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Economic productivity of irrigation water and the closure of a river basin in Southern Spain

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Abstract: The expansion of irrigated areas in river basins where water resource is scarce usually leads to the closure of the river basin (RB), as a final result of a multiple pressure-response process. This has been the trajectory followed by the Guadalquivir RB, which is the main river in southern Spain. As response to these pressures, farmers have tended to use the resource more efficiently through a modernisation of their irrigation methods and the widespread of deficit irrigation and high-precision techniques. These individual decisions have sought to maximise the economic return to the limited resource (water), provoking changes in crops composition in order to maximize the productivity of irrigated agriculture and the mean productivity per irrigation unit. The analysis carried out in this paper shows a significant increase in irrigation water mean productivity in the period (1989-2005), driven by the creation of new irrigated areas devoted to high value crops and with a dominant use of deficit irrigation strategies, while a second phase (2005-2012) is defined by slower growth in terms of the mean productivity of irrigation water, primarily as a result of a significant reduction in water use per area. Findings show the patterns followed by irrigation water productivity in the analysed case study, which seems to have reached its full capacity.

Key words: irrigation water productivity, agricultural water use, irrigation modernization, river basin management

1. INTRODUCTION

Southern Spain is characterised by a semi-arid climate and an increasing water scarcity. In this context, the Guadalquivir RB has undergone intense transformation in the last 50 years, characterised by a significant growth of irrigated areas, a progressive change in the composition of crops and widespread implementation of water conservation technologies (WCTs).

The aim of this paper is to analyse the impacts on irrigation water productivity generated by those responses (public and private) to the 'closure' process of the Guadalquivir RB observed in recent decades, as no further consumption of water resources is allowed. To this end, the rest of this paper is organised as follows. The next section introduces the theoretical framework regarding the concepts of mature water economies and basin closure process. Subsequently, the case study is briefly described and the fourth section outlines the observed impacts on irrigation water productivity. Finally, this work ends with some concluding remarks.

2. BASIN CLOSURE PROCESS, MATURE WATER ECONOMY AND THE IMPACTS ON THE ECONOMIC PRODUCTIVITY OF IRRIGATION

According to Randall (1981), in the 1980s the Australian water economy entered a 'mature phase' characterised by: (1) inelastic water supply with increasing marginal supply costs (aquifers were already heavily exploited, the best dam locations had been taken and other rivers were protected); (2) high and growing demand (with increasing conflicts among water users); (3) an aging infrastructure which required expensive renovation; (4) a context of increasing negative externalities and (5) a rising social cost of subsidising water use. Randall's framework belongs to public policy and agricultural and environmental economics, so it is focused on national policy and the instruments recommended are mainly economic in nature (i.e. water pricing or markets).

A different approach comes from the fields of hydrology and agronomy, where the concept of 'basin closure' has been widely used since 2006, focusing in the necessary adaptation processes required to achieve a 'soft landing' for RBs under a closure trajectory. Examples of basin overbuilding and closure are the Jordan River, the Krishna River, the Colorado River, the Yellow River, among others. In this regard, basin closure is defined as an anthropogenic process and the term has been used to describe the situation in a number of basins and aquifers (Molle *et al.,* 2010). An example of this analytical framework can be found in Comair *et al*. (2013), which describe how population growth and increased agricultural demand are contributing to the closure of the Jordan basin.

To the best of our knowledge, the concepts of 'mature water economy' and 'basin closure' have not been fully integrated in the existing literature and they are rarely included together in the same study. An explanation for this may lie in the different levels of analysis of the two analytical frameworks. Randall's 'mature water phase' is defined at national level, with economic and normative instruments defined at this level. Conversely, basin closure is defined in hydrological terms, and economic instruments may be used when the basin belongs mainly to a single country. Nevertheless, as most of the basins listed above are international, finding sustainable solutions entails greater complexity.

We believe that the framework of a 'mature water economy' phase is complementary to the hydrological and ecosystem concept of a 'closed basin', as the solutions to this problem should consider the local situation (natural, social and technical constraints at aquifer or subbasin level), as well as the national policy institutions (the legal framework for managing water resources). Moreover, basin closure status may be seen as a phase beyond a 'mature water economy', indicating the onset of an 'emergency' phase.

