Water Effectiveness and Productivity Measurement

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Introduction

- The sustainability of ecosystems and its relationship to economic growth is intertwined with water management in both developing and developed nations.
- Water management issues in the agricultural sector often take a central role in controversies over how to allocate this resource that is becoming increasingly scarce in many arid and semi-arid areas around the world (Scheierling et al., 2014).
- With the agricultural sector being the largest user of freshwater, with estimates suggesting irrigated agriculture accounts for about 70 percent of total freshwater withdrawals worldwide (Molden, 2007).
- At the same time, there can be significant interregional competition for water use in agriculture (Middle East or Sub-Saharan African countries) as well as intersectoral competition for water between agriculture, urban and environmental uses (e.g., tourist areas in Southern Europe and North Africa)
    - *The value of water used in agriculture must be balanced against these competing uses.*

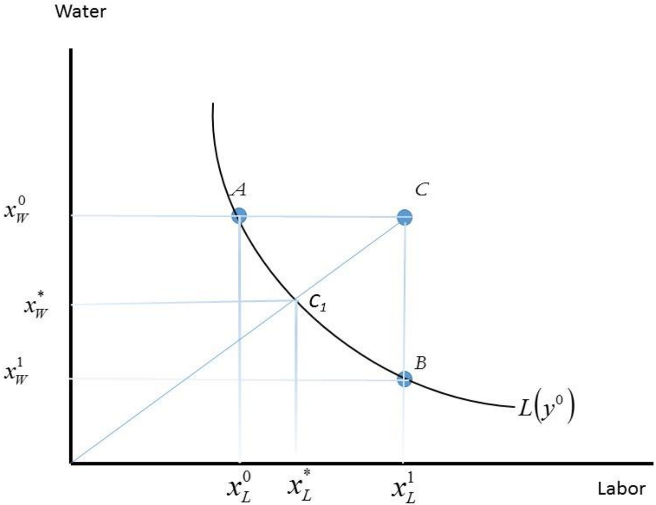
Water Productivity

- Attention on water as a specific factor of production, and the practices and technological innovations that can increase agricultural output per unit of water applied.
  - Blue Revolution (Calder, 1999) and Kofi Annan Foundation (2000) promoting "more crop per drop".
- Vague aspects of this measure which offers little guidance in terms of mechanisms, instruments and policies that can realize additional output per unit of water input (Scheierling et al., 2014).

The Foundation to Measuring Productivity
Output per Unit of Input

- How to define “output per unit of input”?
  - Any reasonable production situation involves multiple inputs that involve variable and fixed factors producing multiple outputs.
  - There are partial productivity measures that focus on a single input (e.g., labor productivity, land productivity, water productivity).
  - The more common approaches embrace the notion of accounting for all factors of production.
- Both partial and multi-factor measures of productivity have their uses
  - Sometimes referred to input efficiency (e.g., fuel or water efficiency).
  - When the firm can substitute inputs as it operates optimally, the multi-factor measure is better suited to measure firm adjustment beyond the short term.

An Illustration



Irrigation Effectiveness: Setting the Stage

- The engineering notion of efficiency: the more advanced the technology is the more effective water application is. For instance, a drip irrigation technology is more efficient than the traditional furrow system (e.g., McGuckin et al., 1992; Omezzine and Zaibet 1998).
- Development of new more effective technologies: This assertion promoted technological innovations in irrigation technology combined with policy schemes to speed up the diffusion process (e.g., Dridi and Khanna, 2005; Genius et al., 2014).
- The economic notion of efficiency: due to improper management practices farmers do not utilize efficiently factors of production including irrigation water. For instance, less experienced or educated farmers may not be able to utilize an input combination minimizing cost of production (e.g., Karagiannis et al., 2003; Yigezu et al., 2013).

Irrigation Effectiveness: Setting the Stage

- Although all approaches aim to a more efficient management of natural resources they fail to provide a complete analysis.
  - A more advanced irrigation technology does not always ensure efficiency in irrigation water (e.g., Yaron et al., 1992; Dinar and Yaron 1992).
  - Policies aimed to speed up diffusion rates do not improve effectiveness as risk averse farmers adopt in order to hedge against the risk of adverse climatic conditions.(e.g., Tsur et al., 1990; Koundouri et al., 2003).
  - Economic efficiency measurement do not take into account the engineering perspective and all factors responsible for irrigation effectiveness (e.g., Chemak, 2012).
- Combining these different strands of the literature we may be able to get a more realistic picture of irrigation water use.

