Is the rebound effect or Jevons paradox a useful concept for better management of water resources? Insights from the Irrigation Modernisation Process in Spain

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IS THE REBOUND EFFECT OR JEVONS PARADOX A USEFUL CONCEPT FOR BETTER MANAGEMENT OF WATER RESOURCES? INSIGHTS FROM THE IRRIGATION MODERNISATION PROCESS IN SPAIN

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Improving the efficiency of water use is usually presented as an opportunity for large water savings, particularly in the agricultural sector. Warnings that this may not translate into reduced consumption is sometimes associated with the rebound effect or Jevons paradox, an appealing concept that can be used to analyse and prevent undesired consequences in the rush for efficiency gains. This article, based on the energy sector, shows that the concept helps to identify possible unintended consequences of increasing efficiency and shows how efficiency gains are shared in society. However, it might be conceptually misleading when applied to water since it reinforces a myth on the consideration of water savings and efficiency, and may be also too restrictive. The recent modernisation of irrigation practices in Spain highlights that the rebound effect is only one of many possible consequences of efficiency improvements.

Keywords: rebound effect, Jevons paradox, efficiency, return flows, modernisation, Spain

Introduction

The availability of water has been identified as a fundamental issue concerning the future of food production. The efficient management of water resources – the idea of producing more with less – is currently high on the list of strategies required to meet current and future development needs, while reducing the pressure on the environment. The path towards efficiency requires the mobilisation of a series of technical, economic and institutional measures. This article, discusses efficiency from a technical point of view, which is efficiency associated with the physical application of water. This issue has received much attention in recent decades, with the call to reduce the amount of water that is ‘wasted’ by traditional agricultural practices and to switch to more efficient systems (e.g. sprinkler and drip irrigation). In Spain, in addition to general objectives on resource availability and rural development, efficiency policies undertaken over the past 10 years have been considered a key measure for the implementation of the EU Water Framework Directive (López-Gunn et al., 2012a, b) (Table 1).

There is increased evidence, however, that investments may not translate into a reduction in the amount of water used. For instance, the paradigm of water savings from efficiency gains has, in some cases, been challenged by referring to the rebound effect or Jevons paradox. This concept refers to efficiency improvement in the technical process of the use of a resource that ultimately defeats the original purpose through a higher overall use by society. This effect and its explanation were first described in relation to the use of coal in England by the economist William Stanley Jevons at the end of the 19th century (Alcott, 2005). There are many examples of the application of this paradox, principally in relation

Table 1. Investment, affected area and projected water savings relative to the two Spanish plans of irrigation modernisation (MARM, 2010)

Plan	Area (ha)	Investment (€10^6)	Total water savings (10^6 m^3)	Water savings per hectare (m^3/ha)
National Irrigation Plan 2000-2008	1,134,900	1,528	1,375	1,212
Shock Plan 2006-2008	866,900	2,409	1,162	1,340
Intermediary evaluation relative to Shock Plan 2006 in MARM (2010)	250,000	-	500	2,000

Not all of the projects aimed to increase conveyance or field efficiency (i.e. reducing withdrawals), so the figure for water savings per hectare varies depending on the project.

to energy, an area where the concept has taken hold. The application of this concept also aims to ensure that energy conservations programmes are effective, by devising rules that should be promoted together with planned efficiency improvements (Van den Bergh, 2010). Therefore, it might appear useful and attractive to apply this framework to water, to evaluate the actual extent of water savings.

The main objective of this article is to analyse whether the rebound effect concept aids the understanding of the consequences of improvements in water efficiency. This is illustrated by considering the modernisation plans in Spain and specifically a case study in the Ebro basin in the north-east of the country. The first section of the article presents the concept of the rebound effect, using energy as an example. The second section highlights the particularities of water when compared to energy, in relation to the concepts of efficiency and losses. The third section focuses on the main explanations for the rebound effect and accompanying policies designed to counteract it. Finally, an alternative framework of analysis is proposed, based on two independent pillars – water resources accounting and the effect on the whole system. This enables the value of applying the rebound effect in the case of water to be recognised, while preventing the misleading aspects that may be implied.

Rationale for the rebound effect and three logical steps in its formulation: from energy to water

Logic of the rebound effect for energy

In general terms, efficiency improvements in a productive process mean a reduction in inputs required per unit of output, thus saving resources.

