Natural resource economics and the rebound effect: An empirical approach in agriculture

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Objective of the presentation

- Climate change affects natural resources' availability and overexploitation during the past leads policy makers to adjust.
- Saving actions through taxing (i.e., carbon tax), pricing or technological improvements aim to restrain natural resource consumption (energy, land, water etc.)

Source: https://en.unesco.org/themes/water-security/wwap/wwdr/2020

Objective of the presentation

- Water is a main natural resource for agricultural production and countries with low inventories are susceptible to low production, increased prices, desertification and famine. Of all the economic sectors, agriculture is the largest consumer of fresh water on the planet with estimates accounting for 70% of total consumption (World Bank, 2020; UNESCO, 2020).
- Irrigational advances aim to reduce water consumption however consumption remains equivalent prior to technological upgrades or even increases

Source: https://www.fao.org/in-action/agronoticias/detail/en/c/1136462/

Who is to blame?

The rebound effect

The rebound effect or Jevon's paradox

William Stanley Jevons in his work "The Coal Question; an Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-mines" observed for the first time that the technological development that would theoretically lead to coal savings for energy supply in British industry ended up increasing the final consumption of coal, iron and other resources instead of saving them.

This phenomenon was called the **Jevons paradox** or **rebound effect**.

Source: https://www.britannica.com/biography/William-Stanley-Jevons

The rebound effect in modern era

The debate over the rebound effect came back to prominence after the 1970's energy crisis. In the early 1980s cost-effectiveness in energy efficiency was thought to increase energy consumption in the long run known as the Khazoom-Brooks postulate (Saunders, 1992).

Howarth (1997) argues that this only applies when: i) energy costs dominate the total cost of energy services and ii) energy service costs constitute a large share of economic activity, i.e. when prices are homogeneous (fixed prices).

The rebound effect: the case of water

- Alcott (2005) states that the rebound effect examines how technological improvements, which are supposed to save resources, result in the use of larger amounts of the resource investigated. This is because, as technology improves, marginal production costs are reduced, providing a lower price for the product that can translate into higher demand and therefore supply and production (Dumont et al., 2013).

- In the case of agriculture, as productivity increases due to water efficiency, farmers seek to maximize their income. Therefore, they continue to consume the same amount of inputs (i.e., water) as before the technical progress, instead of reducing them, in order to achieve higher yields (Song et al., 2018).

So why do policies fail?

As technology changes, a sector generates more output

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income and employment

Natural resource consumption is underestimated when income and employment growth are neglected

The neglected water rebound effect of income and employment growth

Theory and hypothesis

Theory and hypothesis

While the rebound effect is mostly studied at the micro level, technological advances apply also at macro level with much bigger impacts on the environment and natural resources conservation.

The Input-Output Model is a quick and simple approach widely used to examine an economy and generates tangible results, particularly for policy implementation short-term.

The model incorporates output, income and employment in an economy and their interaction with natural resources and commodities such as energy or water.

In this chapter we shall test the rebound effect caused not only by **Output** but **Income** and **Employment** too

The Classic Leontief Model

The Input–Output (I/O) Transactions Table is a two-dimensional matrix developed by Nobel Laureate Wassily Leontief that describes the economy of an area (country, region, city etc.)

		PRODUCERS AS CONSUMERS								FINAL DEMAND			
		Agric.	Mining	Const.	Manuf.	Trade	Transp.	Services	Other	Personal Consumption Expenditures	Gross Private Domestic Investment	Govt. Purchases of Goods & Services	Net Exports of Goods & Services
PRODUCERS	Agriculture												
	Mining												
	Construction												
	Manufacturing				z_{ij}						f_i		
	Trade												
	Transportation												
	Services												
	Other Industry												
VALUE ADDED	Employees	Employee compensation								x_i GROSS DOMESTIC PRODUCT			
	Business Owners and Capital	Profit-type income and capital consumption allowances											
	Government	Indirect business taxes											

Source: Miller and Blair, 2009

The Classic Leontief Model: Basic function

According to matrix theory and reversibility, a change in the final product can be calculated as a result of a change in the final demand f:

$$x = (I - A)^{-1} f, \text{ for } |I - A| \neq 0$$

Where A= $\frac{Z}{X}$ and I the identity matrix

$(I - A)^{-1}$ is the Leontief inverse matrix and illustrates the total requirements (direct and indirect) of an economy to produce its total output given a specific final demand.

