Myths and Maths of Water Efficiency: An Analytical Framework to Assess the Real Outcome of Water Saving Technologies in Irrigation

Gómez Gómez, Carlos Mario *
Pérez Blanco, Carlos Dionisio

University of Alcalá. Plaza de la Victoria, 2. 28802 Alcalá de Henares, Madrid (Spain)
Madrid Institute for Advanced Studies in Water Technologies (IMDEA-Water). C/ Punto Net, 4, 2º piso, Edificio ZYE. 28805 Alcalá de Henares, Madrid (Spain)

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*[Corresponding author] **(**Mario.gomez@uah.es)

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Abstract

Greening the economy is mostly about improving water governance and not only about putting the existing resource saving technical alternatives into practice. Focusing in the second and forgetting the first risks finishing with a highly efficient use of water services at the level of each individual user but demanding an unsustainable amount of water for the entire economy. This might be happening already in many places with the so-called modernization of irrigated agriculture: the world's largest water user and the one offering the more promising water saving opportunities. Actual savings seem to be far from expected and modern irrigation techniques seem not to be contributing to reduce water scarcity and increase drought resilience. In fact, according to the little evidence available, they seem to be doing the opposite: increasing water demand and depletion. Building on basic economic principles this paper aims at showing the conditions under which this apparently paradoxical outcome might appear. This basic model is expected to serve as guidance for assessing the actual outcomes of enhancing irrigation efficiency and to discuss the changes in water governance that would be required for this to make a real contribution to a sustainable water management.

Keywords Agricultural economics; Water economics; Irrigation efficiency; Risk management; Jevons' Paradox; Rebound effect.

JEL code Q15, Q18, Q25, Q51, Q58

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1. *Introduction*

Trends toward increased water scarcity and drought risks are now a recognized fact in many arid and semiarid regions worldwide. Technical opportunities to make water use sustainable do exist, but using them might not result in the desired reversal of the current trends, namely, increasing water scarcity and droughts and climate change driven uncertainties. Technical options to, for example, reduce water use without reducing rural income or harming food security are but a social opportunity that might be wasted if no other measures necessary to improve water governance are set. The real policy challenge is to guarantee that all water uses are coherent with the conservation of the resource base and, further than putting more efficient devices into use, water property rights still need to be addressed and water must be priced accordingly. In this note we show that even when the desired technical shift is successfully implemented, it might end up reinforcing the already unsustainable trends in water use. This is the case of water-conserving irrigation technologies.

Agriculture is the world's largest water consumer and is often believed to be wasteful. Consequently, policy makers have called for measures to increase its efficiency in order to relieve the pressure over water resources. Among these measures, subsidies to enhance irrigation efficiency have rapidly become widespread. It is widely believed that water-conserving irrigation technologies make more water available for both other uses and the environment. However, recent empirical work shows that this may not be the case[1].

The *first argument* comes from the hydrological study of the water balance inside a basin. Take for example a traditional irrigation system. Due to its inefficiency, a large share of the water applied does not effectively contribute to cover the evapotranspiration needs of the plants and is therefore "lost". But much of this water is later on recaptured and returned to the watercourse, and is still available for alternative uses. However, after an efficiency improvement, although the amount of water applied may actually fall, the overall water depletion increases through reduced return flows and lost aquifer seepage. This *hydrological paradox* can be found for example in Scheierling et al. (2006), Jensen (2007), Ward and Pulido-Velázquez (2008) and Rodríguez-Diaz et al. (2012).

The *second argument* comes from economics: without any other change an improvement in irrigation efficiency results makes water a more productive input and will result in an increase, rather than a reduction in water demand. The idea that under certain conditions an efficiency improvement leads to an increase in the use of a resource is well known in economics at least since the XIXth century and has received

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[1] This paper only focuses on water use and demand. Apart from that the green potential of more efficient irrigation techniques can be question regarding water quality (as lower returns are associated with reduced assimilation capacities and then to higher concentrations of nitrates and other pollutants in water bodies, and with the fact that the energy for pumping pressurized devices is much higher than traditional gravity devices (Rodriguez-Díaz, et al., 2011).

different names, such as the *Jevons' Paradox*, the Khazzoom-Brookes effect or the rebound effect (Khazzoom, 1989; Alcott, 2005 and 2008; Tirado et al. 2006) .Consequently, there is considerable interest in determining under what conditions this paradox appears, with several studies in fields such as energy or transportation (Greene et al., 1999; Greening et al., 2000). Surprisingly, its study in the field of water economics is relatively new and mostly based on empirical results (Peterson and Ding, 2005; Pfeiffer and Lin, 2012).

There is no methodological framework that explains under what conditions the *Jevons' Paradox* appears. As a result, it is difficult to predict the sign of the impact of an irrigation efficiency improvement over the amount of water applied. This paper wants to help bridge this gap. In these pages we present an analytical framework to assess the different and opposing economic effects that exist behind an irrigation efficiency improvement and show under what conditions the *Jevons' Paradox* is feasible.

