporation losses as 50% of beneficial use, yielding:

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

We implement these calculations for three estimated consumptive use values:

- **The simulation of sugarcane and rice: 3.15 CU MAF = 6.25 AW MAF,**
- **The rice simulation alone: 1.92 CU MAF = 3.88 AW MAF**
- **A 30% tax on rice, sugarcane, and cotton: 4.35 CU MAF = 8.63 AW MAF**

# **Impact of Reduction in Rice and Sugarcane on Production, Income, KCAL and Other Policy Approaches**

# Impact on Production



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PROVINCES	Change in Production, with Hist Scenario					
	Base		15% ↓ in Rice Acr.	15% ↓ in Sugarcane Acr.	15% ↓ in Rice & Sugarcane Acr.	
	2014	2030	Change	Change	Change	Change
Punjab	2,308	3,677	1,369	-18.7	19.7	-6.5
Sindh	642	1,003	360	-9.3	7.9	-8.4
Other Province	402	716	314	-2.9	5.5	2.4
<b>TOTAL</b>	<b>3,353</b>	<b>5,396</b>	<b>2,043</b>	<b>-30.8</b>	<b>33.1</b>	<b>-12.5</b>

# Impact on Income



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HOUSEHOLD GROUP	Change in Income In % changes					
	Base		15% decrease in % changes			
	2014	2030	% Change	15% decrease in Rice Difference	15% decrease in Sugarcane Difference	15% decrease in Rice & Sugarcane Difference
Rural Farm Poor (RFP)	379	752	4.28	0.02	0.08	0.05
Rural Farm Non-Poor (RFNP)	5,682	10,747	4.29	0.01	0.08	0.05
Rural Non-Farm Poor (RNFP)	1,005	1,575	2.81	-0.05	-0.03	-0.03
Rural Non-Farm Non-Poor (RNFNP)	1,879	3,235	3.40	-0.05	-0.01	-0.02
Urban Poor (UP)	1,248	1,852	2.67	-0.05	-0.04	-0.03
Urban Non-Poor (UNP)	11,715	17,709	2.58	-0.05	-0.05	-0.04

# Impact on KCAL



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## Change in Nutrition, with Hist Scenario- % of Kcals

CROPS	Base		20% decrease in Rice	20% decrease in Sugarcane	20% decrease in Rice & Sugarcane
	2014	2030	Difference	Difference	Difference
Cereals	50.8	50.1	0.36	0.21	0.70
Meat	4.1	5.3	-0.03	0.02	-0.01
Dairy	14.2	11.4	0.12	0.10	-0.07
Vegetables	3.5	1.9	-0.10	-0.08	-0.04
Fruits	2.0	1.0	-0.04	-0.02	0.01
Oil	14.6	15.1	0.32	0.69	0.51
Discretionary(sugar)	10.9	15.2	-0.63	-0.92	-1.11



# Effects of Alternative Policies

Crop	Combined SC and Rice	SC Rice Cotton -30 30 30	Diff. (Col. 3 – 2)	Fertilizer (35%)	Diff. (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
<b>Total</b>	<b>70.1*</b>	<b>68.9</b>	<b>-1.2</b>	<b>69.5</b>	<b>-0.7</b>	<b>69.4</b>	<b>-0.7</b>

\*This scenario yields a reduction of 3.15 MAF relative to the Base

# Last Comments



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Is it possible to get significant water out of agriculture with appropriate strategies/policies? YES! But!

- Will depend on substitution among crops in agriculture
- Strength of demand for better nutrition
- Choice of policies
- Nature of climate change .

Depending on the above dimensions, the required cost to induce reduced acreage will be either higher or lower.

