When "green irrigation" increases demand for water

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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 efficiency 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 management

Résumé

L’irrigation représente plus de 70 % de l’utilisation d’eau au niveau mondial. Pour économiser l’eau dans le secteur agricole, des techniques d’irrigation plus efficaces peuvent être utilisées. Théoriquement, l’investissement dans une technologie d’irrigation économe en eau devrait permettre d’obtenir des rendements similaires à ceux obtenus avec du matériel ancien pour un volume d’eau moins important (« irrigation verte»). Toutefois, l’amélioration de l’efficacité peut avoir un effet non attendu. Les producteurs peuvent avoir une incitation à utiliser plus d’eau soit en irriguant des surfaces agricoles supplémentaires ou en cultivant d’autres cultures nécessitant plus d’eau. Une augmentation de l’efficacité de l’irrigation augmente la productivité du facteur de production (effet rebond ou paradoxe de Jevons). Le but de cet article est d'identifier les facteurs qui garantissent l'efficacité de «l'irrigation verte». Nous montrons que l'effet de rebond dépend du prix de l'énergie. Nos résultats suggèrent que les programmes de subventions à l'investissement ne peuvent pas conduire à une réduction de la consommation d'eau dans le cas de fluctuations importantes des prix de l'énergie et des denrées alimentaires. Notre contribution intègre l'effet du prix de l'énergie sur la demande en eau et des incitations à investir dans les technologies d'irrigation verte. Nous montrons que l'efficacité des politiques de conservation de l'eau dépend des fluctuations du prix de l'énergie et peut varier considérablement en fonction de la conjoncture économique.

Mots clés: Effet rebond, Irrigation, Gestion des ressources en eau

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1. Introduction

The world demand for water is increasing sharply, in particular, due to the growth of the world population and the increase in the area of irrigated agricultural land. Water is not only essential for human life but it is also an essential factor of production for the creation of food resources. The scarcity of water resources observed in many countries could therefore lead certain regions to lose up to 6% of their GDP by 2050 (World Bank, 2016).

Climate change is expected to exacerbate water shortages, especially in regions that are already in water deficit. While prediction suggest that global temperatures may rise from 1.6 degrees Celsius to 6 degrees Celsius by 2050. More frequent and severe droughts will have negative repercussions on agricultural production, while rising temperatures may translate into increased demand for crop water (World Bank, 2016). For each additional degree of warming, 7% of the world's population could experience a decrease of at least 20% in renewable water resources (IPCC, 2018).

Agriculture not only suffers from the increasing scarcity of water but also contributes to the exacerbation of the scarcity of this resource. The world water consumption of used for agriculture has multiplied by six between 1900 and 2014. Irrigation represents over 70% of water use worldwide, more than 44% on average for countries from the OECD and more than 80% for some countries (OECD, 2014).

Economic incentives can be implemented to manage conflicts over the use of water resources. Usually, public policies targeting the scarcity of this natural resource were mainly oriented towards investment in infrastructure to increase the supply of water (construction of dams, canals, purification systems, desalination plants and other hydraulic infrastructure). However, these infrastructures have a very significant financial cost. Lately, other market incentives have gain attention, for instance water price adjustments. Excessive use of water can be encouraged by the fact that, in most countries, farmers do not pay the full cost of the water they use. In the area of irrigation, many studies have focused on estimating the demand for water in agriculture to measure the willingness to pay of farmers for this resource (Pfeiffer & Lin, 2014).

In the European Union, a reference policy document on the rational use of resources entitled "The Roadmap to a Resource Efficient Europe" of the European Commission (EC) identifies potential measures to deal with the current pressure on use some water. A lever for action is the implementation of subsidies to encourage producers to invest in water conservation technologies (European Commission, 2011).

Improving the efficiency in the use of water is generally presented as a solution for saving water in the agricultural sector (European Commission, 2011). The European Union therefore encourage "green irrigation", a term we use to describe the use of irrigation techniques that save water resources (Gómez and Pérez-Blanco, 2015). Theoretically, the investment in water-efficient irrigation technology should allow for yield returns similar to those obtained with old equipment, and that by using a lower volume of water. The amount of water applied to crops with old equipment is often lost through evaporation without being used (Pfeiffer & Lin, 2014).

Although more efficient irrigation techniques can reduce the amount of water need for a given crop, improving efficiency may have an unexpected effect. The demand for water may increase due to changes in the individual behavior of farmers. Indeed, agricultural producers using more productive techniques may have an incentives to use more water, for instance, by irrigating new agricultural areas or by cultivating other crops requiring more water (Li & Zhao, 2018).