The Classic Leontief Model: Impact analysis and multipliers

The Leontief inverse matrix $(I - A)^{-1}$ encodes a change in the external environment into the main variables (product, income, employment) of an economy through the use of multipliers.

<u>Output multiplier</u>	<u>Income multiplier</u>	<u>Employment multiplier</u>
$OM^{\mathrm{I}}_{\mathrm{j}} = \sum_{i=1}^{n+1} \ell_{\mathrm{ij}}$ $^*L = (I - A)^{-1}$	$IM^{\mathrm{I}}_{\mathrm{j}} = \frac{TIE_{\mathrm{j}}}{DIE_{\mathrm{j}}}$ • $DIE_{\mathrm{j}} = \frac{H_{\mathrm{j}}}{X_{\mathrm{j}}}$ • $TIE_{\mathrm{j}} = \sum_{i=1}^{n} \ell_{\mathrm{ij}} \times DIE_{\mathrm{j}}$	$EM^{\mathrm{I}}_{\mathrm{j}} = \frac{TEE_{\mathrm{j}}}{DEE_{\mathrm{j}}}$ • $DEE_{\mathrm{j}} = \frac{E_{\mathrm{j}}}{X_{\mathrm{j}}}$ • $TEE_{\mathrm{j}} = \sum_{i=1}^{n} \ell_{\mathrm{ij}} \times DEE_{\mathrm{j}}$

- H_{j} is the income vector derived from the National Accounts
- E_{j} is the employment vector derived from the National Accounts

The Classic Leontief Model: Impact analysis and multipliers

Multipliers allow us to estimate the effect of an external change on the economy and its variables. Such changes can be government spending through subsidies or investments. In the case of agriculture in the EU, CAP subsidies and Rural Development Plans are the main external stimuli

The Water Leontief Model: Water Footprint

The conventional model was extended by Leontief (1970) to account for environmental repercussions and the same process applies to energy, water, land and other inputs.

A water usage vector $\boldsymbol{W^d}$ to capture both the direct and indirect water consumption (also known as the total water footprint) due to the production process within the industries of an economy is used and the total water footprint $\boldsymbol{W^t}$ for the economy is calculated as in form:

$$W^t = [W^d \times (I - A)^{-1}]$$

Where $w^d_{ij} = \frac{w_{ij}}{X_j}$

w_{ij} is the amount of water (in physical units) to produce the output X_j of the sector i

The Water Leontief Model: Water multipliers

Similar to the classic multipliers presented earlier, water multipliers can be estimated that account for total water consumption in an economy due to an increase in the final demand.

For the first time, Income and Employment multipliers are linked to water consumption!!

The Water Income Multiplier (WIM) estimates the water consumed per unit of an industry's total income growth due to an increase in final demand and is calculated according to the formula:

$$WIM = W^t \times \left[\widehat{IM}\right]^{-1}$$

The Water Employment Multiplier (WEM) estimates the water consumed per unit of total employment growth of a sector due to an increase in final demand and is calculated according to the formula:

$$WEM = W^t \times \left[\widehat{EM}\right]^{-1}$$

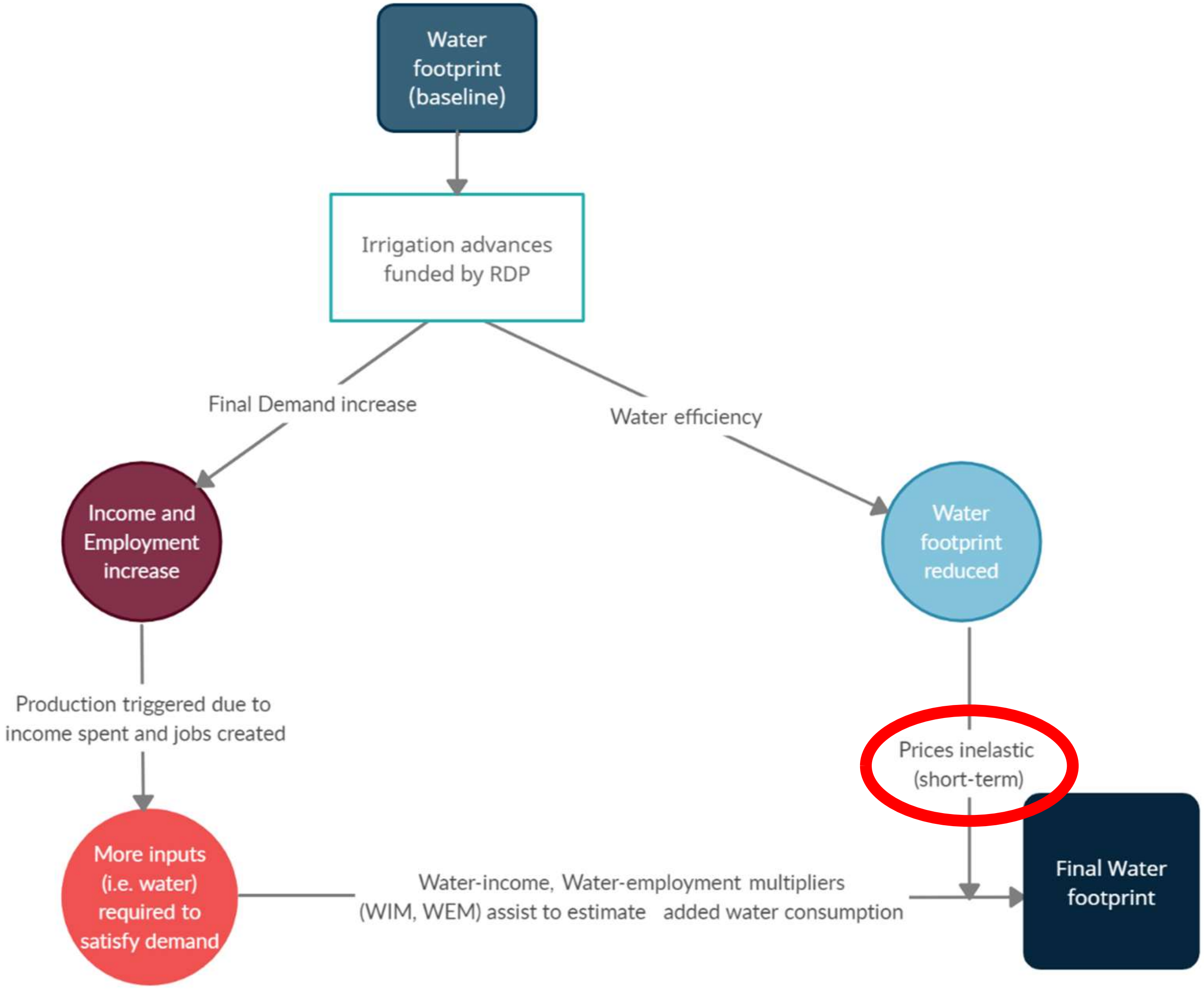
The Water Rebound effect

The Water Output multiplier is identical to the total water footprint W^t and is the main objective in the literature of the **water rebound effect**.