Irrigation Effectiveness: An Engineering Perspective

- Irrigation water efficiency (IWE) is defined as the ratio of effective water use (i.e., the water used by the crop) to the water actually applied by the crop:

$$IWE_k = \frac{\tilde{x}_k^w}{x_k^w} \in [0, 1]$$

- When $IWE = 0$, applied water is completely lost while when $IWE = 1$ the plant absorbs all applied water.
- Hence, a modern irrigation technology will reduce water use improving irrigation water efficiency at the expense of increased capital.
- In pure engineering terms for a furrow system average irrigation efficiency is 0.60 whereas for drip technologies goes up to 0.95.

Irrigation Effectiveness: An Economic Perspective

- Caswell and Zilberman (1986) and Dinar et al., (1992) acknowledge that irrigation water efficiency is not exclusively influenced by the choice of irrigation method.
- They suggested that many other factors are affecting efficiency in water applied summarized into the following:
  - the water holding capacity of the soil
    - e.g. farmers utilizing the same irrigation technology but cultivating in different soils (limestones vs sandy soils) may exhibit different levels of irrigation water efficiency as their crop will absorb different amounts of irrigation water;
  - the prevailing weather conditions;
  - farmers human capital as a proxy of their allocative ability.

Irrigation Effectiveness: A Realistic Perspective

- In a more realistic approach effective water with the following separable structure:

$$\tilde{x}^w = x^w g\left(q, d, \varepsilon, k\right)$$

where

  - $q \in \mathbb{R}_+$ denotes soil water holding capacity;
  - $d \in \mathbb{R}_+$ is an aridity index;
  - $\varepsilon \in \mathbb{R}_+$ is farmer's human capital (e.g., years of schooling);
  - k is an indicator of irrigation technology;
  - $g(\cdot)$ is a positive valued function that belongs to the $(0, 1]$ interval. It is non-decreasing and concave in all of its arguments.

Farm Technology

- The farm technology at year t using irrigation application method k can be represented by the following closed, nonempty production possibilities set:

$$T(t,k) = \left\{ \left(\mathbf{x}_k^v, x_k^w, q, d, \varepsilon, y_k\right) : y_k \leq f\left(\mathbf{x}_k^v, \tilde{x}_k^w, t\right), \right.$$
$$\left. \tilde{x}_k^w = x_k^w g_k\left(q, d, \varepsilon; k\right) \right\}$$

  where

  - $\mathbf{x} \in \mathbb{R}_+^J$ is a vector of variable non-water inputs;
  - $y \in \mathbb{R}_+$ is realized output;
  - $f\left(\mathbf{x}, \tilde{x}^w, t\right) : \mathbb{R}_+^{j+2} \to \mathbb{R}_+$, is a continuous and, strictly increasing, differentiable concave production function, representing maximal output from variable non-water inputs, effective irrigation water, and irrigation technology choice given environmental factors and farmer's human capital constraints.

Irrigation Technology Choice

- For each irrigation technology, producer's short-run problem is to choose variable inputs to maximize profit (e.g. Genius et al., 2013):

$$\pi_1(\cdot) \equiv \max_{x_1^v, x_1^w, y} \left\{ py_1 - \mathbf{w}^v \mathbf{x}_1^v - w^w x_1^w : y_1 \leq f\left(\mathbf{x}_1^v, x_1^w g_1(q, d, \varepsilon; 1), t\right) \right\}$$

$$\pi_0(\cdot) \equiv \max_{x_0^v, x_0^w, y_0} \left\{ py_0 - \mathbf{w}^v \mathbf{x}_0^v - w^w x_0^w : y_0 \leq f\left(\mathbf{x}_0^v, x_0^w g_0(q, d, \varepsilon; 0), t\right) \right\}$$

  where

  - ▷ $p \in \mathbb{R}_{++}$ is the farm crop price;
  - ▷ $\mathbf{w}^w \in \mathbb{R}_{++}$ is irrigation water price;
  - ▷ $\mathbf{w}^v \in \mathbb{R}_{++}^j$ is the vector of variable input prices.