This behavioral adjustment is known in economic literature as the Jevons paradox or the rebound effect: Improving the efficiency of a given technology for using a resource may lead to an increase in the consumption of this resource. This paradox has been the subject of numerous empirical studies in the field of energy and transport (Sorrell & Dimitropoulos, 2008).

When it comes to water management, applied work is very recent, most focuses in ex-post evaluations assessing the impact of investment subsidy programs in water efficient equipment. Empirical results show that these programs have ambiguous effects on water use and do not systematically reduce demand for water. In some cases, these public programs have even led to an increase in water use (Song, Guo, Wu, & Sun, 2018).

There are few theoretical works researching the conditions under which an improvement in efficiency could lead to an increase in water demand. These studies show that the increase in water use can be observed not only following an improvement in irrigation technology, but also following a change in the cost of water. (Song et al., 2018).

A key element in the farmers' behavior adjustment is related to the price of energy, an important component of the cost of irrigation. A more efficient irrigation system is directly associated with higher energy demand, so any variation in the level of irrigation efficiency will have an effect on both water demand and energy demand. Consequently, a rise in the price of energy increases the prices of energy-intensive factors of production and in particular the demand for water (Pfeiffer & Lin, 2014).

The aim of this article is to identify the factors that guarantee the effectiveness of "green irrigation. We show that the rebound effect of water depends on the price of energy. Our results suggest that investment subsidy programs cannot lead to a reduction in water consumption in a context of rising energy and food prices. Our contribution is to endogenize the cost of irrigation, taking into account the effect of the energy price on water demand and the incentives to invest in green irrigation technologies. We show that the effectiveness of water conservation policies depends on fluctuations in the price of energy and can vary considerably depending on economic conditions.

We propose a model of irrigation water demand, based on Huffaker & Whittlesey (2003), which allows us to analyze the variation of the irrigation water demand following an increase in the efficiency of the irrigation system. Then, we carry out a comparative static analysis in order to determine under which conditions an improvement in efficiency leads to an increase in water demand (rebound effect). Furthermore, we analyze the incentives to invest in more efficient irrigation technologies under an endogenous energy price.

These results have important public policy implications. In some cases investment subsidies will not allow water savings. In this case, other measures must be implemented to account for the impact of changes in the price of energy.

The article is organized as follows. Section 2 presents how the water rebound effect is model in the literature and the main results. The third part proposes a micro-economic model to analyze how the demand for irrigation reacts to the improvement in efficiency. The fourth section discusses the results and presents some empirical evidence. Finally, we present some conclusion and extensions of this work.

2. Improving irrigation efficiency: a review of the literature

The conversion to more efficient irrigation technology has often been encouraged by different policies in many countries. However, these technologies have not always led to water savings. After defining the concept of irrigation efficiency, we offer a synthesis of the existing literature measuring the effect of investment subsidy programs on water consumption.

2.1. What is more effective irrigation?

An irrigation technology efficiency, noted by the variable ε, is defined by the ratio between the crop water needs and the amount of water used (FAO, 2004):

$$(1)\ Irrigation\ \ efficiency\ (\boldsymbol{\varepsilon}) = \frac{(amount\ \ of\ water\ need\ by\ the\ \boldsymbol{crop})}{(amount\ of\ water\ applied\ to\ the\ crop\ )}$$

Crops water requirements depend on several factors, intrinsic or extrinsic to it: type of crop (species, variety), stage of vegetation, type and state of soil moisture, climatological conditions (precipitation, insolation, wind). The amount of water needed for cultivation is called evapotranspiration (ET) needs.

Take the extreme case of a perfectly efficient technology. The volume of water supplied to the crop is exactly the quantity it needs, in this case ε = 1. In practice, there is no irrigation technology that achieves a perfect level of efficiency, in other words, the variable ε is less than 1 (Huffaker & Whittlesey, 2003; Sears et al., 2018).

Each technology is characterized by a specific level of efficiency. For example, sprinkler irrigation has an average efficiency of 65%. A subsurface drip irrigation system has an average efficiency of 90%. The latter technique is more efficient because infiltration of water and runoff are lower than in sprinkler irrigation (Barta et al, 2004).