2. *How would farmers respond to an irrigation improvement?*

Of course, an increase in water efficiency will reduce the amount of water required to obtain the same products as before. This is the obvious and common sense first effect that makes technological advances attractive. But the technical shift means also a change in the incentives in place and farmers will not normally continue producing the same. Two additional effects over water demand need to be considered.

The second effect is the result of a variable cost increase that, similar to the first one, reduces water demand. The cost of applying water with more sophisticated irrigation devices (e.g., drip irrigation) is more expensive than with traditional devices (e.g., gravity irrigation), and the additional energy and labor required will increase the water application cost and reduce water demand.

The third effect refers to the fact that a better irrigation system makes water more productive and, for this reason, farmers would probably be willing to demand more water than before. This productivity effect over water use can be of great importance, though it is frequently ignored in discussions about water efficiency improvements.

Summing up, the improvement in water efficiency leads to three different effects making possible to obtain the same production with less and more expensive water, but with a better water productivity. The relevant question we want to solve is what would be the combined effect of the technical shift over the demand for water. In other words, under what conditions an improvement in the efficiency with which water is used in agriculture will lead to a reduction in water use and demand and then to a positive contribution to reduce water scarcity and make water use more sustainable in the long term.

3. *What would happen with water use and demand after an efficiency improvement?*

The answer to this question lies formally on the response of water demand (or water applied, W) to improvements in the irrigation efficiency, that is to say, on the sign of the following derivative:

$$\frac{\partial W}{\partial E} \qquad [1]$$

A positive sign (i.e.,$\frac{\partial W}{\partial E} > 0$) means that more water is applied after an efficiency improvement, and thus that the *Jevons' Paradox* applies.

To find the answer we need to combine the above mentioned effects of the technical shift:

- An increase in water efficiency will reduce the amount of water required to produce the set of goods the economy is currently producing.
  The amount of water effectively used by crops (EW) is a portion E (($E \in [0, 1]$) of the amount of water (W) used or applied by farmers. E measures the technical efficiency of the irrigation technology in place with, for example, typical values of 0.5 for traditional gravity, 0.7 for sprinklers and 0.9 for drip devices. To produce the same crops the amount of water applied (W) can be reduced in the same percentage as the efficiency is increased. Then, *if production remains constant*, the efficiency elasticity of water demand is equal to minus one. This overoptimistic scenario, where no other effects are considered, is the hidden assumption of many studies assessing the prospects of saving water from irrigation (a good example of this can be found in the Spanish Irrigation Plan[2]).

- *An increase in water efficiency increases the water application cost:*
  The unitary water application cost ($c(E)$), is an increasing function of the technical efficiency of the irrigation devices in place. More sophisticated techniques require more energy (to pump water) and more labor to control the delivery of water to the crops ($c'(E) > 0$). Assuming labor and energy costs as constant, the cost effect of an irrigation improvement can be formally measured by the following efficiency elasticity of the water application cost:

$$\epsilon_c = c'(E)\frac{E}{c(E)} > 0 \qquad [2]$$

- *An increase in water efficiency increases water marginal productivity:*
  Effective water serves to produce crops ($Y = F(EW)$) with a positive but decreasing marginal productivity ($f(EW)>0; f'(EW)<0$). Assuming a unitary price for crops and all productive factors apart from water as constant, the yield function can be represented as:

$$Y = F(EW) \text{ with } f(EW) > 0 \text{ and } f'(EW) < 0. \qquad [3]$$

  This implies that the marginal productivity of effective water increases at a decreasing rate with water efficiency. The partial effect of an increase in water efficiency (E) can be represented by the following elasticity of the marginal productivity of effective water:

$$\epsilon_E = \frac{\partial f(EW)}{\partial E}\frac{E}{f} = \frac{f'(EW)}{f(EW)}EW < 0 \qquad [4]$$

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[2] The Spanish Irrigation Plan (Plan Nacional de Regadíos, PNR) was a large investment effort with the aim of reducing agricultural water use in traditional and overexploited irrigated areas. The PNR was programmed to deliver 3 056 million EUR in order to modernize 1 135 million ha in the period 2000-2008 (MARM, 2008). However, since the implementation of the PNR, agricultural water demand in these areas is far from decreasing (Gómez and Pérez, 2012; EEA, 2009).

4. *What is the overall effect of the technical improvement over water consumption?*

To answer this question we have to integrate all the above mentioned effects into a comprehensive analysis of the demand for water when the irrigation technique is improved.