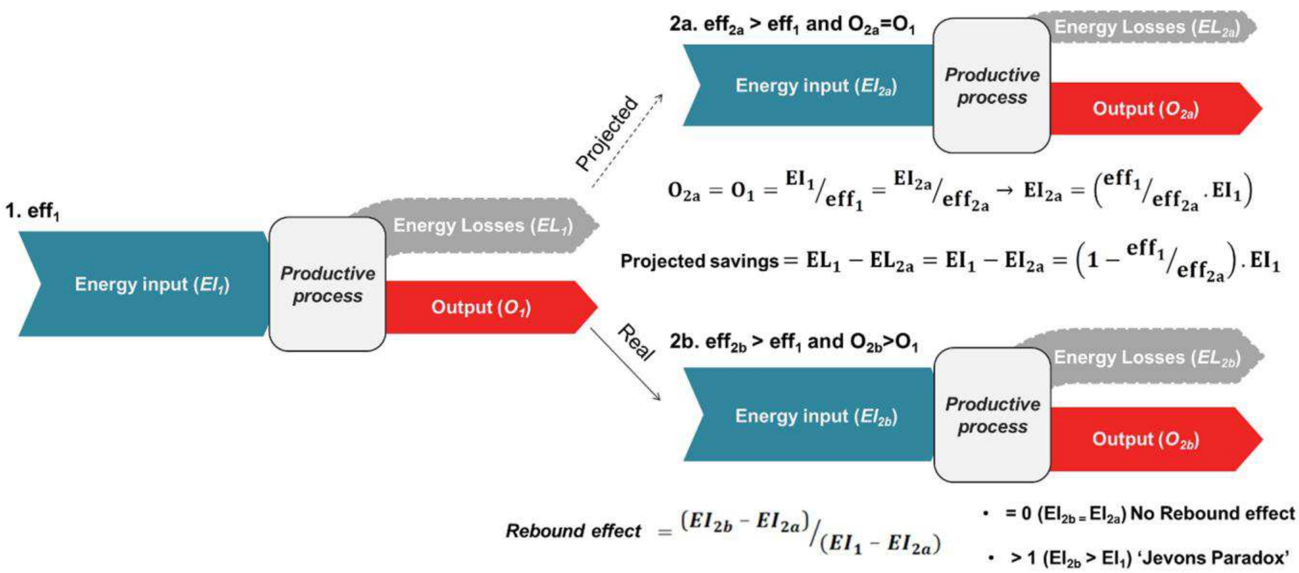

Figure 1. Estimation of projected savings resulting from improved efficiency in a productive process (2a), and identification and quantification of the rebound effect and Jevons paradox (2b)

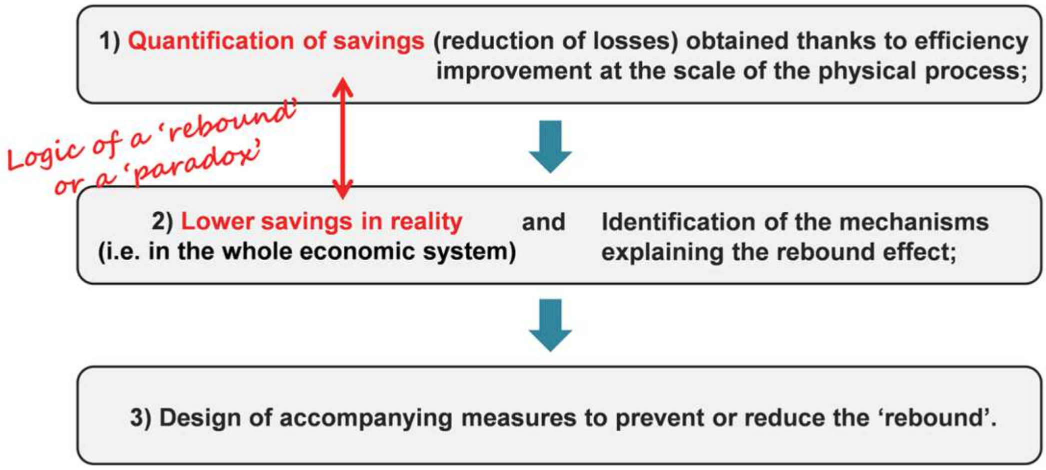

Figure 2. Three successive steps of the rebound effect concept and identification of the logic of a 'rebound' or 'paradox'

The amount of savings can be estimated directly on the basis of the initial and final expected efficiencies and the initial quantity of input, assuming the same level of output (Fig. 1). A typical example for energy is transport: to reach a certain destination, fuel savings will be obtained by switching to a more efficient car or using public transport, instead of using one's own private vehicle. Thus, the first step in the logic of the rebound effect involves identifying the potential savings obtained from efficiency improvements.

In reality, when considering the broader economic system in which technical improvements are nested, economic agents react to changes in efficiency in such a way that the original aim to reduce resources may ultimately trigger an increase in demand. This is the rebound effect (Fig. 1)[1]. A key point in this scenario is that, in parallel to more energy use, more output is also obtained and therefore welfare or final benefits could increase.