The need to preserve water resources leads to the establishment of regulations. The conversion to more efficient irrigation technologies has often been encouraged by many governments and international organizations, notably through investment grants (Menet et al. 2018, Sears et al., 2018).

2.2. Evidence of the rebound effect in the literature

Some theoretical contributions (Gómez & Pérez-Blanco, 2014; Huffaker & Whittlesey, 2003; Wang, Park, & Jin, 2015) suggest the existence of an unexpected effect following an improvement in the efficiency of the irrigation system. It arises when the behavior of agricultural producers adjusts following the adoption of new technologies (Gómez & Pérez-Blanco,2014; Song et al., 2018).

Gómez & Pérez-Blanco (2014) show that the total effect of improving the efficiency of the irrigation system depends on three opposing effects: the technical effect, the cost effect and the productivity effect. The real impact of water conservation policies can be overestimated when the interaction of these three effects is not taken into account.

The first effect, the technical effect, suggests that, all other things being equal, the amount of water used in irrigation decreases by the same percentage as that which affects the efficiency. Suppose a farmer who adopts a new technology that leads to a 25% improvement in efficiency, the expected water savings are also 25% (all other things being equal).

This is the underlying principle behind a large number of irrigation management policies. However, this expected impact overlooks the fact that farmers can adapt their behavior following a change in initial incentives, which can create other effects.

The second effect corresponds to the cost effect. The main costs related to irrigation are the cost of investing in capital, corresponding to irrigation equipment; the cost associated with the consumption of water and the cost related to the consumption of energy necessary for the operation of the irrigation equipment (generally electricity). These costs are the components of the irrigation cost. The use of a more efficient irrigation system leads to a more intensive use of energy. The total cost of irrigation will be higher due to the higher energy costs. Consequently, the cost effect drives down the amount of water used (due to the increase in the cost of irrigation resulting from the improvement in efficiency).

Finally, the third effect, the productivity effect, arises from the fact that water productivity increases because water is applied in a more efficient way. The same quantity of water applied more efficiently, will lead to a higher crop yield, which constitutes an incentive to use more water resources. This effect can therefore lead to a higher demand for water.

The first two effects lead to a decrease in the amount of water used and the third effect, to an increase. The third effect could reduce the expected water savings from the policy. In this case, we observe what is called the rebound effect or the Jevons paradox (Gómez & Pérez-Blanco, 2015). For instance, in China, the efficiency of irrigation systems has increased continuously over the past two decades. However, the volume of water withdrawn did not decrease as expected (Song et al., 2018).

The rebound effect is therefore a function of the cost and productivity of irrigation (Julio Berbel et al., 2015). If the productivity effect is high enough, access to more efficient irrigation technology would encourage farmers to adjust the type of crop, favoring crops with higher water requirements, as well as to increase the irrigated area (Li & Zhao, 2018; Lisa Pfeiffer & Lin, 2014). In addition, if the demand for water is elastic and if the new technology increases agricultural yield, the volume of water used will increase (Huffaker & Whittlesey, 2003; Lisa Pfeiffer & Lin, 2014; Ward & Pulido-Velazquez, 2008).

Institutions can play a key role in water conservation policies. Several studies show that the rebound effect is weak, even nonexistent, when the use of water and soil are restricted up to a certain threshold (eg Berbel & Mateos, 2014; Li & Zhao, 2018; Ward & Pulido-Velazquez, 2008). This is why regulations concerning water extraction rights can limit the rebound effect without reducing the incentives to improve irrigation technology (Berbel et al., 2015; Li & Zhao, 2018).

2.3.Role of energy prices on investment

The price of energy is a key element in adjusting farmers' behavior, since it is an important component of the cost of irrigation (L. Pfeiffer & Lin, 2014; Zilberman, Sproul, Rajagopal, Sexton, & Hellegers, 2008). A rise in the price of energy increases the prices of energy-intensive factors of production and in particular the demand for water. Furthermore, tt will have an impact on the price of food as well (Zilberman et al., 2008).

An efficient irrigation system is an energy intensive production factor. Consequently, the impact of a change in the cost production inputs following a shock on the price of energy has a negative impact on invest decisions in a more efficient irrigation system. The impact of energy prices on efficiency investment decisions has not been widely discussed in the literature (Wang, Zhou, & Zhou, 2012).

We propose a demand model for irrigation water that allow us to assess the potential rebound effect and the incentives to invest in a more efficient irrigation system under different economic conditions. In particular, we seek to analyze the effect of a unique public policy (notably an investment subsidy) in the event of an increase in the price of energy.