Rural Development plans aim to improve water efficiency through funding of irrigational advances. My hypothesis was that the total water footprint is underestimated as the achieved water efficiency was overarched by indirect water consumption of income and employment growth according to the formula:

$$WF = w^t + \sum W \ldots \times FD + \sum \ldots \times FD$$

As the stimulus of the external factor is impermanent, the added water consumption of income and employment will phase out and true water efficiency will be achieved long-term.


Water footprint (baseline)
Irrigation advances funded by RDP
Final Demand increase
Water efficiency
Income and Employment increase
Water footprint reduced
Production triggered due to income spent and jobs created
Prices inelastic (short-term)
More inputs (i.e. water) required to satisfy demand
Water-income, Water-employment multipliers (WIM, WEM) assist to estimate added water consumption
Final Water footprint

The neglected water rebound effect of income and employment growth

An empirical study in a Mediterranean Region

Study area

- The Region of Thessaly (EL61-NUTS2) is geographically located at the center of continental Greece and its regional economy is highly dependent on agriculture.

- Contributes 5% of national GDP, but the agricultural sector is offering gross added value (GVA) three times greater than the national average.

- Irrigation water accounts for 91.83% of total water requirements annually in the Region.

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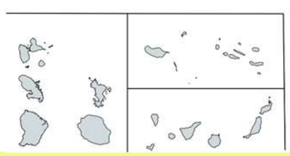
- Moreover, irrigation water cost is negligible and ranges from 0.06% for Pears to 4% for Cotton of total production cost (Ministry of Environment and Energy,2017).



Study area

- Irrigation is based on subterranean waters that are the main hydrological source in the region, with almost 65% of total water consumption being extracted from groundwater (Ministry of Environment and Energy, 2017)
- Cotton, durum wheat and maize are the most popular arable crops with pears, apples and peaches covering the majority of fruit plantations.
- Tomato is the most important vegetable cultivated, with 54% of total vegetable production and covering 27% of garden area, while alfalfa sums up to 64% of total fodder production and 49% of total fodder land.

Rural Development Plan 2014-2020 for Greece: Action 4.1.2 "Implement investments that contribute to water savings"

- The aim of the Action is to save water between 5-12.5% for agriculture in regions with poor water conditions
- Budget of the Action for Greece is €36.000.000, and the Ministry of Rural Development and Food (2021) is responsible for implementation
- Realistic scenario of implementation is 8,75% according to the Ministry of Rural Development and Food
- Three scenarios were developed. Water savings were linked linearly to budgets according to recommendations from local experts and the Ministry call

	Scenario I	Scenario II	Scenario III
Budget	€4.900.000	€25.200.000	€33.600.00
Water savings	8,75%	45%	60%

Policy scenarios: The water rebound effect

		Total consumption (m3/€)	Action 4.1.2	WIM impact	WEM impact	Final Water Foo
Baseline Scenario	Water Footprint of Thessaly Region	15,050	Rebound effect	-	-	15,050
Scenario I (8,75% water savings)	Instead of 3% reduction 12,76% increase due to rebound effect	14,624		1,012	1,336	16,971
Scenario II (45% water savings)	Instead of 14,57% reduction 65,64% increase due to rebound effect	12,858		5,203	6,869	24,930
Scenario III (60% water savings)	Instead of 19,42% reduction 87,53% increase due to rebound effect	12,127		6,938	9,159	28,224

Policy scenarios: Depreciation of the rebound effect

Water depreciation timespan

	Water footprint plus the rebound effect (m3/€)	Year 1	Year 2	Year 3	Year 4	Year 5	Goal (m3/€)
Scenario I (annual saves 3%)	16,971	16,462	15,968	15,489	15,024	14,574	14,624
Scenario II (annual saves 14,57%)	24,93	21,298	18,195	15,544	13,279	11,344	12,858
Scenario III (annual saves 19,42%)	28,224	22,743	18,326	14,767	11,899		12,127

While at first glance Scenario III seems to increase the water footprint enormously and be inefficient, it reaches the intended goal a year earlier than the other two scenarios!

Thank you

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