Efficient irrigation technologies and water rebound effect

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Abstract

Agricultural use of water, accounting for 70% of water use worldwide, both contributes and is confronted to water scarcity. This problem becomes more urgent as world's population continues to grow and climate change accelerates. Improving the efficiency of water use is usually presented as an opportunity for large water savings in the agricultural sector. However, recent literature has pointed out that the introduction of more efficient irrigation systems may actually increase water catchment depletion. This is explained by the so-called 'rebound effect' or Jevons paradox, a phenomenon widely study in the energy sector. The price reduction following the efficiency improvement leads to an increase in water use which ends up eroding, completely or partially, the savings expected from the new technology. In this paper we would like to contribute by developing a theoretical framework that explains irrigation behavior. The aim is to assess the yield response to irrigation water for different irrigation techniques and the incentives to save water on intensive and extensive margins. We would evaluate the main tools used in EU to manage water scarcity, for instance water reuse.

Keywords: Rebound effect, Irrigation water, Low Energy Precision Application, Water resource management and policies

1 Introduction

Global water resources are under pressure mainly because of two linked phenomena: world population growth and climate change impacts. In that context, agriculture is both a major cause and casualty of water scarcity. The availability of water has been identified as a fundamental issue concerning the future of food production. As pointed by the OECD, farming accounts for almost 70 percent of all water withdrawals, and up to 95 percent in some developing countries. Furthermore, water scarcity is expected to intensify as a result of climate change. It is predicted

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to bring about increased temperatures across the world in the range of 1.6℃ to as much as 6℃ by 2050. For each 1 degree of global warming, 7 percent of the global population will see a decrease of 20 percent or more in renewable water resources. Furthermore, more frequent and severe droughts are having an impact on agricultural production, while rising temperatures translate into increased crop water demand. In addition to improvements in water-use efficiency and agricultural productivity, action to harvest and reuse our freshwater resources and increase the safe use of waste water are needed.

The increasing global demand for resources, such as water, has been met with a new wave of resource efficiency policies worldwide. In Europe, a reference document on resource efficiency policy named *Roadmap to a Resource Efficient Europe* from the European Commission (2011), identify potential measures for various resources and sectors to cope with the current pressure on water use. Improving the efficiency of water use is usually presented as an opportunity for large water savings in the agricultural sector. For example, investing in more efficient irrigation technology is usually regarded as a means to reduce the use of water by irrigated agriculture. However, this may not translate into reduced consumption.

Some authors report that the introduction of irrigation systems that apply water more uniformly may actually increase water catchment depletion: the so-called 'rebound effect' or Jevons paradox (Berbel et al., 2015; Sears et al., 2018). The principal explanation is linked to the reduction in relative cost of water per unit of output potentially accompanied by a reduction in the absolute price of water. In line with that, an increase in demand would occur if water was initially limited by its price. This phenomenon means that the introduction of a new technology that increases the efficiency of using a natural resource does not necessarily lead to less consumption of this resource. Any type of improvement in technical efficiency of water requirements reduces water demand causing price of water to decrease. The price reduction leads to increase in water use which ends up canceling out the initial efficiency completely or partially.

Some studies try to measure the size of these possible rebound effects. A few studies analyze changes in water pricing policies in different countries such as China (Song et al., 2018), Mexico (López-Morales, Duchin, 2011), Spain (Berbel et al., 2015) and the United States (Li, Zhao, 2018). These studies reveal that water saving policies (with particular reference to water pricing) aimed at improving water productivity are not as effective as expected because of the partial rebound effect determined by an increase in the irrigated land.

In this paper we would like to contribute by developing a theoretical framework that explains irrigation behavior. Starting with simple model for multi-crops like the one presente by Wang, Park, Jin (2015), this modeling will be used to research the conditions under which improved irrigation may lead to increased water use and/or consumption and how farmers respond to different water-conservation measures such as water reuse.

The methodology follows a two-step approach. In a first step we estimate the yield response to decreased water uses for the main crops cultivated in the area and for different irrigation techniques. In a second step, the estimated production function is integrated into an economic optimization model to calculate relevant impacts.

2 Framework

In this section we present the theoretical basis for irrigation water demand based in Wang, Park, Jin (2015). This framework will allow us to assess the yield response to irrigation water for different irrigation techniques and the incentives to save water on intensive and extensive margins.