Evidence of a higher level of input in comparison to the baseline scenario and/or identifying reasons for this increase to happen forms the second step of the rebound effect. The rationale for identifying a 'rebound' or 'paradox' is related to the difference between the initial projected results at the physical process scale and the observed results within the economic system (Fig. 2).

Various explanations for the rebound effect have been discussed and analysed for energy (Alcott, 2005; Van den Bergh, 2010). These are usually classified as direct and indirect micro- and macroeconomic effects (Table 2).

At the microeconomic level, the basic rule determines that a drop in energy input due to efficiency gains leads to a drop in the marginal cost per unit of product, which potentially implies a lower price for the product and translates into higher demand. The drop in costs can also be accentuated by an associated fall in the input price, which is linked to a lower demand. For this direct rebound effect (the case mainly analysed in the literature), it is essential to consider the elasticity of demand, as consumption would rise only if cost is a limiting factor.

Table 2. Main types of rebound effect (adapted from Maxwell et al., 2011), using transport as an example

Type of rebound effect	Transport example
Direct (microeconomic): increased efficiency and associated cost reduction for a product/service results in a higher level of consumption because of an increase in demand	Car is used more often or to go further, since the cost for each kilometre travelled has dropped
Indirect (microeconomic): savings from cost reductions due to efficiency gains allow more income to be spent on other products and services	Money saved due to cheaper public transport is used to go on overseas holiday
Economy-wide (macroeconomic): increased efficiency drives overall economic productivity, which results in increased macroeconomic growth and consumption at a macroeconomic level	As a general consequence of increased mobility, the economy works better, so that incomes (and hence expenditure on goods and services) rise

Once the rebound effect mechanism is identified, accompanying policy measures are usually explored to ensure that the potential reduction in consumption due to efficiency improvements are secured, or at least that the rebound effect is minimised (Van den Bergh, 2010) (third step in Fig. 2). At this point, the key for designing an effective set of measures lies in the correct identification of the drivers of the rebound effect that need to be targeted. In relation to microeconomic effects, the usual proposal is to increase the price of energy, which offsets the drop in cost. In the case of transport, this may involve introducing a tax on fuel in response to more efficient cars.

Rebound effect for water

The rebound effect or Jevons paradox has recently been considered in an increasing number of reports or scientific papers in relation to water (e.g. EEA, 2012; UNEP, 2012). In many cases it implies that an improvement in efficiency may not materialise. Only a few papers provide a deeper analysis (e.g. Pfeiffer and Lin, 2012; Gómez and Gutierrez, 2011; Llop, 2008). Use of the three sequential steps described for energy in Fig. 2 provides an opportunity to analyse the unintended consequences of increased water efficiency:

1) Quantification of potential savings. Traditionally, the quantification of water savings is based on the premise that, with more efficient systems, a higher fraction of the water being withdrawn is destined to the desired output, allowing a reduction in initial withdrawals. Efficiency can be considered relative to the final output, such as plant transpiration for biomass production or water delivered to homes, or to intermediary transfers (conveyance efficiency). As with energy, the volume withdrawn initially and the initial and expected efficiencies are the data needed to estimate water savings (Fig. 1).

2) Evidence of, or reason for, higher water demand. In many cases, only the basic direct microeconomic effect is described, as is often the case for energy. For instance, UNEP (2012) states: "This 'rebound effect' occurs because greater efficiency reduces the price of the goods produced, incentivising higher levels of consumption". Equally, Llop (2008) identifies that "… any improvement in the technical efficiency of water requirements reduces water demand, and this causes a decrease in the price of water. Price reduction leads to an increase in water use, so the initial efficiency is completely or partially cancelled out". Energy and water are similar within this framework, with demand elasticity being essential in the characterisation of the rebound effect, since the explanation involves supply, demand and price.

The indirect rebound effect, in which monetary savings from efficiency cost reductions enable more income to be spent on other products and services, does not usually occur for water, but it could if, for example, money saved from reduced groundwater pumping costs is used to finance an increase in the irrigated area or for drilling a new well. From a macroeconomic perspective, the issue of potential impacts from efficiency improvements for the whole economy has also been raised, principally through the application of input–output models (Llop, 2008). Studies that introduce a more detailed analysis (Pfeiffer and Lin, 2012; Gómez and Gutierrez, 2011) also identify other reasons for a rise in demand (to be discussed below).

3) Designing complementary preventive measures. Accompanying measures are also proposed to make savings effective, as for energy. In line with the direct price effect explanation, it can consist of "price interventions in order to produce the desired effect on water resources and water shortages" (Llop, 2008). Another measure would be to explicitly specify that the savings should not satisfy new demands, e.g. through the revision of withdrawals rights. The important point here is that water savings are considered attainable if correct policy measures are implemented.