In this research paper, we present a case study of a closed basin that has reached the limit where no additional water sources are foreseen, and in which economic instruments (reallocation, volumetric pricing, water rights markets, etc.) and technical strategies (water saving, improved water productivity and water efficiency) have already been widely implemented. Figure 2 represents the closure process of a RB (adapted from Berbel *et al*., 2013). As WCTs increase irrigation water productivity, the expansion of new irrigated areas consequently leads to increasing pressures on the resource and the basin. In parallel, the extensive modernisation of irrigation systems has enabled widespread use of DI techniques, which have led to a remarkable increase in the economic productivity of irrigated agriculture (Expósito and Berbel, 2016). This in turn affects the characteristics of water demand by reducing the elasticity of demand with respect to the increasing water prices (Expósito and Berbel, 2017). Guadalquivir RB defined by this scenario with increasing pressures on water demand and growing scarcity of the resource,and therefore it can be assumed that the basin has reached a state of closure, with no additional water relevant resources to be consumed.

3. CASE STUDY CHARACTERISATION

The Guadalquivir RB, which is representative of the Mediterranean region, contains 23% of the total irrigated area in Spain (CHG, 2016). The competitiveness of its agriculture, with a focus on high value crops in a context of water scarcity, explains the remarkable expansion in irrigated areas and modernisation of irrigation systems in recent decades, to the point where there are now more than 850,000 hectares of irrigated land. The Guadalquivir is the longest river in southern Spain, with a length of about 650 km and a basin extension of over 57,527 km^2. Land in the basin is divided between forests (49.1%), agriculture (47.2%), urban areas (1.9%) and wetlands (1.8%). The basin has a Mediterranean climate with an average rainfall of 573 mm, occasional periods of prolonged drought, and an average annual temperature of 16.8 ºC.

The current reservoir capacity in the Guadalquivir RB is 8,600 hm^3 and the average water use in the basin amounts to about 3,800 hm^3 per year (CHG, 2016), of which about 3,400 hm^3 goes to meet the demand of irrigated agriculture (which represents 85% of the total water demand in the basin). The current Guadalquivir Hydrological Plan (2015-2021) declares that the level of the resource consumption has reached its maximum and that no significant supply increases are foreseen in the years to come. Against this backdrop, demand management has become the only available tool to manage water demand in the different socio-economic sectors, including agriculture (Corominas, 2010). Thus, the use of more efficient irrigation techniques plays a key role in achieving water-saving objectives, especially in a context of continuing pressure to increase irrigated areas, despite the explicit administrative moratorium on any further transformation of rain-fed lands into irrigated farmland.

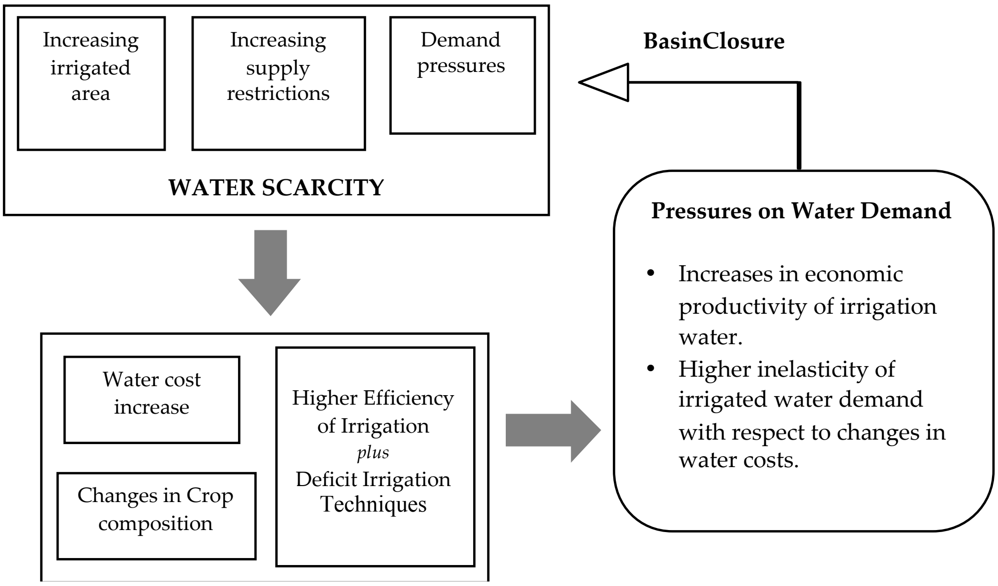

Figure 1. Model of Basin Closure Process.