3. Modeling of irrigation water demand

This section presents the theoretical basis for a model of demand for irrigation water based on the Huffaker model, (2008). This framework will allow us to analyze in which context the farmer will have an interest in investing in a more efficient irrigation technology and what will be the effect of an improvement in irrigation efficiency on water demand.

3.1. Water demand and components of the irrigation price

The farmer's demand for water depends on the prices production inputs: the price of water, the price linked to investment in a more or less efficient irrigation system, and the price of the energy needed to run the irrigation system (electricity for example). The demand for water also depends on the technical efficiency of the equipment used.

The cost of irrigation for the farmer is noted Cw, it includes the cost of fuel and labor necessary for the irrigation of water. The price linked to the investment in the irrigation system is assumed as a linear and increasing function of the efficiency level I (ε).

Following the approach presented by Wang et al. (2015), we model the farmer's program, in his choice of water demand, as a two-stage decision. In the first stage, the producer chooses the irrigation technology and in the next stage, he chooses the irrigation water level that maximizes his profit, subject to the technology chosen in the first stage. The program is solved by retro-induction.

First, we will present a simplified model describing the maximization program of the farmer, in the case where the Cw is constant. Subsequently, this cost will be defined as a function of the energy price, which will make it possible to study the investment in efficiency as well as the variation in water demand with energy prices.

3.2.Constant irrigation cost

Each unit of water applied to the crop is used to meet its water needs or its demand for evapotranspiration (ET). The efficiency of the irrigation system is the percentage of the total volume of water supplied which satisfies the crop's demand for ET, denoted by the efficiency variable ε ∈ (0.1].

Taking equation (1), we have the relationship $ET = \varepsilon W$: the crop water needs correspond to a fraction ε of the total water consumption, denoted W (Gómez & Pérez-Blanco, 2014).

We assume the farmer's yields function defined by $Y = Y\,(W, \varepsilon)$, where Y is concave with respect to the level of water supplied and the efficiency of the irrigation system. First, we solve the second step of the program. The farmer chooses the level of irrigation $W(\varepsilon)$ water that maximizes his profit, subject to the efficiency level ε.

The program is written as follows:

$$(2)\quad \max_{W} \pi = \max_{W} PY(W, \varepsilon) - C_W W$$

The first-order necessary condition (FOC) for program (1) is written:

$$(3)\quad \frac{\partial \pi}{\partial W} = P\frac{\partial Y}{\partial W}(W^*, \varepsilon) - C_W = 0$$

We measure the change in optimal demand for irrigation water, following an improvement in efficiency, by calculating the total derivative of equation (3) with respect to efficiency (ε). The variation in water demand following a variation in efficiency is given by:

$$(4)\quad \frac{\partial W}{\partial \varepsilon} = -\frac{\frac{\partial^2 Y}{\partial \varepsilon \partial W}(W^*,\varepsilon)}{\frac{\partial^2 Y}{\partial W^2}(W^*,\varepsilon)}$$

This result shows us that, in the case of a constant extraction cost, the variation in water demand following a variation in efficiency depends on the sign of the cross derivative between efficiency and water consumption. In other words, the relationship of complementarity or substitutability between the two factors of production.

If this derivative has a positive sign ($\partial^2 Y/\partial\varepsilon\partial W > 0$), such as Gómez & Pérez-Blanco (2014) suggest, the demand for irrigation water W increases and there will be a rebound effect (productivity effect).

If this derivative has a negative sign ($\partial^2 Y/\partial\varepsilon\partial W < 0$), we observe a decrease in water use. Therefore, the policy has a positive effect only in the case where improving efficiency decreases water productivity.

We solve the first stage of the program, where the farmer decides the level of investment in irrigation technology. The maximization program for this stage is given by:

$$(5)\ \max_{\varepsilon} \pi = \max_{\varepsilon} PY(W(\varepsilon),\varepsilon) - C_W W(\varepsilon) - I(\varepsilon)\varepsilon$$

The FOC for program (5) is written:

$$(6)\ \frac{\partial \pi}{\partial \varepsilon} = P\left[\frac{\partial Y}{\partial W}\frac{\partial W}{\partial \varepsilon} + \frac{\partial Y}{\partial \varepsilon}\right] - C_W \frac{\partial W}{\partial \varepsilon} - \frac{\partial I}{\partial \varepsilon}\varepsilon - I(\varepsilon) = 0$$

Using the previous results, we replace (3) on the FOC (6), we find:

$$(7)\ P\frac{\partial Y}{\partial \varepsilon} = \frac{\partial I}{\partial \varepsilon}\varepsilon + I(\varepsilon)$$

This condition tells us that the marginal revenue of the farmer increases after improving the efficiency of the irrigation system.