Consideration of losses and technical efficiency

Definition of losses and efficiency

Analysis of the rebound effect so far has been based on a similar approach for energy and water. The premise is the identification of savings at the scale of the physical process of water application. Economic or systemic effects then counteract these savings. Nevertheless, by focusing on the systemic consequences, the rebound effect does not question the reality of the savings from a physical point of view and, most importantly, takes them for granted to formulate a paradox. However, water and energy are fundamentally different. Energy that is not converted to the useful output is really lost, e.g. being dissipated as friction and heat (Fig. 1). However, a specific use of water does not necessarily consume all the water withdrawn. Most of water abstracted for domestic or industrial use is returned for treatment and reuse downstream (by usually directly discharging into a river)[2]. In the case of irrigation, some of the water will be consumed, either productively (through crop transpiration) or non-productively (by evaporation from wet soil and foliage), while the remaining fraction will flow back into the irrigation canal or river through run-off and drainage, or percolate into the ground and recharge aquifers. Many irrigation areas have developed on alluvial plains where aquifers are directly connected to rivers.

It is problematic to qualify return flows as losses because these will infiltrate back to the river system or aquifers and can eventually generate value for other downstream users, sustain river flows or recharge aquifers. Methodologies to categorise the different fractions of water withdrawals as a function of destination have been proposed. An approach based on the framework by Molden and Sakthivadivel (1999) and Perry et al. (2009) (Fig. 3) identifies recoverable return flows, i.e. the fraction of total water that will be available for reuse downstream. Thus, efficiency cannot be considered a definitive indicator for the performance of the system (Frederiksen and Allen, 2011; Jensen, 2007). For example, in the Alto Aragón irrigation district of Spain (Lecina et al., 2010), the switch from surface irrigation to 'more efficient' sprinkler irrigation indicated that a higher share of withdrawals was effectively consumed (and therefore not available downstream) (Box 1). The debate has also been presented using the terms 'dry' and 'wet' water savings (Seckler, 1996).

Nevertheless, this critique should not lead to the extreme opposite view that all water applied in excess of crops' evapotranspiration or excessive urban use will necessarily end up downstream for reuse. Return flows might go into saline or contaminated aquifers, percolate into areas where aquifers are so deep that they are not economically viable at the present time or return during floods and go directly to the sea. Excessive evaporation also occurs in poorly managed irrigation systems. Meanwhile, excessive abstractions can lead to serious environmental damage of part of a river, depending on where return flows rejoin it. Thus, the main issue is to insist on an accurate evaluation of local hydrological and hydrogeological settings and conditions of use beforehand, to identify losses and target savings.

Modernisation of irrigation in Spain

In Spain, the reality of the projected savings of the irrigation modernisation plans can be questioned. Many of the savings were to be obtained from areas located in the upper or middle sections of river basins (Fig. 4), meaning that return flows were potentially reused by a series of users downstream. However, there is no evidence of a methodology integrating the reusability of the return flows in the technical reports on the implementation of the plans (e.g. MARM, 2010). In fact, the actual amount of projected savings (Table 1) indicates that quantification may have relied on the 'traditional approach' as shown in Fig. 3. The expectation of large water savings due to a technological change was the main evidence for the investment. In a context of political tension around massive water transfers, the win–win opportunity (water savings and rural development) offered by the modernisation of irrigated areas was largely supported (López-Gunn et al., 2012b) (Fig. 5). A real estimation of the potential savings should have been based on a detailed local assessment, as presented by Lecina et al. (2010) (Box 1).

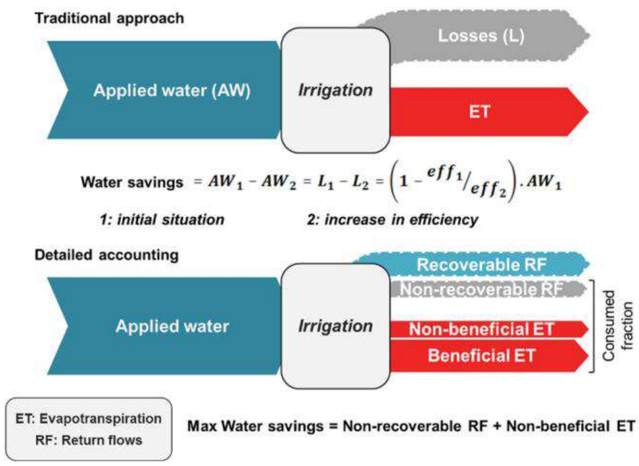

Figure 3. Quantification of water savings

Within the traditional view, it is based on the change in efficiency. In a detailed accounting framework (Perry et al. 2009; Molden and Sakthivadivel, 1999), the reusability of the return flows must be assessed.