- $\pi_k(p, w^v, \mathbf{w}^w, q, d, \varepsilon, t)$ is homogeneous in crop, variable input and irrigation water prices, non-decreasing in p, and non-increasing in w^v and w^w.

Irrigation Technology Choice

- However, future profit flows after adoption of the new irrigation technology are not known with certainty due to:
    - ignorance of the exact performance of the new irrigation technology;
    - the higher probability of committing errors in the use of this technology.
- Therefore, additional information might possess a positive value as farmers may prefer to delay adoption in order to get more information on the new equipment.
- Hence, farmers will adopt the innovative irrigation technology if and only if (Koundouri *et al.*, 2006):

$$E\left[\pi_1(\cdot)\right] - E\left[\pi_0(\cdot)\right] \geq VI$$

- ▷ where $VI \geq 0$ represents the expected value of new information.

TFP Measurement

- Taking logarithms of the production function and totally differentiating with respect to t yields:

$$\dot{y} = \frac{\partial \ln f}{\partial t} + \sum_j \frac{\partial \ln f}{\partial \ln x_{kj}^v} \dot{x}_{kj}^v + \frac{\partial \ln f}{\partial \ln \tilde{x}_k^w} \dot{x}_k^w$$

$$+ \frac{\partial \ln f}{\partial \ln \tilde{x}_k^w} \left[\frac{\partial \ln g_k}{\partial \ln d} \dot{d} + \frac{\partial \ln g_k}{\partial \ln \varepsilon} \dot{\varepsilon} + \frac{\partial \ln g_k}{\partial \ln k} \dot{k} \right]$$

or, in elasticity form,

$$\dot{y} = TC + \sum_j e_j^x \dot{x}_{kj}^v + e^w \dot{x}_k^w + e^w e^d \dot{d} + e^w e^\epsilon \dot{\epsilon} + e^w e^k \dot{k}$$

where

  - e_j^x and e^w are the output elasticities of the variable inputs and irrigation water, respectively.
  - e^d, e^ε and e^k are the irrigation effectiveness elasticities of general environmental conditions, farmer's educational level, and irrigation technology choice, respectively.

TFP Measurement

- Using the Divisia Index of TFP growth, $\dot{TFP} = \dot{y} - \sum_j s_j^x \dot{x}_j - s^w \dot{x}^w$, with $s_j^x = e_j^x / E$ and $s^w = e^w / E$ being the corresponding cost shares, results in:

$$\dot{TFP} = \overbrace{\dot{TC}}^{a} + \overbrace{\left(\frac{E-1}{E}\right)\left(\sum_j e_j^x \dot{x}_{kj}^v + e^w \dot{x}_k^w\right)}^{b}$$
$$+ \overbrace{e^w e^d \dot{d} + e^w e^\epsilon \dot{\epsilon} + e^w e^k \dot{k}}^{c}$$

with

- $a \rightarrow$ impact of change in farm technology
- $b \rightarrow$ relative impact of scale economies
- $c \rightarrow$ improvements in irrigation effectiveness through
    - changes in environmental conditions
    - changes in human capital
    - changes in irrigation technology

Empirical Model: Adoption Decision

- Farmers will choose to adopt the modern irrigation technology if and only if:

$$Y_{it}^{*} \equiv E\left[\pi_1(\cdot)\right] - E\left[\pi_0(\cdot)\right] - VI \geq 0$$

- Y_{it}^{*} is an unobservable random index for each farmer that defines his/her propensity to adopt the new irrigation technology. For purposes of estimation, denote by

$$Y_{1it}^{*} = h_1\left(\mathbf{z}_{1it};\alpha_1\right) + e_{1it} \quad \text{and} \quad Y_{0it}^{*} = h_0\left(\mathbf{z}_{0it};\alpha_0\right) + e_{0it}$$

- The profits of farmer *i* at year *t* if he/she is an adopter or not, respectively
  - $\mathbf{z}_{kit} \in \mathbb{R}_{+}^{I}$ are the farm characteristics affecting farm's profitability;
  - α_k are the associated parameters;
  - $e_{kit} \sim N\left(0, \sigma_k^2\right)$.