Farmers buy raw water at a unitary price *P* (e.g., per cubic meter bought) and apply it to the field incurring in a unitary cost *c(E)* which, as above said, increases with the efficiency of the irrigation system in place. Then, the cost of applying one cubic meter of water is equal to *P + c(E).*

But only a fraction E of the water applied is effectively used by the crops. So to obtain one unit of effective water farmers need to apply $\frac{1}{E}$ units of water. Summing up, the marginal cost of the effective water is equal to:

$$CMg\ (EW) = \frac{P+c(E)}{E} \qquad [5]$$

Farmers will demand water up to the point where marginal productivity equals the marginal cost of effective water:

$$f(EW) = \frac{P+c(E)}{E} \qquad [6]$$

Accordingly, the water demand function can be expressed as:

$$P = f'(EW)E - c(E) \qquad [7]$$

Provided that following the efficiency improvement there is no complementary price policy and thus water prices remain constant, the effect of this policy over water demand can be obtained from the demand function [7] as follows:

$$\frac{\partial P}{\partial W} dW + \frac{\partial P}{\partial E} dE = 0\ ; \qquad \text{then: } \frac{dW}{dE} = -\frac{\partial P/_{\partial E}}{\partial P/_{\partial W}} \qquad [8]$$

That is to say:

$$\frac{dW}{dE} = -\left(\frac{W}{E} - \frac{f(WE)}{f'(WE)E^2} - \frac{c'(E)}{f'(WE)E^2}\right) \qquad [9]$$

Which (after multiplying both sides by $\frac{E}{W}$) can be transformed into a elasticity of water demand with respect to the efficiency of the irrigation system:

$$\epsilon_{W,E} = -1 - \frac{1}{\epsilon_E} + \left(\frac{\epsilon_c}{\epsilon_E}\right)\left(\frac{c(E)}{P+c(E)}\right) \qquad [10]$$

This result adds up the following three effects of improving irrigation efficiency over water demand:

- A *technical effect* meaning that increasing water efficiency in one percentage point would reduce water demand in one percentage point. A reduction in water demand proportional to the relative improvement in water efficiency (indicated by the number-1).

- A *productivity effect* meaning that the improvement in water productivity will lead to an increase in water demand. This is measured $-\frac{1}{\epsilon_E} > 0$ and its importance depends on the shape of the marginal productivity of water (and in particular on how rapidly it decreases when more water is used).

A *cost effect*, meaning that the higher application cost of water will lead to a further reduction in water demand. This is measured by $\left(\frac{\epsilon_C}{\epsilon_E}\right)\left(\frac{C}{P+C}\right) < 0$. Its size depends on two ratios: the first shows on how important is the marginal cost with respect to the marginal change in water productivity and, the second, measures how important is the application cost with respect to the average water costs (the water price included).

5. *Conclusions and suggestions for further research:*

The existence of practical alternatives to improve the way water is used in the economy represents a real opportunity to find the way to reduce water scarcity without impairing short term welfare. However, the common belief that considers water efficient devices as synonymous of water saving techniques is rather naive as it tends to ignore the entire physical, economic and institutional framework where these alternatives are implemented.

Making a technical shift a real contribution to reduce water pressures is a difficult task. To start, water demand needs to be reduced in a minimum amount only to compensate for higher evapotranspiration. In other case, the technical shift will lead to a higher water depletion and then to the Hydrological Paradox. But the simple economic analysis nor the few assessment studies available does not confirm that enhancing irrigation techniques is a guarantee to reduce water use and water demand.

Consider for example the following extreme, but still likely, case. Assume an agricultural area where energy is heavily subsidized and the better irrigation devices do not increase the (financial) cost of applying water (for the sake of the argument let us assume that $\in_C = 0$). In addition to that, water is scarce in such a way that most of the time there is idle irrigation capacity and the technical shift will allow more effective water at the same cost as before. Then the productivity effect $\left(-\frac{1}{\in_E}\right)$ is higher than one and will overcome the technical effect (-1). In such a situation improving the irrigation technology will lead to a *Jevons' Paradox* and, contrary to the common belief, water will be scarcer and the real outcome of the presumed water saving technologies will worsen the already unsustainable use of water. The intuition behind the example shows that water technologies might be less effective precisely in the situations where water savings are more needed: that is to say, water stressed areas with subsidized infrastructures and low water and energy prices.

Even in this extreme case there is a place for more efficient technologies, but not as the panacea and, in any case, only as a part of an institutional change towards a sustainable water management. No doubt that the technical shift will increase farmers' income. This increase can be used as an opportunity, for example, to agree upon a reduction in energy subsidies and the implementation of metering and volumetric tariffs. This policy mix, rather than a simple technical shift, can find the way to make the reduction of water scarcity compatible with the maintenance and eventual improvement of farmers' welfare. Technical options are only opportunities; the real challenge of the transition towards a sustainable water use relies on building better institutions and putting effective incentives in place.

Assessing the impact of better irrigation technologies in a particular area remains an empirical question. This paper presents a sound analytical framework to approach this question, but it needs to be complemented with some stylized numbers. Research effort might be focused on finding a better estimation of water productivity, irrigation costs and water pricing in the relevant locations.

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