Misleading approach reproduced by the rebound effect framework

The vision of savings based on a 'traditional quantification' (Fig. 3) or that drip irrigation saves water appeals to the common sense, up to the point that it appears unnecessary to introduce a detailed methodology (as happened in Spain) and is almost considered as self-explanatory. It is the same for formulation of the logic of a 'rebound' or 'paradox' (Fig. 2), in which the quantification of savings is an intuitive premise. The possibility to obtain the savings is also reinforced by the proposal of accompanying measures to make them effective (third step in Fig. 2). However, the basic formula, which may be valid for energy, does not apply to water from the physical point of view. Introducing the concept of the rebound diverts attention from the core of the debate on water

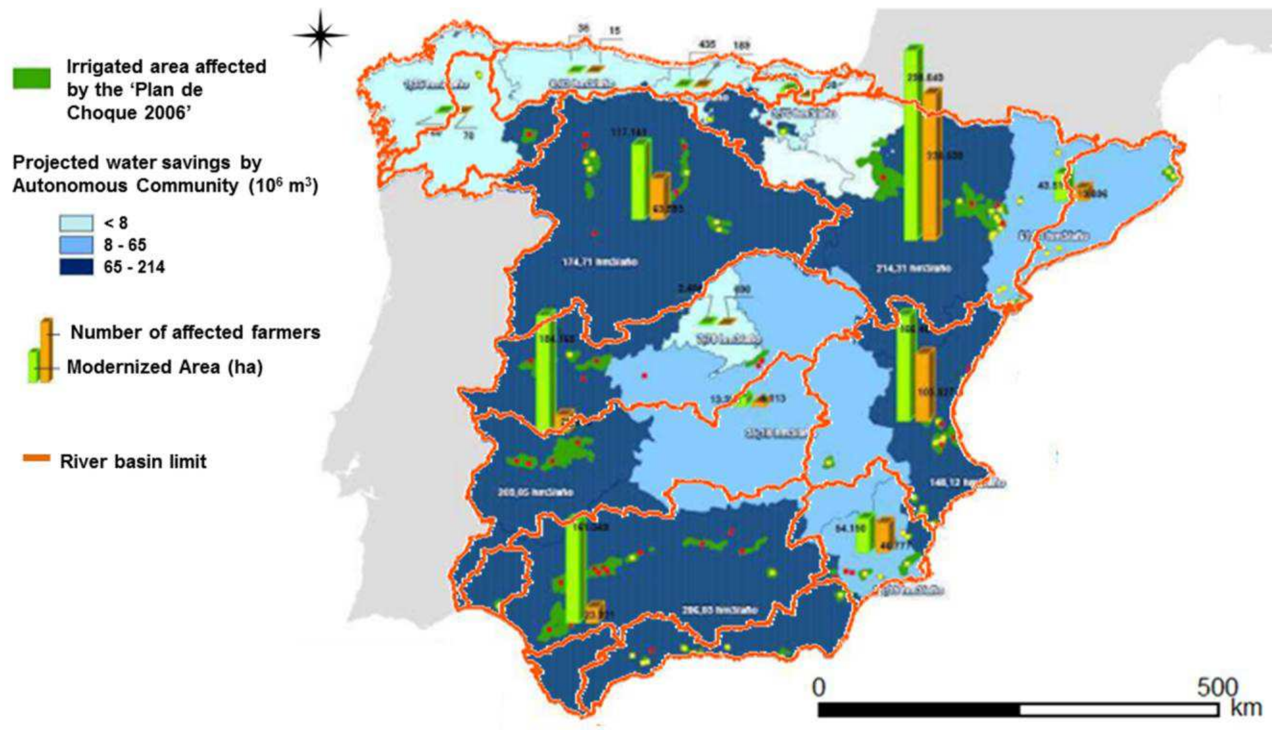

Figure 4. Map of the irrigated areas affected by the Shock Plan (Plan de Choque 2006) within the river basins in Spain (based on MARM, 2010)

saving quantification, while helping to create a false expectation.

Can unintended consequences really be prevented?

Traditional explanation based on price

The above observations do not mean that the effects of efficiency improvements should not be considered for water in relation to induced changes in the behaviour of economic agents. In fact, they highlight that these effects should not be referred to as a 'rebound' or 'paradox' as there is no obvious method to quantify water savings that may or may not be real from a physical perspective. Thus, the economic or systemic consequences, potentially based on the case of energy, should be considered. However, possible explanations should be carefully identified, particularly since the proposed accompanying measures depend on an accurate diagnosis of the problem.