Empirical Model: Adoption Decision

- From the above, the probability of farmer *i* adopting modern irrigation technology at time *t* is given by the following:

$$\begin{aligned} Pr[Y^*_{it} = 1] =& Pr\left[Y_{0it} - Y_{1it}\right] \\ =& Pr\left[e_{it} < h\left(\mathbf{z}_{it}; \alpha\right)\right] \\ =& \Phi\left[h\left(\mathbf{z}_{it}; \alpha\right)\right] \end{aligned}$$

  where

  - $e_{it} = e_{0it} - e_{1it}$
  - $\mathbf{z}_{it} = \mathbf{z}_{0it} - \mathbf{z}_{1it}$
  - $\alpha = \alpha_0 - \alpha_1$
  - $\Phi[\cdot]$ is the cumulative of the normal distribution

- The model is estimated as a simple probit model taking into account the panel structure of the data.

Empirical Model: Farm Technology

- Concerning farm technology, we assume that the transition production function takes the following transcendental logarithmic (translog) form:

$$\ln y_{it} = \beta_0 + \beta^t t + \sum_j \beta_j^v \ln x_{jit}^v + \beta^w \left(\ln x_{it}^w + \ln g_{it}\right) + \sum_j \beta_j^{vt} \ln x_{jit}^v t + 0.5 \left[\sum_j \sum_m \beta_{jm}^{vv} \ln x_{jit}^v \ln x_{mit}^v + \beta^{tt} t^2 \right]$$

where

  - ▷ $\ln g_{it} = -\left[\left(\beta_0^d d_{it} + \beta_0^q q_{it} + \beta_0^\varepsilon \varepsilon_{it} \right) + \left(\beta_1^d d_{it} + \beta_1^q q_{it} + \beta_1^\varepsilon \varepsilon_{it} \right) F(k_{it}; \gamma, \delta) \right]$
  - ▷ $F(k_{it}; \gamma, \delta) = \left(1 - \exp\left[-\gamma (k_{it} - \delta)^2 \right] \right)$

Empirical Illustration: Data on Greek Greenhouse Farms

- Greek farmers cultivating vegetables in greenhouses.
- The survey was undertaken within the context of the Research Program TEAMPEST financed by the European Commission.
- 56 small-scale greenhouse farms randomly selected from the Ierapetra Valley in the southeast region of the island of Crete, Greece
  - in this specific area of Crete vegetable cultivation under greenhouses is flourishing in the last twenty years.
- The survey covers cropping seasons from 2009-10 to 2012-13, resulting in a balanced panel dataset of 224 total observations.

Results

Table 1: Summary Statistics of the Variables

Variable	Non Adopters	Adopters	All Farms
Number of farms	23	33	56
Irrigation Technology Adoption Model			
Farmer's Age (in years)	53.98	33.32	41.80
Farmer's Education (in years)	9.77	13.17	11.77
No of Extension Visits	1.49	5.85	4.06
Farm Size (in stremmas)	4.11	6.37	5.44
Subsidies (in Euros)	569.6	796.1	703.1
Translog-Transition Production Function			
Output (in Euros)	57,952	87,424	78,528
Labor (in hours)	333.0	772.4	591.9
Seeds (in Euros)	1,271	1,574	1,449
Intermediate Inputs (in Euros)	7,893	9,579	8,886
Irrigation Water (in m^3)	1,202	1,467	1,358
Irrigation Water Effectiveness Function			
Soil Water Holding Capacity (in cm/s)	1.31×10^{-3}	2.60×10^{-3}	1.96×10^{-3}
Climatic Conditions	1.11	1.25	1.19
Land Surface Slope (in degrees)	0.09	0.11	0.10

Table 2: Maximum Likelihood Parameter Estimates of the Probit Model

Parameter	Estimate	St.Error	Parameter	Estimate	St.Error
Constant	-6.0926	1.8643**	Extension Visits	0.4842	0.0835**
Farmer's Age	-0.0337	0.0115**	Farm Size	0.1198	0.0523*
Farmer's Education	0.6086	0.2891*	Subsidies	0.0010	0.0003**
Farmer's Education-Squared	-0.0233	0.0115*		—	
Pseudo R-squared			0.7078		
Marginal Effects:					
Farmer's Age	-0.0117	0.0040**	Farm Size	0.0414	0.0180*
Farmer's Education	0.2121	0.0978*	Subsidies	0.0003	0.0001**
Extension Visits	0.1688	0.0301**		—	

The marginal effects were evaluated at the mean values while their corresponding standards errors were obtained using the *Delta* method.