3.3. Variable irrigation cost

The cost of irrigation can be affected by different exogenous shocks that can modify the cost of transport or agricultural inputs. Given that energy is an important input in agricultural production, variations in its price have an impact on energy-intensive agricultural production factors, water demand and food prices. This section analyzes the effect of an increase in the energy price on efficiency investments and demand for irrigation water.

a variation in the energy price will affect demand for irrigation water through different channels. There is a direct effect, reflected in the increased cost of irrigation. In addition, an indirect effect appears through the choice of irrigation technology: more efficient irrigation systems require more energy for their operation.

For simplicity, we consider that there are no transport costs and that the only energy-intensive factor of production is the level of efficiency of the irrigation technology. The energy price is noted p_e.

The second stage farmer's optimization program corresponds to:

$$(8)\ \max_W \pi = \max_W PY(W(\varepsilon(p_e),p_e),\varepsilon(p_e)) - C_W(\varepsilon,p_e)W(\varepsilon(p_e),p_e)$$

The FOC for program (8) is:

$$(9)\ \frac{\partial \pi}{\partial W} = P\frac{\partial Y}{\partial W}(W^*(\varepsilon(p_e),p_e),\varepsilon(p_e)) - C_W(\varepsilon,p_e) = 0$$

we take the total derivative of equation (8) with respect to p_e in order to evaluate the variation of the optimal demand for irrigation water $W^*(\varepsilon,P,C_W,p_e)$ following a change in the energy price. We find that:

$$(10)\qquad \frac{\partial W}{\partial p_e} + \frac{\partial W}{\partial C_W}\frac{\partial C_W}{\partial p_e} = -\frac{\frac{\partial^2 Y}{\partial \varepsilon \partial W}}{\frac{\partial^2 Y}{\partial W^2}} + \frac{\frac{\partial C_W}{\partial p_e}}{P\frac{\partial^2 Y}{\partial W^2}} + \frac{\frac{\partial C_W}{\partial \varepsilon}\frac{\partial \varepsilon}{\partial p_e}}{P\frac{\partial^2 Y}{\partial W^2}}$$

This result shows that the variation in water demand following a variation in the energy price is made up of three terms. First, we find the classic result, presented in the previous section (equation (4)), corresponding to the productivity effect. As we discussed earlier, this effect can be negative (water savings) or positive (rebound effect).

The following term is negative and corresponds to the cost effect discussed in the previous section (Gómez & Pérez-Blanco, 2014). Indeed, an increase in the price of energy will increase the price of water irrigation.

Finally, the third term can be positive or negative; its sign depends on the change in investment in efficiency following an increase in the energy price. A change in the energy price may change farmers' incentives to invest in a more efficient irrigation system. We evaluate this hypothesis in the first stage of the farmer's program, where he decides the level of investment in irrigation technology.

The maximization program of the first step, equation (11) infra, shows us again that the marginal revenue will always increase after the improvement of the efficiency of the irrigation system.

$$(11)\qquad \frac{\partial \pi}{\partial \varepsilon} = P\left[\frac{\partial Y}{\partial W}\frac{\partial W}{\partial \varepsilon} + \frac{\partial Y}{\partial \varepsilon}\right] - C_W\frac{\partial W}{\partial \varepsilon} - \frac{\partial I}{\partial \varepsilon}\varepsilon - I(\varepsilon) = 0$$

In order to assess the effect of an increase in the energy price on investment in more efficient irrigation technologies, we take the total derivative of the FOC (10) with respect to p_e, which give us:

(12) $$\frac{\partial \varepsilon}{\partial p_e} = \frac{P\frac{\partial^2 Y}{\partial \varepsilon \partial W}\frac{\partial W}{\partial p_e}}{2\frac{\partial I}{\partial \varepsilon} - P\left[\frac{\partial^2 Y}{\partial \varepsilon^2} - \frac{\partial^2 Y}{\partial \varepsilon \partial W}\frac{\partial W}{\partial \varepsilon}\right]}$$

This result suggests that if water productivity does not increase with more efficient irrigation ($\partial^2 Y/\partial\varepsilon\partial W < 0$), the investment in more efficient irrigation will be interesting for farmers since they will be able to save water and thus compensate for the increase in the cost of production resulting from the rise in the price of energy. Returning to the previous result, all elements of equation (10) will be negative, indicating that water consumption will decrease.