The principal explanation is linked to the reduction of the relative cost of water per unit of output (UNEP, 2012), potentially accompanied by a reduction in the absolute price of water (EEA, 2012). Accordingly, an increase in demand would occur if water use was initially limited by the price of water. However, price rarely constrains water use, particularly in the agricultural industry (Hellegers and Perry, 2006); rather, the limiting factor is water availability or water rights. Therefore, it is problematic to identify a reduction in price – and subsequent increase in demand – as the prevalent reason of the rebound effect, since water use is usually inelastic to price change. This means that the related accompanying policy of increasing water price as a disincentive to water

Figure 5. Shock Plan: the main justification for the modernisation of irrigation in Spain is to save water for a 'sustainable rural development' Source: Plan de Choque (2006)

Box 1. Modernisation in the Alto Aragón irrigation project (based on Lecina et al., 2010)

The Riego de Alto Aragón irrigation project is located in the Ebro river basin, north-east Spain. In 2003, the irrigated area covered 121,000 ha, with 73% using surface irrigation and 27% sprinkler irrigation. As part of the National Irrigation Modernisation Plan, 52,200 hectares that used 292 Mm^3 of water were upgraded from surface to sprinkler irrigation. The investment of €500 million had an average annual amortisation cost of about €300/ha for farmers, including public subsidies and interest rates. Based on traditional accounting (Fig. 3), 47 Mm^3 of water savings could be expected (Fig. 6). Evidence for such savings can be obtained by considering the destination of water flows at the start and under different scenarios (Fig. 6):

- Analysis of the different fractions at the start reveals that the maximum attainable savings (i.e. with 100% efficiency) would be no more than 10 Mm^3 (the sum of the non-beneficial evapotranspiration [ET] and non-reusable return flows).
- Sprinkler 1 scenario is a hypothetical case that assumes the beneficial ET remains unchanged, the usual assumption when calculating savings (see Figs. 1 and 3). Even if withdrawals are lower, sprinkler irrigation consumes 23 Mm^3 of water more than surface irrigation. Indeed, most of the non-productive fraction is destined to be reused downstream in the Ebro river basin because the irrigation project is located in the middle section of the basin. Furthermore, overall evaporation (non-beneficial ET) increases because of high-wind evaporation that is associated with water application by sprinkler.
- Sprinkler 2 depicts the actual result of modernisation when there are no restrictions on water availability. The modernised system withdraws and consumes more water. Consumptive use (previously available for other uses downstream) increases by 134 Mm^3. Yet, the higher beneficial ET implies that higher profits are obtained (higher land productivity) because of, among other factors, the increased yields and the shift to more profitable and water-intensive crops.
- Sprinkler 3 considers a constant consumed fraction. The rise in total and consumptive use as illustrated in Sprinkler 2 is only possible if sufficient water is available (e.g. more water is maintained in the reservoirs thanks to higher efficiency) and water rights are not exceeded. However, to ensure there is no increase in consumptive use, a constant consumed fraction could be imposed. Nevertheless, land productivity remains basically the same as before modernisation, and the investment is not amortised.

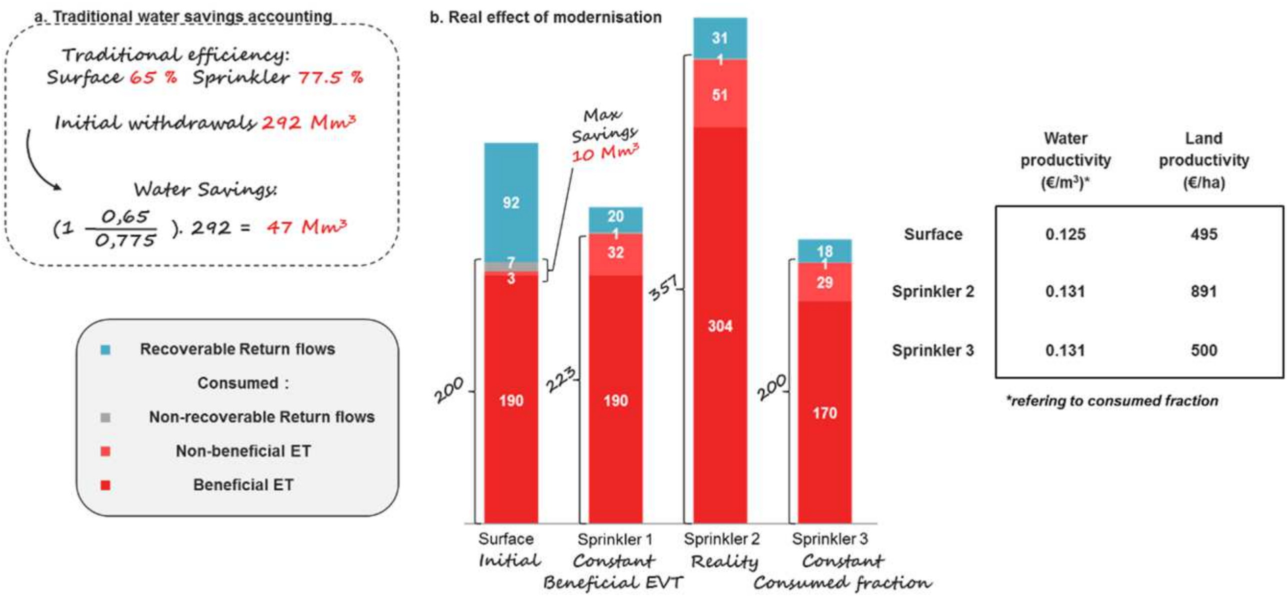

Figure 6. Traditional accounting of water savings and the real effect of modernisation of 52,200 ha in the Alto Aragón irrigation district (Ebro river basin, Spain). Adapted from: Lecina et al. (2010)