* and ** indicate statistical significance at the 5 and 1 per cent level, respectively.

Adoption Behavior

- Farmer's educational level and extension visits together with farm size and subsidies received are positively related with farmer's probability to adopt the new overhead sprinkler technology.
- A positive value on waiting for better information
  - Greenhouse farmers who have better information assign a lower value on the option to wait and, for this reason, are more likely to adopt than other farmers.
- Higher probability of adoption for younger farmers.
- Larger farms that commonly face higher irrigation water cost are more likely to switch to the overhead sprinkler technology since the associated benefits from the reduced irrigation cost are significantly higher for them compared with smaller farms in the sample.

Adoption Behavior

- Farms receiving more subsidies experience lower actual installation and implementation costs due to the higher financial aid received which in turn provide important economic incentives toward adopting the overhead sprinkler technology.
- Education impact mixed.
- Policies intending to advance adoption rates for overhead sprinkler technology among greenhouse farmers in the Ierapetra Valley should focus on increasing farmers human capital levels rather providing economic incentives.

Results

Table 5: Adoption Rates, Climatic Conditions and Irrigation Water Effectiveness over the 2010-13 Period

Year	2010	2011	2012	2013
% of Adopters	23.21	33.90	47.43	58.93
Change in Adopters	—	10.69	13.53	11.50
Probability to Adopt	0.3493	0.3677	0.4498	0.4680
Climatic Conditions	1.1316	1.4305	1.1025	1.0932
Irrigation Water Effectiveness	0.7103	0.7161	0.7392	0.8049

Results

Table 8: Decomposition of TFP Growth (Average Annual Values for the 2010-13 Period)

Components	TFP Growth	(%)
TFP Growth	1.1396	
Scale Effect:	0.1024	(8.96)
Land	0.0000	(0.00)
Labor	0.0039	(0.35)
Seeds	0.0231	(2.03)
Intermediate Inputs	0.0438	(3.84)
Irrigation Water	0.0314	(2.75)
Climatic Effect	0.0775	(6.78)
Overall Technical Change:	0.9598	(84.22)
Output Enhancing TC	0.8499	(74.40)
Neutral TC	0.7261	(63.56)
Biased TC	0.1238	(10.84)
Irrigation Water Effectiveness TC	0.1099	(9.62)

Irrigation Water Effectiveness

- Increases as the percentage of adopters increases over time.
- Robust positive relation between soil and climate conditions and irrigation water effectiveness, revealing at the same time significant.
- Farmers facing poor soil and climate conditions exhibit a higher probability to adopt the new irrigation technology.
- Policies intending to advance diffusion rates would not significantly improve effectiveness for farms facing favorable soil and climatic conditions.

Concluding Remarks

- Properly measuring the impact of irrigation water technology on productivity growth requires defining the technology that can address three important issues related with irrigation water use:
    - irrigation water applied deviates from the amount of water that is actually consumed by the crop;
    - the transition between the alternative irrigation technologies does not take place in a single time period;
    - changes in irrigation technology influences output growth indirectly by augmenting farms soil characteristics and atmospheric conditions which, in turn, affect irrigation water effectiveness.

Concluding Remarks

- The speed of transition between traditional (drip) and innovative (overhead sprinkler) irrigation technologies is relatively quick, approximating a threshold process.
- Policies aiming to enhance adoption rates for overhead sprinkler technology should be directed toward increasing farmer's human capital levels rather providing economic or other incentives.
- Training seminars targeting target groups of less-educated farmers and more frequent on-farm extension visits can be more effective than other policies such as subsidizing new irrigation technology.
- Policy schemes aiming to enhance irrigation water effectiveness through advancing diffusion rates can be more effective if they target specific groups of farmers who face the most adverse soil and climatic conditions.

Concluding Remarks

- Productivity Growth
  - Technical change dominates.
    - Most of this is driven by neutral TC;
    - Biased TC $\approx$ Irrigation Water Effectiveness TC.
  - Careful not to mask neutral technical change with irrigation water technology.
- Policy Implications
  - Role of R&D
  - Role of Diffusion and Training
    - Policies that can ease the adoption of new technologies.

Thank You!

Questions?