In other words, the higher the cost of production (in response to rising energy prices), the more the farmer will have an interest in investing in more efficient irrigation technology to save water.

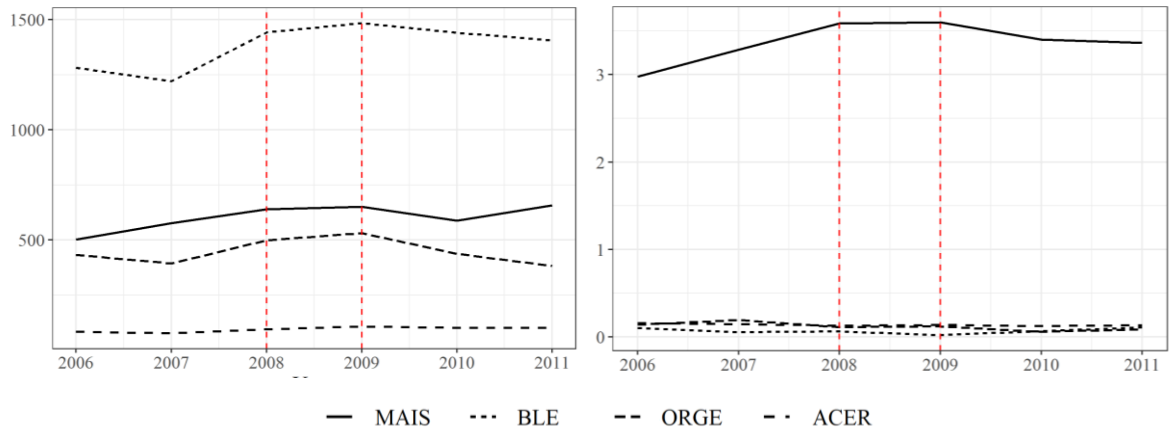
On the other hand, if water productivity is increased through more efficient irrigation ($\partial^2 Y/\partial\varepsilon\partial W > 0$), the farmer will have no incentive to invest in efficiency. If water productivity increases with the efficiency of irrigation, the farmer would benefit from increasing water consumption, because of the higher productivity of water. Indeed, in this case the reduction in water consumption, expressed in equation (10), will be lower or even zero.

Thus, the cost of production being high as a result of the rise in the price of energy, investment in efficiency is not the priority of the farmer.

4. Empirical analysis

We use the Agricultural Accounting Information Network (RICA-Agreste) for France. This data set gather accountancy data from farms for the determination of incomes and business analysis of agricultural holdings at the farm level. The annual sample covers over 4000 farms. The information collected, for each sample farm, concerns approximately 1000 variables. These variables refer to physical and structural data, such as location, crop areas, livestock numbers, labour force, etc. and economic and financial data, such as the value of production of the different crops, stocks, sales and purchases, production costs, assets, liabilities, production quotas and subsidies, including those connected with the application of CAP measures.

Figure 1. Evolution of production and the irrigated area of corn, wheat, barley and other grains in France between 2006 and 2011



(a) Production (b) Surface irrigation (ha)

Source : Authors' elaboration, data RICA-Agreste

In this section, we present a first descriptive analysis of the French Agricultural Accounts between 2006 and 2011, period including the last shock of oil prices. Figure 1 illustrates the evolution of production and the irrigated area of cereals between 2006 and 2011. Both the production of corn and the corresponding irrigated area show an increasing trend during the period of the price shock.

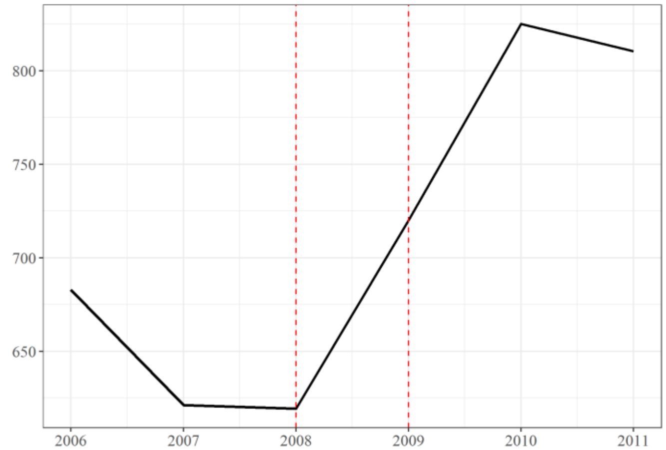
Figure 2 focuses on corn producers, since this is one of the most water-intensive crops. During the oil price shock, irrigation water charges increase, which can be explained by the increase in the irrigated area. On the other hand, the level of investment (excluding land) decreases during the same period, while subsidies for investment remain constant.