use could be misguided or pointless. An exception, where price usually restrains additional withdrawals, relates to groundwater, because the costs of pumping have a direct impact on profitability. Meanwhile, urban and industrial users should be considered carefully, since the demand function is very different from agricultural use.

Actual effects at system scale

The absence of price effects does not mean that there is no increase in consumption. In fact, introducing a preconceived explanation of the rebound effect concept causes a distraction from the relevant identification of unintended consequences. The example from Alto Aragón (Box 1) based on Lecina et al. (2010) shows how efficiency improvements can lead to higher consumptive use. This is primarily due to the higher efficacy and reliability of sprinklers: the more an irrigation technology is able to satisfy the water requirements of crops, the more it is efficacious, and efficacy rises with efficiency (Dinar and Zilberman, 1991). Indeed, technologies such as sprinkler or drip irrigation enable the application of water on demand, i.e. when the plant needs it most. This generates increased yields compared to surface irrigation systems, which usually operate by turns (Lecina et al., 2010; Ward and Pulido-Velázquez, 2008). Farmers may also switch to more profitable and water-consuming crops as a result of this higher reliability.

An additional effect is that more water is left in reservoirs because of a lower demand in terms of withdrawals. This conserved water may allow farmers to fully use their irrigation quotas, or it can be kept for a subsequent irrigation campaign. Thus, efficiency improvements exert an effect similar to dams: water is kept upstream, potentially affecting downstream users and the environment (Ward and Pulido-Velázquez, 2008; Molle and Turral, 2004). Furthermore, more efficient irrigation technologies allow the irrigation of low-quality land (Pfeiffer and Lin, 2012; Dinar and Zilberman, 1991).

All these consequences seem far more difficult to control than the ones traditionally described in the rebound effect framework (e.g. rising prices). It is often claimed that water rights should be revised according to the efficiency improvement to ensure that consumptive use does not rise. However, if not enough water was initially delivered to farmers to meet their rights (which is common in Spain), the increased upstream availability could be used to respect these rights, leading to more consumption even if they are revised according to the change in efficiency. Moreover, rights are sometimes defined in terms of area. To really prevent any quantitative impact on downstream users, the consumptive use could be conserved on the basis of the initial real situation and not the theoretical situation based on rights. However, the example from the Ebro river (Box 1) shows that modernised systems may not be able to increase profitability – with the same level of consumptive use, the investment is not paid back. Similar results have been found by Ward and Pulido-Velázquez (2008) who, apart from questioning the general interest of modernisation, show that farmers might use more water to obtain returns on their investment. It would also be hard to prevent farmers from using the full capacity of the new systems. Nevertheless, an opposite effect should also be considered: the high running costs of modernised (pressurised) systems linked to higher energy input may incentivise farmers to use water more rationally, while establishing the conditions for volumetric pricing (Rodríguez-Díaz et al., 2011).

Conclusions and recommendations

The main reasons the rebound effect is not considered to be the appropriate term to use for the consequences of water efficiency, compared to energy, comes from analysing the three sequential and interrelated steps from the rebound effect and the recommended policy prescriptions. This is summarised in Fig. 7:

- First, the use of the Jevons paradox or rebound effect reinforces the mistaken view that water not consumed is definitively lost, which is not the case. This is because the identification of savings is the basis for the formulation of a ‘rebound’ or ‘paradox’. Furthermore, the common accompanying measures to effectively reach the projected savings assume these are attainable.
- Secondly, a unique and rarely effective explanation, based on price mechanisms, is usually given, distracting from the identification of other effects that are much more difficult to control.

An alternative framework addressing the full range of consequences from a shift in irrigation technology should be based on two distinct pillars (Fig. 7):

- Water flows accounting: physical implications in terms of the reorganisation of the water flows through changes in the different fractions of destination of water applied to identify real potential water savings.
- Systemic assessment: an approach that looks at the entire system, framed into and influenced by economic and institutional conditions, thus enabling a more accurate and contextual identification of the main factors for the change in water use.