We present a model for irrigation water demand in which farmer can grow a combination of two crops. In this framework, every unit of applied water will be utilized to satisfy the crop's capacity to transpire water, or its demand for evapotranspiration (ET), also known as the effective water. Consequently, the crop's demand for ET will determine the consumptive water use (W). Finally, the conversion of irrigation water to ET, and ultimately to yield, depends on the efficiency level ϵ of the irrigation system, where $\epsilon \in (0, 1]$.

Assume that the farmer has two crop choice $i \in 1, 2$. The crop yield function, $Y_i = Y_i(W_i, \epsilon)$, is concave with respect to applied water and the efficiency level. Both crop benefit from the same irrigation technology. The maximum yield Y_i^m attainable at the satiation ET level, E_i^m, where E_i^m and Y_i^m are fixed for a given crop type. One crop is more water intensive that the other, meaning that they have different satiation ET levels.

The unitary cost to increase the efficiency level is given by $C(\epsilon)$, increasing and convex in ϵ.

The farmer allocates the land among the different crops, where ℓ_i is the percent of land allocated to crop i and $\sum_i \ell_i \leqslant 1$.

Assuming that crop 1 is more water intensive than crop 2, 4 conditions follow. First, we have that $E_1^m > E_2^m$, meaning the satiation ET level is higher for crop 1. Second, $P_1 Y_1^m > P_2 Y_2^m$ which implies that the revenue from crop 1 is higher than that of crop 2, otherwise, there would not be any incentives to produce the more water intensive crop. Third, $P_1 \frac{\partial Y_1}{\partial W_1}(0, \epsilon) \leqslant P_2 \frac{\partial Y_2}{\partial W_2}(0, \epsilon)$, which means that crop 2 is more tolerant to water-conservation measures. Finally, condition fourth says that $P_1 \frac{\partial^2 Y_1}{\partial W_1 \partial \epsilon}(W, \epsilon) - P_2 \frac{\partial^2 Y_2}{\partial W_2 \partial \epsilon}(W, \epsilon)$ is an increasing function in W, meaning that, as a result of its drought tolerant nature (condition 3), crop 2 is more responsive to irrigation efficiency increases under dryland production and low irrigation levels.

Farmers' program is defined as a two-stage decision problem. First, farmers choose the irrigation technology. Second, they maximize its profit by choosing an optimal level of water use W, conditional on the level efficiency level chosen in the first stage. The profit maximization program on the second stage is defined as:

$$\begin{aligned} \max_{W_i, \ell_i} \quad & \sum_{i=1}^{2} \ell_i P_i Y_i(W_i, \epsilon) - C_W \sum_{i=1}^{2} \ell_i W_i \\ \text{subject to} \quad & \sum_i \ell_i \leqslant 1; \;\; \ell_i \geqslant 0 \quad (i = 1, 2) \end{aligned} \tag{1}$$

The Kuhn-Tucker conditions for this maximization program are:

$$\ell_i P_i \frac{\partial Y_i}{\partial W_i} - \ell_i C_W = 0 \quad \text{for } i = 1, 2 \tag{2}$$

$$P_i Y_i - C_W W_i + \lambda \leqslant 0 \tag{3}$$

$$\ell_i (P_i Y_i - C_W W_i + \lambda) = 0 \quad \text{for } i = 1, 2$$

$$\sum_i \ell_i - 1 \leqslant 0 \tag{4}$$

$$\lambda \left(\sum_i \ell_i - 1 \right) = 0 \quad \text{for } i = 1, 2$$

Under these conditions, we know that there are not idle land ($\sum_i \ell_i - 1$). Farmers have two type of optimal solutions at hand: they can grow both crops (interior solution) or they can grow only one of the crops.

By using this framework, we will try to assess the conditions under which improved irrigation may lead to increased water use and consumption and how farmers respond to different water-conservation measures such as water reuse.

3 Applications: European case

The aim of this paper is to improve the model presented in the previous section in such way as to take into account water reuse.

According to a recent report of the European Commission (European Commission, 2018), agricultural irrigation has a highest potential for an increased uptake of water reuse. This measure would help to reduce direct abstraction from water bodies and groundwater which can significantly contribute to the alleviation of water scarcity in Europe.

This analysis could be applied in European regions for wheat producers and for corn producers.

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