The data are consistent with the results of the model. It would seem that the rise in commodity prices gives farmers incentives to increase the irrigated area without investing in more efficient technologies, which in turn results in an increase in the use of irrigation water. In the next section, we summarize these results and present some policy implications.

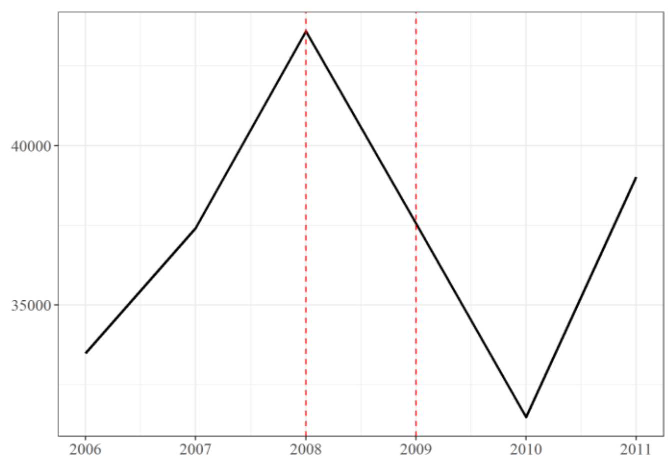
5. Implication for environmental policies

The model presented above suggests that, in certain economic contexts, policies encouraging "green" irrigation can result in an increased demand for water and therefore contributing to water scarcity. Water savings or rebound effects depend on the relationship between two production factors: water and irrigation efficiency.

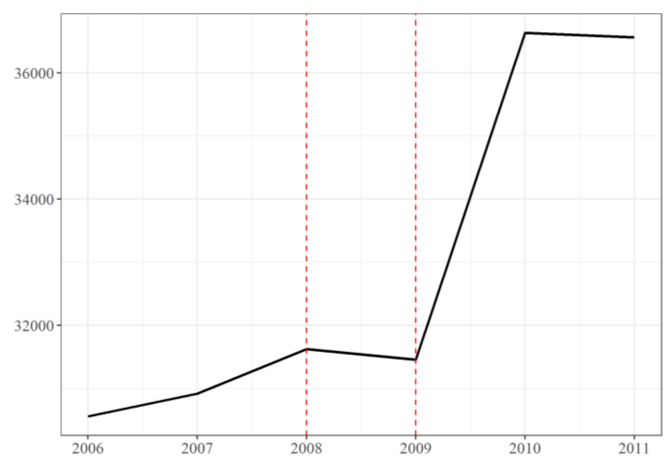
Figure 2. Evolution of irrigation water charges, investment subsidies for investment for corns producer in France between 2006 and 2011



(a) Irrigation water charges (in euros)



(b) Gross tangible investment (excluding land) (in euros)



(c) Operating grants: decoupled aid (in euros)

Source : Authors' elaboration, data RICA-Agreste

Table 1 presents a summary of the model results. We analyze two economic situations (rising energy prices and rising food prices) compared to a reference situation. The baseline situation summarizes the effect of a water conservation policy where only the change in efficiency is taken into account. (case considered in the literature).

When water productivity does not increase with a more efficient irrigation, improving efficiency always leads to water savings. Conversely, if water productivity is increased through more efficient irrigation, the model suggests that the adjustment of water consumption depends on the interaction between the productivity effect (which results from irrigation more efficient) and the cost effect (which exists because more efficient technology requires more energy). Water savings will then depend on the dominant effect. If the productivity effect dominates, there will be a rebound effect. Otherwise, there will be water savings although lower than those expected.

Moreover, variation in the price of energy can have different effects, playing both on the rebound effect and on the incentives to invest in a more efficient irrigation system. Here we analyze two scenarios depending on whether the productivity of water decreases (case 1) or increases (case 2) following the adoption of a more efficient irrigation system. Afterwards, we analyze a third case, when we observe an increase in food prices.