The price effect (i.e. what is usually understood as the rebound effect) would be integrated in the second pillar, and should be considered as relevant in some specific situations. Additional insights could be obtained from the rebound effect or

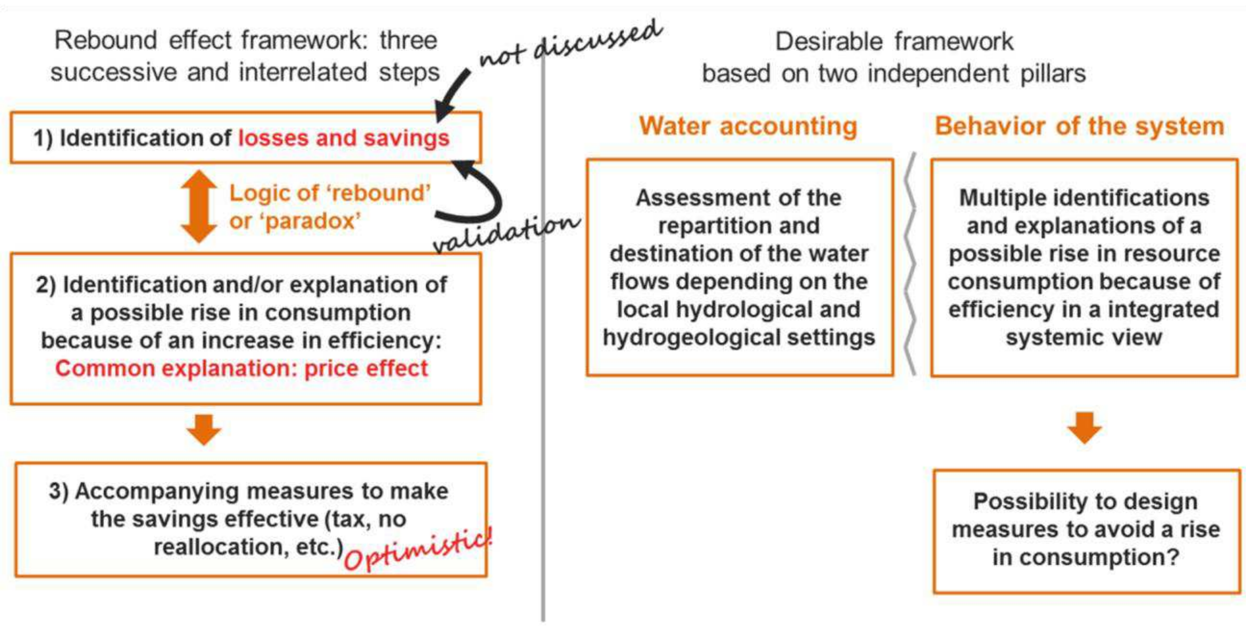

Figure 7. From the rebound effect framework to a proposed framework based on two pillars (water flows accounting and systemic assessment)

Jevons paradox from other types of resources, once it is recognised that its scope is limited to the second pillar.

In Spain, the reusability of return flows has not been assessed in the modernisation plans. In addition, the example from Alto Aragón (Box 1) shows the potential consequences of a more efficient but also more efficacious technology – a higher consumptive use. In this context, there are increasing demands, especially from environmental non-governmental organisations, for measures that would ensure real 'savings' (i.e. more water for the environment). However, the same critique as that used for the rebound effect could be applied: by claiming the realisation of savings and the establishment of measures to make them effective, the physical reality of these savings is not questioned.

This article has focused on efficiency from a quantitative perspective, mainly because the rebound effect concept addresses this aspect. However, once the principal justification of efficiency improvements (the estimated large water savings) is demystified, it appears even more necessary to have a detailed analysis on all the potential consequences that result from increasing efficiency. The implications in terms of water quality (Gleick et al., 2011; Dinar and Zilberman, 1991), energy requirements (Rodríguez-Diaz et al., 2011) or farmers' quality of life and rural development (CEPS, 2012) should also be assessed. Other benefits and associated costs should be identified, allowing detailed cost-benefit or cost-effectiveness analysis to determine whether the technology change is justified or to compare it with other possible measures.

Meanwhile, the true nature of the investment could be recognised with it being more justified for rural development reasons than for environmental reasons. What was a rebound or even an unintended consequence (e.g. the intensification of irrigation) would be the central objective of the project and the possible savings a potential co-benefit. However, the silver lining is that an increasingly efficient and efficacious use in the context of a semi-arid environment fully optimises the use of water to the point of having possibly low redundancy and thus a less resilient system.

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[1]The Jevons paradox is a rebound effect higher than 100%, although both terms are usually used interchangeably. In this article, only the concept of rebound effect is used, which is thus a wider term than the Jevons paradox.

[2]Return flows should not be identified as new resources, and the race towards wastewater reuse as a way to alleviate water stress is also pernicious in many cases.

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