- The tax rates needed can also be thought of as the opportunity costs, and will need to be covered with whatever policy is chosen

**Growth Impacts from changing Rice and Potato  
growth on economic outcomes, land and water use**

# Comparison of Punjab Growth rates, 2014-2030



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	Okara Historical	Base	Base Climate (LFPHE)	Low Rice	High Rice	Low Potato	High Potato
Wheat	-3.69	1.04	1.60	1.52	0.93	1.18	1.07
Rice B	5.88	<b>5.79</b>	0.48	<b>3.26</b>	<b>7.04</b>	5.81	5.98
Rice I	--	<b>6.06</b>	-0.55	<b>4.03</b>	<b>6.80</b>	6.19	6.23
Cotton	-18.30	0.57	3.15	1.44	-0.13	0.45	0.45
Sugarcane	1.50	2.10	1.54	2.24	1.93	2.09	2.07
Maize	3.54	2.13	3.53	2.39	1.96	2.13	2.09
Potato	5.79	<b>5.60</b>	6.92	6.21	5.07	<b>4.80</b>	<b>7.19</b>
Other	--	3.33	4.68	3.94	2.96	3.34	3.18

# Elasticities based on Growth rates, 2014-2030



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	Low Rice	High Rice	Low Potato	High Potato
Wheat	1.15	-0.60	0.91	0.08
Basmati Rice	<b>-1.00</b>	<b>1.00</b>	0.02	0.11
IRRI Rice			0.15	0.10
Cotton	3.86	-6.83	-1.42	-0.73
Sugarcane	0.16	-0.46	-0.03	-0.05
Maize	0.31	-0.43	0.01	-0.07
Potato	0.28	-0.53	<b>-1.00</b>	<b>1.00</b>
Other	0.46	-0.61	0.03	-0.16

Rates for rice and potatoes are high and low relative to base growth rates

**Bold values** show 1 percent increase or decrease in each crop

# Value Effects Using Growth Elasticities, 2014-2030



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	Low Rice	High Rice	Low Potato	High Potato
Wheat	139.95	-73.56	99.74	8.61
Basmati Rice	<b>-38.07</b>	<b>38.07</b>	0.56	2.82
IRRI Rice			8.02	5.15
Cotton	108.34	-191.69	-37.87	-19.39
Sugarcane	4.55	-12.84	-0.57	-1.22
Maize	5.88	-8.08	0.33	-1.97
Potato	4.70	-9.04	<b>-9.36</b>	<b>9.36</b>
Other	61.25	-80.73	3.26	-19.76
Total	286.6	-337.9	64.1	-16.4
Adj. (50% cotton)	232.4	-242.0	83.1	-6.7

# Effects of land and water resources on Growth rates, 2014-2030



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## Changes from Base

	Base	Land 50% Growth decline	Water -- 10 MAF Tw decline	Land and Water Reductions
Wheat	1.04	0.15	0.12	-0.21
Rice B	5.79	-0.72	1.14	-0.99
Rice I	6.06	-0.04	0.25	-0.92
Cotton	0.57	-0.15	0.53	0.17
Sugarcane	2.10	-0.10	0.06	-0.13
Maize	2.13	-0.06	0.24	-0.21
Potato	5.60	-0.31	-0.50	-0.33
Other	3.33	-0.13	0.04	-0.12

# Value Added Effects of land and water resources 2014-2030



NEXUS Gains:  
Realizing Multiple Benefits  
Across Water, Energy, Food  
and Ecosystems

## Changes from Base

	Base	Land 50% Growth decline	Water -- 10 MAF Tw decline	Land and Water Reductions
Wheat	115.4	18.73	14.30	-26.00
Rice B	140.5	-25.44	41.50	-36.26
Rice I	161.9	-1.70	10.40	-36.72
Cotton	15.1	-4.05	15.10	5.11
Scane	50.3	-2.80	1.61	-3.73
Maize	33.9	-1.06	4.62	-3.99
Potato	62.7	-5.14	-7.81	-4.79
Other	288.0	-14.75	0.77	-18.62
<b>Total</b>	<b>867.7</b>	<b>-36.22</b>	<b>80.48</b>	<b>-124.99</b>



INITIATIVE ON  
NEXUS Gains

**Thank You!**

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