As shown in Figure 2, the irrigated area in the Guadalquivir basin has increased continuously over the past two decades, mainly through the conversion of rain-fed olive groves into irrigated groves (MAGRAMA, 2015). In 2005, an administrative moratorium was declared on new irrigated areas in the main subbasin (comprising 90% of the irrigated area), with marginal increases in irrigated areas still allowed in the remaining 10% of the basin. The impact of this moratorium is reflected in the reduction of the average annual growth rate of irrigated areas, from 9% in the period 1989-2005 to 0.8% in the subsequent period.

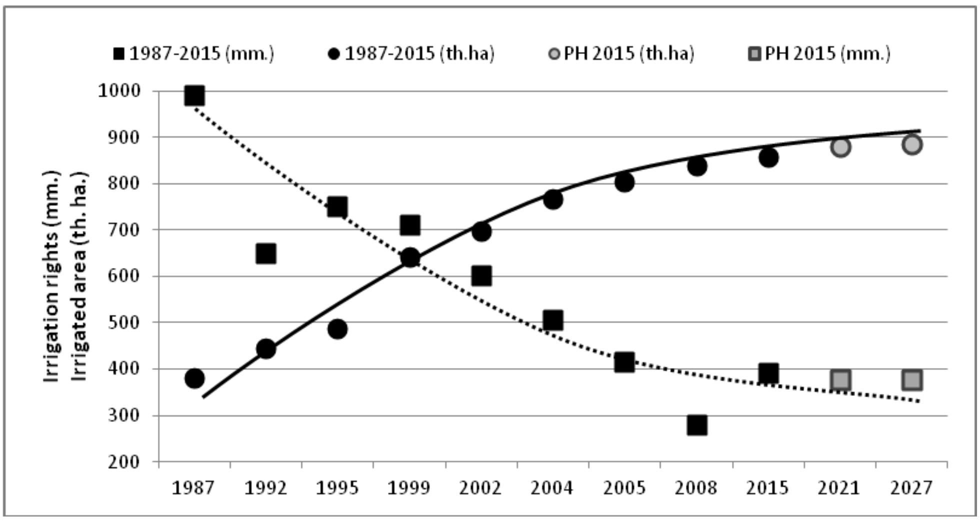

Figure 2. Average irrigation rights and irrigated area.

Farmers have adapted to this reduction in irrigation-water rights by modernising, investing in WCTs and using deficit irrigation (DI) strategies. The modernisation process of irrigation techniques has played a decisive role in the significant increase in irrigation water productivity in recent decades. The fact that the irrigated area in the basin doubled at the same time as a drastic reduction took place in the average irrigation rights per hectare can only be explained by the major investments made in WCTs. In this context, the greater water-use efficiency as an expected effect of irrigation modernisation, along with farmers' increasing commitment to crops with a more efficient water consumption and greater capacity to generate high agricultural yields (i.e. olive groves), have helped the basin to reach high efficiency levels in the use of the scarce water resources available.

The modernisation of irrigated agriculture in the Guadalquivir RB in recent years has been promoted by the regional government through the Andalusian Irrigation Plan (1995-2008) and the Irrigation Agenda H-2015 (CAP, 2010, 2011). The total investment for Andalusia (where the Guadalquivir RB accounts for 85% of the total irrigated area) was estimated at 1.54 billion EUR (of which 59% was publicly subsidised) for 347,234 ha (representing an average investment of 4,438 EUR/ha) in the analysed period. According to Corominas and Cuevas (2017), water efficiency (defined as the amount of water productively used divided by the total water supply) in the modernised areas in the Guadalquivir RB has risen from 0.67 to 0.84. The intense modernisation process in the Guadalquivir RB is reflected in the continuous increase in the surface area of drip-irrigated land in the basin. It is currently the principal irrigation method in the RB, employed in 66% of the total irrigated area, up from 12% in 1989. The comparison at a national level highlights the intense process of modernisation that has taken place in the Guadalquivir RB, which is well ahead of the rest of Spain in this regard. We would argue that the greater degree of mechanisation and modernisation achieved in this RB is reflective of the high level of agronomic development reached, and typical of closed RBs.

The substantial investments made as part of the intense modernisation process in the basin have also resulted in an increase in water costs, both in nominal (50%) and real terms (12%), during the last two decades, due mainly to the higher energy-use intensity of drip and sprinkler irrigation techniques and having to resort to deeper or more distant sources. The greater water-use efficiency due to the modernisation of irrigation along with the observed water cost increases have led to significant changes in the composition of major crops cultivated in the basin. Thus, farmers have tended to respond by dedicating more land to high value-added crops that use irrigation water more efficiently, with olive and citrus crops being notable examples. In parallel, the average irrigation water application in the basin fell approximately by 600 m^3/ha between 2005 and 2012, which affected most of the crops but had a particularly notable impact on traditional olive groves, where the use of DI techniques is more widespread. In this regard, ARIS ratios have decreased in major crops of the RB, especially in olive groves (Expósito and Berbel, 2016).

4. IMPACTS ON IRRIGATION WATER PRODUCTIVITY

As a result of the abovementioned responses to the closure process of the Guadalquivir RB, irrigation water productivity has increased dramatically in recent decades. Table 1 shows the yields obtained by rain-fed and irrigated agriculture in terms of Gross Value Added (GVA) in the RB. We assume that the increase in the economic productivity of irrigated agriculture due to improvements in labour and capital factors (improved seeds, machinery, etc.) is incorporated in the productivity of land and estimated by the increase over rain-fed farming productivity. Therefore, mean irrigation water productivity may be estimated as the difference between the estimated economic productivity (in terms of GVA generated per hectare) of irrigated agriculture and that of rain-fed farming.

Results show a relevant increase in the irrigation water mean productivity. However, significant differences are observed between the two analysed periods, 1995-2005 and 2006-2012. In the period 1995-2005, a remarkable expansion of irrigated area occurs in the Guadalquivir RB, with a 153% increase recorded (mainly in woody crops such as citrus and olive groves, which represent about 60% of the total increase in irrigated area in the RB). This expansion of irrigated areas in the basin, along with a 60% reduction in water consumption per hectare as a result of the modernisation of irrigation techniques, explains the significant increase in the irrigation water mean productivity in the period 1995-2005, rising from 0.11 to 0.49 EUR/m^3 (345% increase).

Table 1. Irrigation water mean productivity in the Guadalquivir RB.

	1989	2005	2012	Annual increase rate 1989-2005	Annual increase rate 2006-2012
[1] GVA of irrigation farming (EUR/ha)	1,579	2,653	2,660	4.00%	0.10%
[2] GVA of rain-fed farming (EUR/ha)	416	598	659	2.60%	1.40%
[3] Increase in productivity due to irrigation [3]= [2]-[1] (EUR/ha)	1,163	2,055	2,001	n/a	n/a
[4] Average irrigation water application (m^3/ha)	9,995	4,137	3,392	-3.40%	-2.60%
[5] Irrigation water mean productivity [5] = [3]/[4] (EUR/m^3)	0.116	0.497	0.603	19.30%	3.00%
[6] Irrigated area (ha)	316,646	801,865	845,986	9.00%	0.80%
[7] Rain-fed area (ha)	2,412,091	2,128,952	1,950,853	n/a	n/a

Source: Data for 1989 and 1995 from Carrasco et al. (2010). Own elaboration for 2012. Constant prices (base 2005).

During the period 2006-2012, the average water consumption per hectare decreases by 20%, to approximately 3,400 m^3/ha, while the capacity of irrigated agriculture to generate greater GVA levels than rain-fed agriculture remains largely unchanged (2,001 EUR/ha in 2012 compared to 2,055 EUR/ha in 2005). In our opinion, this would seem to indicate that the observed increase in the irrigation water mean productivity (from 0.49 to 0.60 EUR/m^3) in this period can be explained almost exclusively by the higher production efficiency of irrigated farming, which is thus able to generate the same yield levels with lower levels of water consumption.

The capacity of the Guadalquivir RB to increase the agricultural GVA through irrigation tends to level out in terms of GVA per irrigation unit. As a result of the marked expansion of irrigation agriculture in the basin, water resources have become the limiting production factor, in contrast with the traditional model that defines land as the limiting factor. Since the degree of modernisation and efficiency of irrigation techniques in the basin is already high, the ability of irrigated farming to continue generating greater GVA declines, a situation which characterises the current closure of the basin.

Table 2. Productivity of rain-fed and irrigated crops in the Guadalquivir RB, 2012.

Type of crop			[1] Crop GVA/ha (EUR/ha)	[2] Irrigation rights (m^3/ha)	[1]/[2] GVA/irrigation (EUR/m^3)
Cereals	Wheat	rain-fed	431	-	-
	Rice	irrigated	2,451	13,000	0.19
	Corn	irrigated	2,768	6,250	0.44
Industrial	Sunflower	rain-fed	471	-	-
	Cotton	irrigated	1,155	5,600	0.21
	Sugar beet	irrigated	2,726	4,500	0.61
Citrus	Oranges	irrigated	6,300	5,500	1.15
Olive groves	Table olives	rain-fed	1,426	-	-
	Oil-mill olives	rain-fed	1,302	-	-
	Table olives	irrigated	1,755	1,500	1.17
	Oil-mill olives	irrigated	2,500	1,500 – 2,250	1.11 – 1.67

Table 2 shows the 2012 data on GVA per hectare for major irrigated and rain-fed crops, obtained by applying a similar method to that used previously to estimate irrigation water productivity in the basin. Estimates show that the highest GVA-to-irrigation water ratio is achieved by olive and citrus crops. These crops have registered the largest increase in cultivated area over the analysed period, accounting nowadays for more than 60 % of total irrigated area in the Guadalquivir RB. According to Castillo *et al.* (2017), prices of major crops in the Guadalquivir RB have decreased in real terms in the last two decades, and this reduction in price has not been fully offset by the increase in physical production, meaning that income per hectare has decreased in real terms. Farmers have reacted to this situation by switching from commodity crops (i.e. cereals, sugar beet, and cotton) to higher value crops (i.e. citrus, olive).

5. CONCLUSIONS

The analysis of our case study has clearly revealed how greater resource-use efficiency has led to the expansion of irrigated areas of those crops with higher levels of GVA per irrigation unit (i.e. olive and citrus crops). In our opinion, the declining capacity of irrigated farming in the basin to generate greater GVA per hectare, as shown by the slowing rate of average annual increase in irrigation water mean productivity in the period 2005-2012, would explain the present situation in the Guadalquivir RB. This slow-down in productivity gains reflects the diminishing returns to scale of technical innovation, with DI, crop change and irrigation modernisation reaching the limits of their capacity to create new value, which in turn means that the economic productivity of irrigation water in the basin reaches a plateau.

As described in our research work, the factors driving irrigation water productivity in the Guadalquivir RB are multidimensional by nature:

1) Economic dimension.
   a) Change in crop patterns towards a preponderance of more productive crops.
2) Technical dimension.
   b) Increase in conveyance efficiency (distribution channels).
   c) Water-saving techniques (mainly drip irrigation and high-tech systems).
3) Agronomic dimension.
   d) Implementation of deficit irrigation (DI).
4) Institutional dimension.
   e) Reduction in water rights allocation.

The first three responses (crop pattern change, improved conveyance efficiency and water-saving techniques at farm level) are well documented (e.g. Molden *et al*., 2010; Molle *et al*., 2007). However, the last two responses (extensive use of DI techniques and reduction in water rights allocation) are distinctive features of the Guadalquivir RB and the published evidence on them is scarce; our analysis of these features can therefore be considered one of the main contributions of our analysis.

In our opinion, Guadalquivir can be defined as a closed basin as almost all water resources are allocated to farmers, other economic uses and environmental flows. Additional consumption demands - resulting from the increasing efficiency of irrigation techniques and the widespread use of DI practices with high-productivity crops (i.e. olive, citrus, and almond crops) - will continue to intensify the pressures in the basin. In this context, the Water Authority needs to enforce policy control and ensure good governance to prevent additional consumption demands that cannot be met with the already depleted resources.

In future studies, we plan to expand the microeconomic analysis of the closure process of a river basin by extending the study to other basins with different hydrological and environmental characteristics. Such an analysis would allow us to produce more robust results regarding the evolution of irrigation water productivity at a global basin level, as well as in major crops of the basin. We hope that this paper opens up new avenues for research in the field of water policy and encourages further study of the role of increasing water productivity in the evolution of a river basin.

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