Efficiency of Irrigation Water and Productivity Measurement

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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 utilise 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).
Although all approaches aim to a more efficient management of natural resources the 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 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:

\[ IWE = \frac{\tilde{x}_w}{x_w} \]

where \( IWE \in [0, 1] \). At the extreme, 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.
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 summarised into the following:

- the water holding capacity of the soil,
- the prevailing weather conditions,
- farmers human capital as a proxy of their allocative ability, and
- the method of water application, i.e., irrigation technology.
Combining the two approaches we may express effective water with the following separable structure:

\[ \tilde{x}^w = x^w g(q, d, \varepsilon, k) \]

where \( q \in \mathbb{R}_+ \) denotes soil water holding capacity, \( d \in \mathbb{R}_+ \) is an aridity index (e.g., Stallings, 1968), \( \varepsilon \in \mathbb{R}_+ \) is farmer’s human capital (e.g., years of schooling) and, \( k \) 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 soil water holding capacity and farmer’s human capital, and non-increasing and convex in weather conditions.

We also assume that capital intensive irrigation technology (i.e., drip) enhances irrigation effectiveness.
According to the engineering perspective, irrigation technology always enhances irrigation effectiveness.

However, what we observe is a non-uniform distribution of irrigation technologies among farmers in the same area (e.g., drip, sprinklers or even furrow).

Discriminating between capital intensive and traditional irrigation methods, then the indicator $k$ may be proxied by (it can be always extended to more than two)

$$k = \begin{cases} 
1 & h_1(z) \geq 0 \quad \text{modern technology} \\
0 & h_0(z) < 0 \quad \text{traditional technology}
\end{cases}$$

where $z$ may include all those variables affecting individual choice (e.g., farm characteristics, risk perceptions, information) documented in technology adoption literature.
Summarizing the above, farm technology at year $t$ is represented by the following closed, nonempty production possibilities set:

$$T(t) = \{(x, x^w, q, d, \varepsilon, z, \epsilon, y) : y = f(x, \tilde{x}^w, t), \tilde{x}^w = x^w g(q, d, \varepsilon, k)\}$$

where $x \in \mathbb{R}_+^J$ is a vector of variable non-water inputs, $y \in \mathbb{R}_+$ is realized output, and $f(x, \tilde{x}^w, t) : \mathbb{R}_+^{j+2} \rightarrow \mathbb{R}_+$, 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 farmers’s human capital constraints.
Taking logarithms in both sides of the production function and totally differentiating with respect to time yields:

\[
\dot{y} = \sum_j \frac{\partial}{\partial \ln x_j} \ln f \dot{x}_j + \frac{\partial}{\partial t} \ln f + \frac{\partial}{\partial \ln x^w} \ln f \dot{x}^w \\
+ \frac{\partial}{\partial \ln \tilde{x}^w} \left[ \frac{\partial}{\partial \ln d} \ln \tilde{x}^w \dot{d} + \frac{\partial}{\partial \ln \epsilon} \ln \tilde{x}^w \dot{\epsilon} + \frac{\partial}{\partial \ln h} \ln \tilde{x}^w \dot{h} \right]
\]

or

\[
\dot{y} = \sum_j e^x_j \dot{x}_j + TC + e^w \dot{x}^w + e^d \dot{d} + e^\epsilon \dot{\epsilon} + e^h \dot{h}
\]
Using the Divisia Index of TFP growth, \( \hat{TFP} = \dot{y} - \sum_j s_j^x \dot{x}_j - s^w \dot{x}^w \) with 
\[ s_j^x = e_j^x / E \]
and 
\[ s^w = e^w / E \]
being the corresponding cost shares results in:

\[
\hat{TFP} = TC + \left( \frac{E - 1}{E} \right) \left( \sum_j e_j^x \dot{x}_j + e^w \dot{x}^w \right) + e^d \dot{d} + e^e \dot{\epsilon} + e^k |_{k=1}
\]

1. the impact of change in farm technology
2. the relative impact of scale economies
3. improvements in irrigation effectiveness through
   - changes in environmental conditions
   - changes in human capital
   - changes in irrigation technology
Using detailed farming data and utilizing any functional specification for the production function, the model can be econometrically estimated providing:

- irrigation effectiveness among surveyed farmers including the impact of irrigation method, environmental conditions and human capital on it’s observed value
- factors affecting adoption of modern, capital intensive irrigation technologies among farmers
- decomposition of TFP growth rates and evaluation of the impact of irrigation effectiveness upon them
- the choice of the factors affecting both irrigation effectiveness and adoption behaviour can be enhanced with any variable that is of particular interest for policy makers