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Analysis

The water footprint of the Spanish agricultural sector: 1860–2010

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ABSTRACT

Since 1860, the Spanish agricultural sector has undergone an intensive process of development resulting in important structural changes, not only in the sector itself, but also in the relationship of the agrarian system to natural resources. This paper studies the evolution of domestic water consumption as a consequence of increasing agricultural production, as well as the impact that the growing need for water had on the construction of infrastructure for irrigation. To that end, we examine the water consumed in the production of vegetable and animal goods for five different years: 1860, 1900, 1930, 1962 and 2010. From these results, a detailed analysis of the trends in water consumption and changes in compositional patterns is carried out. We determine to what extent the development of the agricultural sector conditioned the construction of new irrigation infrastructure. Finally, a Decomposition Analysis (DA) is applied to analytically identify and quantify the main explanatory factors behind that evolution, and to understand the increase in agricultural water consumption over the long term. Our findings show the large pressures on water resources exerted as a result of the expansion of the Spanish agricultural sector during the last 150 years.

1. Introduction

Modern economic growth and the changes associated with it (income and population growth, urbanization, structural change) profoundly modified the relationship of economies to natural resources. On the one hand, the energy transition, first to coal, then to oil, multiplied the productivity of economic activities. In this context, the use of fossil fuels was crucial for the development of industrialization (Allen, 2009; Wrigley, 1988; Stern, 2011). On the other hand, that intense growth generated severe impacts on the environment. An extensive literature has addressed these impacts from a long-term perspective: energy transition (Rubio, 2005; Gales et al., 2007; Kander et al., 2014), atmospheric pollution (McNeill, 2000; Krausmann et al., 2008; Stern, 2005; Stern and Kaufmann, 1996), forest resources (Iriarte-Goñi and Ayuda, 2008, 2012), the effects of land use on ecological biomass flows (Krausmann et al., 2012; Kastner, 2009; Kohlheb and Krausmann, 2009; Musel, 2009; Schwarzlmüller, 2009), and materials use (Krausmann et al., 2009). This sequence of parallel economic and environmental transformations has been conceptualized as a change in the social metabolism of economies (Fischer-Kowalski and Haberl, 2007).

The large-scale consumption of water has also been strongly influenced by modern economic growth (Duarte et al., 2013, 2014a). In fact, the scanty historical data seems to point to large increases in water withdrawal from the 19th century on. McNeill (2000) indicates that in year 2000, global water use was sixteen times higher than in 1800, and according to L'Vovich and White (1990), while global water withdrawals remained stable for centuries, they increased thirty-five-fold from 1680 to 1980. Water use has grown, principally, because of the formidable expansion of agriculture experienced in the last two centuries, allowing large populations to achieve food security, but simultaneously using up more land, while undertaking waterworks – on a massive scale – for the extension of irrigation in arid or semi-arid regions. Worldwide, irrigation is applied to over 18% of cultivated land and provides between 30% and 40% of gross agricultural production, and these figures are higher in arid and semi-arid regions (Federico, 2005). Irrigation, especially in arid countries, has substantially increased agricultural production, has imposed regularity, and has allowed for significant changes in land use. Recent estimates for the case of Europe during the second half of the 20th century show a significant influence in labour and total factor productivities (Martín-Retortillo and Pinilla, 2014 and 2015).

Certain studies have addressed the impact of agricultural development on the human appropriation of biomass over the long term (Krausmann et al., 2012; Kohlheb and Krausmann, 2009; Musel, 2009), although the effect of these processes on water resources has not been tackled from a historical perspective.

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In this context, the objective of this article is to analyse the effect of the expansion of the agricultural sector on water consumption. Specifically, we explore the impact of the growing requirements for water in semi-arid countries on the need to construct irrigation infrastructure, from the mid-19th century to the present day. This has been done for Spain, a very relevant case within the subject addressed.

Spain, as a semi-arid developed country that underwent a long process economic growth, has increased its water withdrawals, with major effects on its landscape. At the beginning of the XXI century, Spain was the 13th country in terms of irrigated area in the world (Gleick et al., 2009) and stands out as the second country in the ranking of irrigated land on the European continent, excluding the former Soviet Union republics (Martín-Retortillo and Pinilla, 2015). Gassert et al. (2013) state that Spain ranks 39/176 as a country with more water bodies environmentally stressed worldwide. Besides, Spain has one of the largest water footprints in the world, amounting to about 2000 m^3/capita/year with the agricultural sector representing about 80% of the total water footprint (Aldaya et al., 2008).

The Spanish agriculture sector went from being the most important sector of the Spanish economy in the 19th century and the early 20th century, to being notably smaller by the beginning of the 21st. According to Prados de la Escosura (2003) agriculture represented 39.2% of GDP and 63.5% of employment in the period 1855–1866. It had decreased somewhat by 1901–1913, to 31% of GDP and 58.7% of employment, and then fell sharply, so that by the period 1992–2000, agriculture accounted for only 4.5% of GDP and 7.8% of total employment. The development of agricultural production in Spain between 1850 and 2000, the causes of its growth, and the characteristics of its transformation, have been widely studied by economic historians (GEHR, 1983; Garrabou and Sanz, 1985; Jiménez Blanco, 1986; Barciela, 1986; Simpson, 1995; Gallego, 2001; Clar and Pinilla, 2009). Similarly, the literature has studied the long-term environmental impacts of this agricultural growth process (González de Molina, 2002; Cussó et al., 2006a, 2006b; Marull et al., 2008; Guzmán Casado and González de Molina, 2006; Infante-Amate, 2012; Infante-Amate and González de Molina, 2013; