Economic Impacts of Water Scarcity under Diverse Water Salinities

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אוניברסיטת חיפה
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Modelling European Agriculture with Climate Change for Food Security
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Research Motivation- Israeli group

Water scarcity due to increasing demands and declining supply of natural waters (Climate change, bad management)

Purified Natural Fresh water
Desalinated water
Potable water שפירים
Brackish water מליחים
Reclaimed wastewater מושבים

Each water type is characterized by different salinity, quality and costs

Increasing use of secondary water sources may cause higher prices of agricultural product and induce energy demands

Economy-wide analysis is needed to estimate these impacts

Computable General Equilibrium (CGE) models are commonly used for economy-wide analysis

However water modeling in CGEs is still far from satisfactory

Methodological enhancement is needed - IGEM

Cooperation with VALUE

Estimation of CES between water sources

Israel as a case study

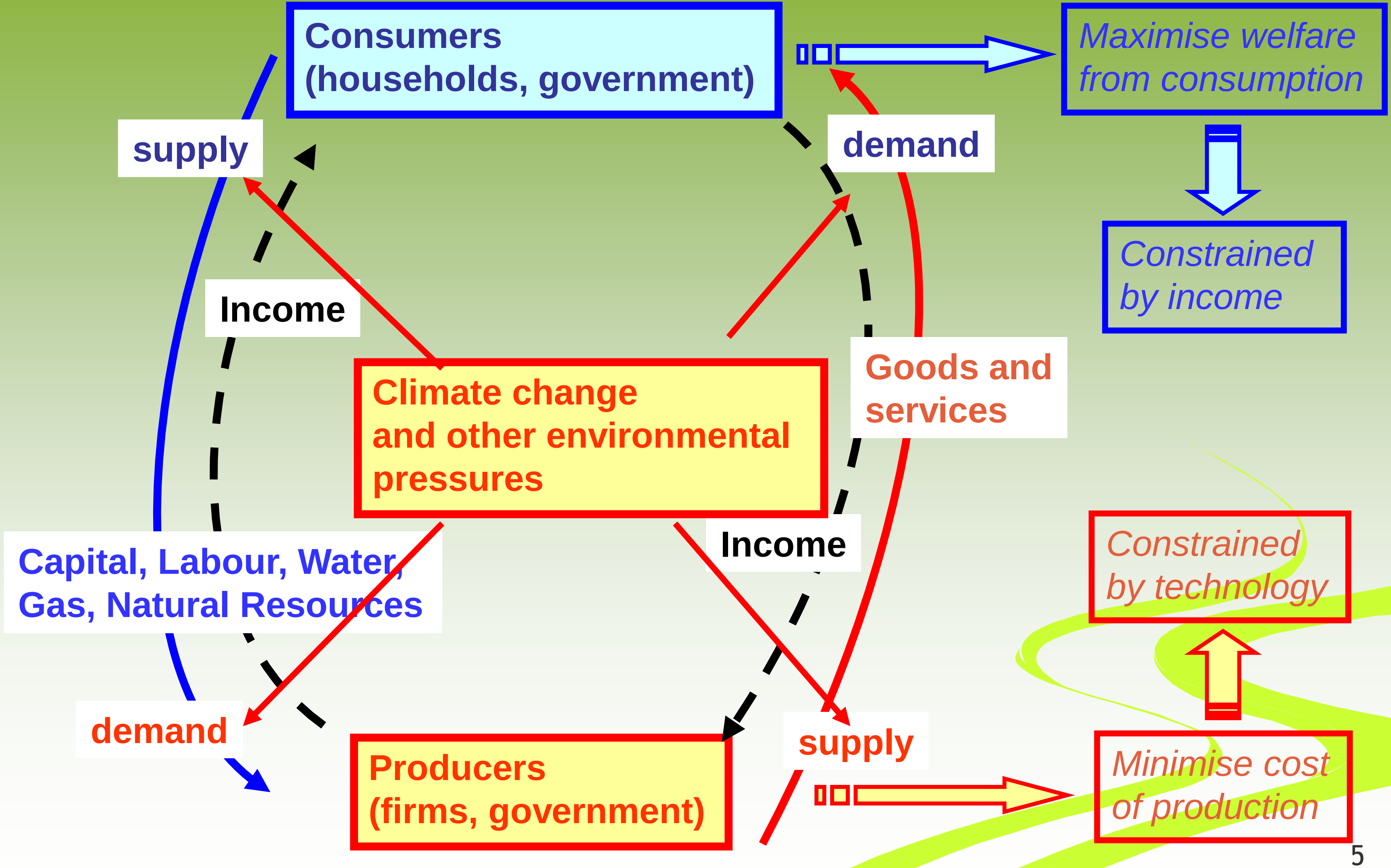
Purpose of the Study

- Assess the impact of climate change on the Israeli water economy on the agricultural sector, and the food supply, under different desalination policies.
- Methodological innovation in modeling water:
  - ➢ Evaluating the general structure and values of key water related parameters in production functions.
    - ✓ (1) the substitution of irrigation water with different qualities and salinities
    - ✓ (2) the link between the consumption of freshwater by domestic and industrial consumers and the amount of treated wastewater to be used in agricultural production.
  - ➢ Constructing a consistent economic database, building upon official data of water values in Israel.
- Enhancing the model to better reflect the characteristics and operating principles of the water economy.
- Comprehensive assessment of the impact of water scarcity.

IGEM - Israeli General Equilibrium Model

- Static CGE-type model representing the entire Israeli economy.
- Small open economy, 5 energy sectors, 5 water sectors *(potable: natural and desalinated, Shafdan* - tertiary treated wastewater, *reclaimed and brackish),* 13 other sectors, government, investment agent, foreign agent, single representative household.
- Final demands are determined by market prices.
- Standard assumptions of: market clearing, zero excess profits, balanced budget for each agent.
- The economy is assumed at equilibrium at the benchmark.
- Simulated scenarios are implemented as a ‘counter-factual’ with exogenous shocks. Output represents the state after all markets reach a new equilibrium.

The dynamics of CGE and climate change



Consumers (households, government)

Maximise welfare from consumption

Constrained by income

supply

demand

Income

Climate change and other environmental pressures

Goods and services

Capital, Labour, Water, Gas, Natural Resources

Income

demand

supply

Constrained by technology

Producers (firms, government)

Minimise cost of production

The Vegetative Agricultural Land-Use Economic Model

Dr. Ruslana Rachel Palatnik

Input From VALUE To IGEM

- σ^T- Constant Elasticity of Substitution (CES) between water types in agricultural production

- General characteristics:
  - $\sigma^T>0$
  - If σ^T close to 0→substitution between water types is nearly fixed and unresponsive to changes in relative prices.
  - As σ^T ↑ → the easier to substitute from one water type to another

Deriving Constant Elasticity of Substitution (CES)

- VALUE is used to derive an artificial dataset for CES rates between water types in agricultural production.
- The dataset is generated by running VALUE while changing relative prices of water types used as inputs and evaluating the reallocation of overall regional land and water.

Regression Model

- Assuming firms behavior in the neoclassical model with a cost minimization objective, the CES production function of Q (agric. output) is presented as:

$$Q = A(\alpha W_1^{\sigma} + (1-\alpha) W_2^{\sigma})^{1/\sigma}$$

α - distribution parameter

W_1 - quantity of water type 1

W_2 - quantity of water type 2

σ - elasticity of substitution between the two water types

- The standard reduced form of the first-order-conditions is:

$$\frac{\alpha}{1-\alpha}\left(\frac{W_1}{W_2}\right)^{\sigma-1} = \frac{Pw_1}{Pw_2}$$

Pw_1 - price of water type 1

Pw_2 - price of water type 2

- Taking logarithm and econometrically estimating parameters:

$$\ln\left(\frac{W_{1i}}{W_{2i}}\right) = \beta + \sigma \ln\left(\frac{Pw_{2i}}{Pw_{1i}}\right) + u_i$$

i – observation,

$$\beta = \sigma \ln\left(\frac{1-\alpha}{\alpha}\right)$$

Hierarchical multi-level structure

Once CES is determined for the lowest level, composite quantities and prices need to be calculated for estimating CES at the next level.

$$P_{12} = [\alpha_{12}P_1^{((1-\ \sigma12)/\sigma12)} + (1-\ \alpha_{12})P_2^{((1-\ \sigma12)/\sigma12)}\ ]^{(\ \sigma12/(1-\ \sigma12))}$$

$$Q_{12} = [\alpha_{12}Q_1^{((1-\ \sigma12)/\sigma12)} + (1-\ \alpha_{12})Q_2^{((1-\ \sigma12)/\sigma12)}\ ]^{(\ \sigma12/(1-\ \sigma12))}$$

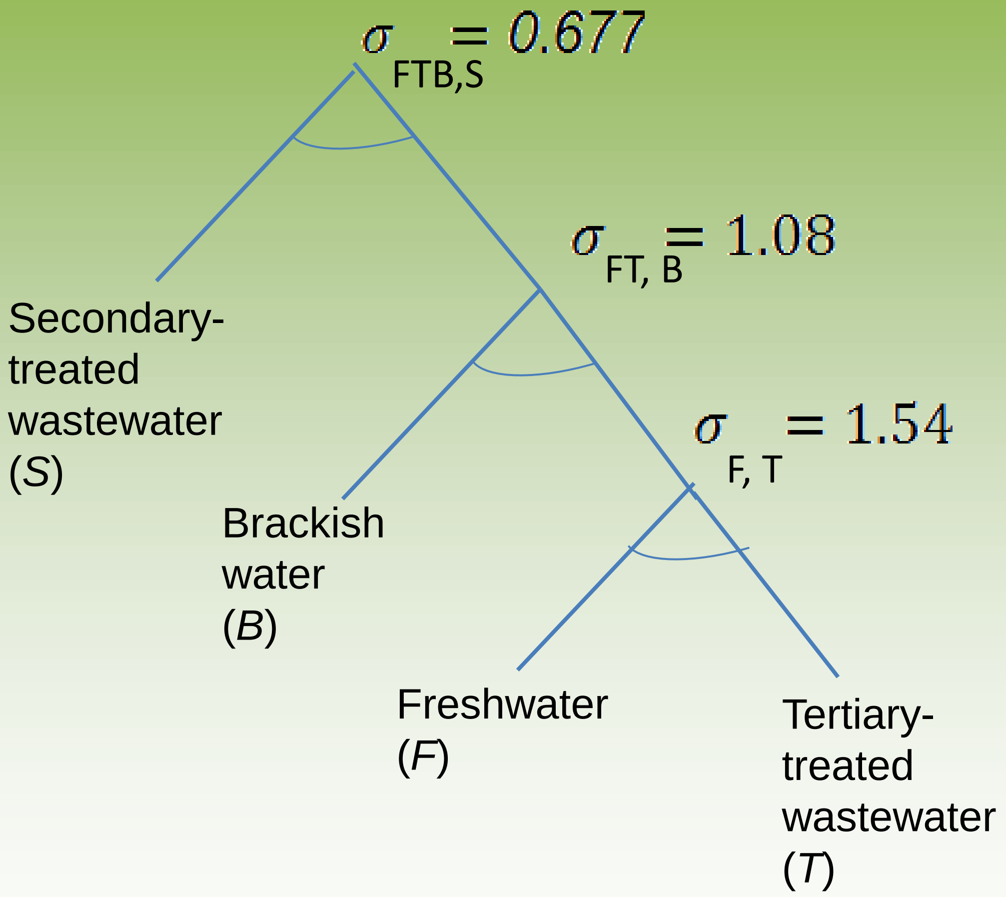
P_{12} – composite price

Q_{12} - composite quantity

α_{12} - relative share of type 1 water out of the entire composite quantity

σ_{12} - elasticity of substitution between the two water types

Estimated nesting CES structure for water inputs



$\sigma_{FTB,S} = 0.677$

$\sigma_{FT,\,B} = 1.08$

$\sigma_{F,\,T} = 1.54$

Secondary-treated wastewater (*S*)

Brackish water (*B*)

Freshwater (*F*)

Tertiary-treated wastewater (*T*)

SAM WATER

- Israel Water Satellite Accounts 2006 (CBS, 2011)
- Provide unique data that allows to introduce detailed representation of water sectors in values

	Surface water	Ground water	Desalinated water	Recycled effluents	Other water
AFF	3	4	4	1	1
ROIL	13	16	16	6	4
COIL	0	0	0	0	0
COAL	0	0	0	0	0
MNF	279	393	0	0	0
ELE	103	224	299	141	166
CON	27	33	32	11	8
TRD	5	6	5	2	1
ASR	0	0	0	0	0
TRC	7	9	9	3	2
BIF	4	5	5	2	1
BAC	164	267	0	0	0
PAD	22	28	27	10	7
EDU	0	1	1	0	0
HWS	0	0	0	0	0
CSS	1	1	1	0	0
IBS	32	40	38	14	10
Labor	230	787	103	43	0
Capital	1040	1911	86	86	79

3rd Modification

Tertiary-treated wastewater and recycled water are produced from wastewater that is collected, purified, and diverted to agriculture.

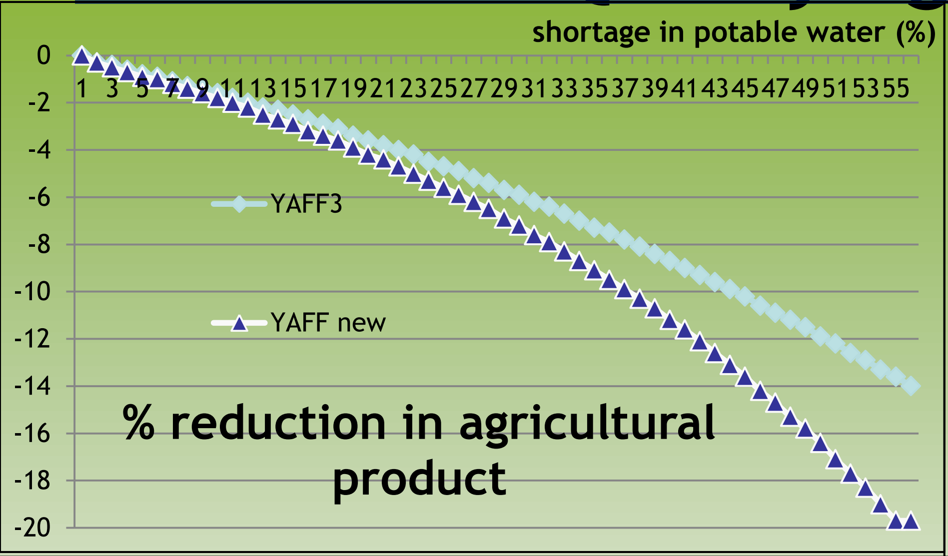
Their available quantities were linked to changes in the availability of potable water.

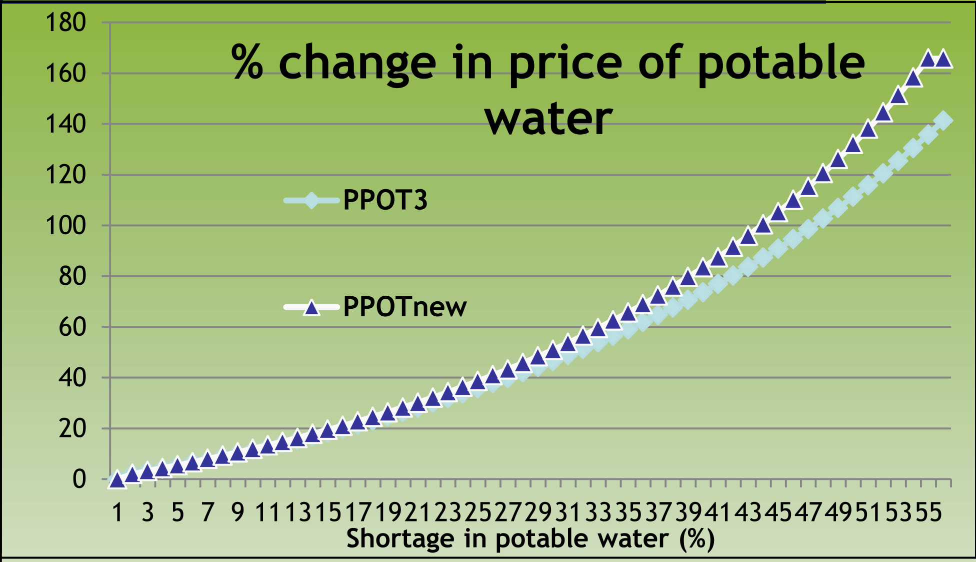
Qualifying the results

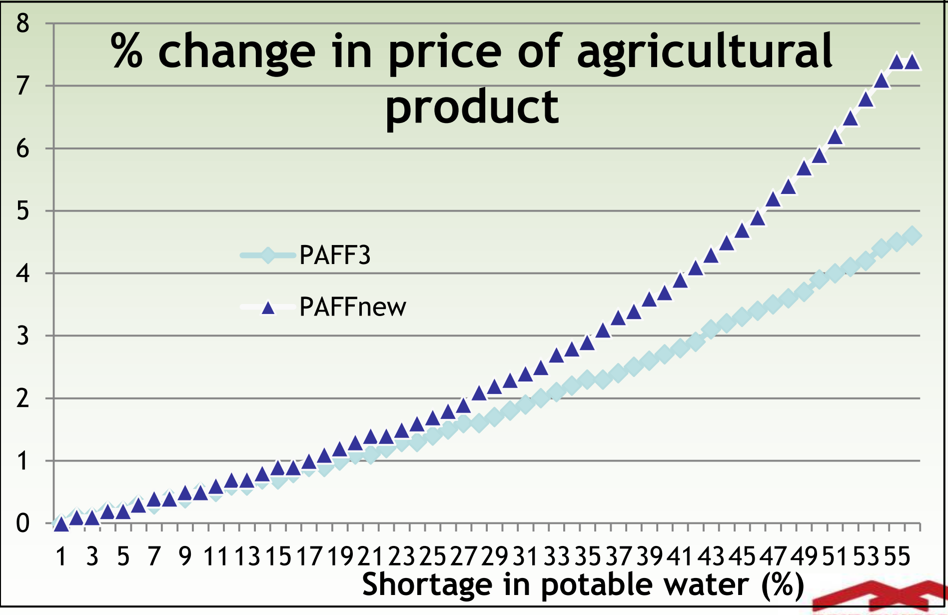
- Unique in the literature in evaluating substitutability between different water types.

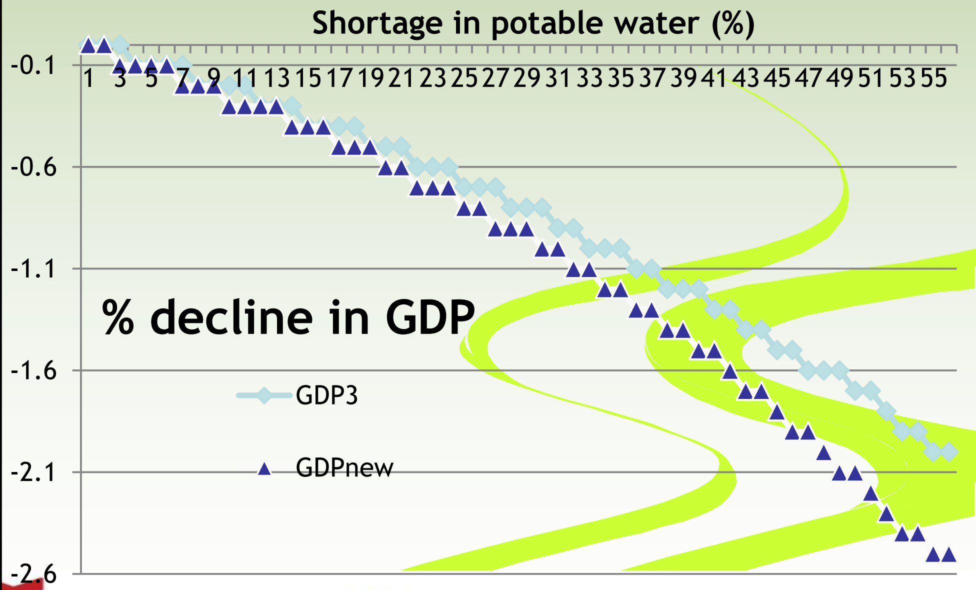
- Contrary to Luckmann et al. (2011) the results provide evidence that:
  - ➢ Potable, reclaimed and saline water inputs are not equally substitutable in agricultural production in Israel.
  - ➢ Estimated rates of substitution are considerably lower than assumed in Luckmann et al. (2011) .

Qualifying the results









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Water Shortage Scenarios (based on Long Term National Master Plan for The Water Economy (IWA, 2011))

Scenario	Year	Desalination MMY	Natural Fresh-water MMY	Shortage of Potable Water (%, MMY) at Desired Supply Reliability Level of Potable Water							
				75%		90%		95%		**100%**	
				%	MMY	%	MMY	%	MMY	%	**MMY**
1	2020	280	1,140	16	220	16	220	22	320	31	**520**
2	2020	750	1,140	-	-	-	-	-	-	4	**50**
3	2030	280	1,080	28	420	33	520	36	620	40	**720**
4	2030	750	1,080	-	-	4	50	12	150	19	**250**
5	2050	280	1,020	50	1020	52	1120	54	1220	56	**1320**
6	2050	750	1,020	35	550	39	650	42	750	45	**850**

Results -2020

Scena-rio	Desalina-tion MMY	Indicator	Shortage of Potable Water at Desired Supply Reliability Level of Potable Water			
			75%	90%	95%	100%
1	280	Price of potable water	21.1	21.1	32.2	**53.7**
		Agricultural production	-3.2	-3.2	-4.7	**-7.6**
		Price of agricultural products	0.9	0.9	1.4	**2.4**
		GDP	-0.4	-0.4	-0.7	**-1.0**
2	750		No shortage			Negligible negative impact

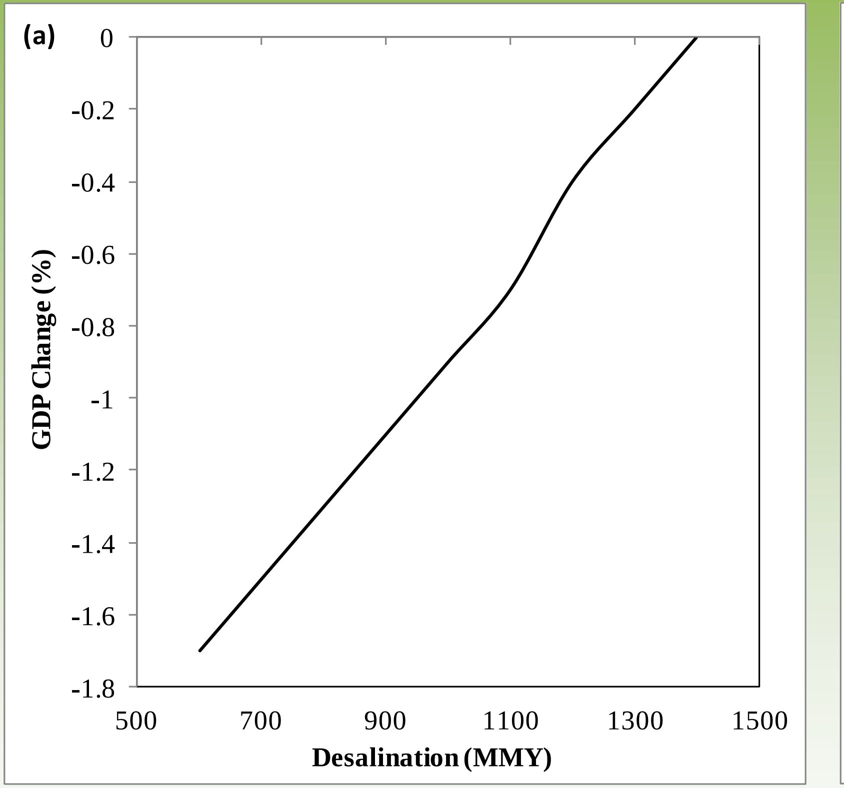
Results -2030

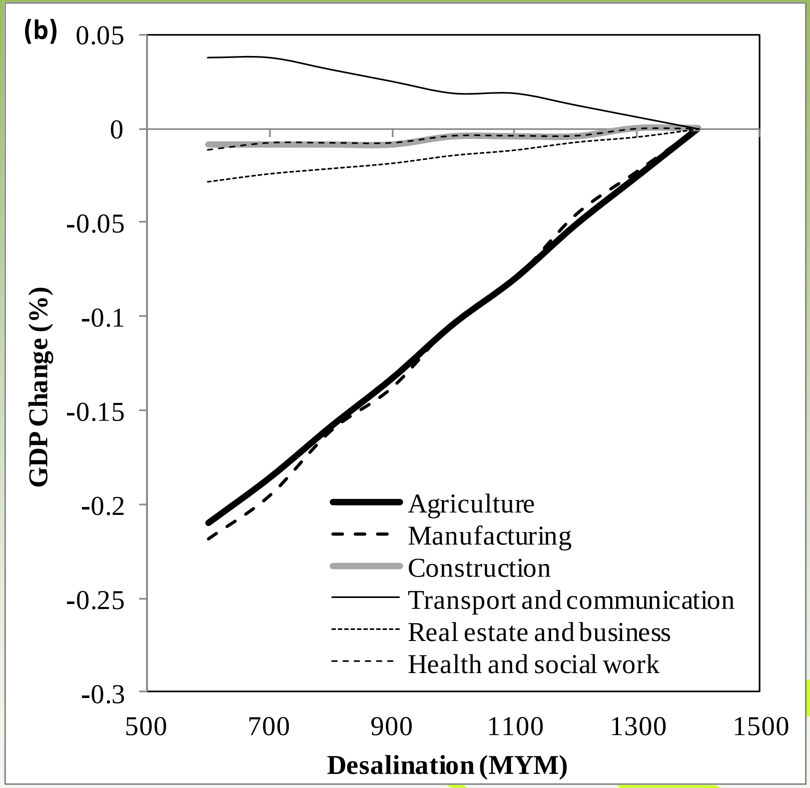
Scena-rio	Desalination MMY	Indicator	Shortage of Potable Water at Desired Supply Reliability Level of Potable Water			
			75%	90%	95%	100%
3	280	Price of potable water	45.8	59.5	69.0	83.5
		Agricultural production	-6.5	-8.3	-9.5	-11.2
		Price of agricultural products	2.1	2.7	3.1	3.7
		GDP	-0.9	-1.1	-1.3	-1.5
4	750	GDP	No shortage	-0.1	-0.3	-0.5

Results -2050

Scenario	Desali-nation MMY	Indicator	Shortage of Potable Water at Desired Supply Reliability Level of Potable Water			
			75%	90%	95%	100%
5	280	Price of potable water	132.1	144.6	158.4	165.8
		Agricultural production	-16.4	-17.7	-19	-19.7
		Price of agricultural products	5.9	6.5	7.1	7.4
		GDP	-2.1	-2.3	-2.4	-2.5
6	750	Price of potable water	65.7	79.7	91.6	105.2
		Agricultural production	-9.1	-10.7	-12.1	-13.6
		Price of agricultural products	2.9	3.6	4.1	4.7
		GDP	-1.2	-1.4	-1.6	-1.8

Impact of desalination levels on GDP under reliability level of 90% in 2050.





Conclusions

In the absence of a suitable solution for the projected shortage in potable water:

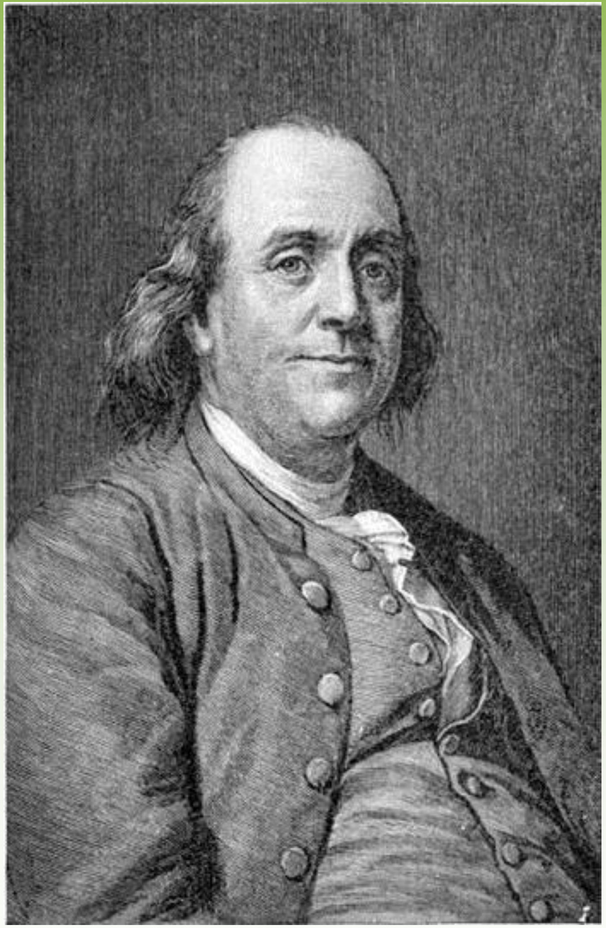
- there will be, starting in 2030 and steadily growing thereafter, a major impact on agriculture and the water economy:
- Failing to implement the plan for enlarging the desalination capacity to 750 MMY will result, under equilibrium conditions and at the highest desired level of supply reliability:
  - decline in agricultural output of 19.7%,
  - increase in the price of agricultural products of 7.4%,
  - increase in the relative price of potable water of 165.8 %
  - and decline in GDP of 2.5%.

Conclusions

The implementation of the approved plan for enlarging the desalination capacity will mitigate the impact, but there will still remain a sizable shortage in potable water that will result, at the highest desired level of supply reliability:

- in a decline in agricultural output of 13.6%,
- increase in the price of agricultural products of 4.7%,
- increase in the relative price of potable water of 105.2 %
- and decline in GDP ranges of 1.8%.

- ✓ Paper submitted to **Special Issue on Economics of Salinity Impacts and Management,** [Water Economics and Policy]
- ✓ Accepted for presentation at **EAERE2015**



> “When the well is dry, we know the worth of water.”

Benjamin Franklin