Table 1. Summary of results and water conservation policies

		Reduced water consumption	**Other Effects**	**Water conservation policy**
Reference situation:				
	$\frac{\partial^2 Y}{\partial \varepsilon \partial W} < 0$	Always		- Aid for investment in efficiency
	$\frac{\partial^2 Y}{\partial \varepsilon \partial W} > 0$	Weak or nonexistent (rebound effect)		- Investment aid with regulations on water withdrawals
Energy price increase:				
case 1	$\frac{\partial^2 Y}{\partial \varepsilon \partial W} < 0$	Always	- increased cost of irrigation - Incentives to invest in efficiency	Aid for investment in efficiency
case 2	$\frac{\partial^2 Y}{\partial \varepsilon \partial W} > 0$	Weak or nonexistent (rebound effect)	- increased cost of irrigation - No incentives to invest in efficiency	- Subsidy to energy prices - Investment aid with regulations on water withdrawals
Augmentation prix des denrées alimentaires :				
case 3 (a)	$\frac{\partial^2 Y}{\partial \varepsilon \partial W} < 0$	Always	- Incentives to produce more - Increase water consumption	Aid for investment in efficiency
case 3 (b)	$\frac{\partial^2 Y}{\partial \varepsilon \partial W} > 0$	Weak or nonexistent (rebound effect)		Investment aid with regulations on water withdrawals

In the first scenario (case 1), an increase in the price of energy compared to the reference situation leads agricultural producers to invest in more efficient irrigation technology. Thus, water savings from efficiency could compensate for the increase in the cost of production induced by the rise in the price of energy. In this situation, investment aid encouraging efficient irrigation technologies could help farmers reduce the cost of production through lower water consumption.

In the second scenario, an increase in the price of energy does not encourage agricultural producers to invest in more efficient irrigation technology. When water productivity increases with the efficiency of irrigation, the water savings from efficiency are small or even negative (due to the rebound effect).

Aid for investment in efficiency would be of less interest to farmers who seek to reduce their cost of production, since the water savings are less consequent (or even zero). This is why the water conservation objective will only be achieved if an energy price subsidy is put in place to reduce the burden caused by rising costs, and thus provide incentives to invest in efficiency. In addition, the investment incentive policy must be accompanied by a regulation on the water consumption of each farmer to avoid the rebound effect.

The third scenario arises when the rise in the price of energy causes a reduction in the supply of agricultural products and, thereby, in the rise in food prices. Farmers have an interest in producing more, which leads to increased water consumption related to irrigation.

In a situation of rising food prices, the direct cost effect (equation (10)) will be weaker. The increased revenue resulting from the higher price will offset the increased cost of using water. As a result, the water savings expected from a more efficient irrigation system will be lower (or even negative if there is a rebound effect), since in all cases farmers will seek to increase their production.

Thus, if water productivity does not increase with more efficient irrigation, public policy instruments must encourage investment in a more efficient irrigation system, so that agricultural producers can increase production without increase water consumption. Furthermore, if water productivity increases with efficiency, regulating the water consumption of each farmer is essential in order to avoid the rebound effect.

6. Conclusion

The role of public policies is essential to ensure the preservation of water. Our results suggest that there is a need to harmonize different policy objectives, such as income support for farmers and environmental objectives, so that the overall impact of policies is amplified and not canceled out. The model presented in this paper suggests that, in certain economic contexts, policies encouraging "green" irrigation can contribute to increasing the demand for water and therefore contribute to water scarcity. Water savings or the rebound effect depend on the relationship between two factors of production: water and irrigation efficiency.

Our results provide further evidence that investment subsidy programs cannot systematically lead to a reduction in water consumption in the event of large fluctuation in energy and food prices. Our contribution includes the effect of the price of energy on water demand and incentives to invest in green irrigation technologies. We show that the effectiveness of water conservation policies depends on fluctuations in the price of energy and can vary considerably depending on economic conditions.

A natural extension of this work is to quantify empirically the impact of alternative policies aimed at reducing water consumption. We want to measure the effects of recent shocks on the price of oil on farmers' investment decision in more efficient irrigation technologies by using microdata for France from the Agricultural Accounting Information Network (RICA) for the period 2006 - 2011. Preliminary results suggest that investment in efficient irrigation technologies would decrease in the face of high oil prices, while production and, therefore, water consumption would tend to increase.

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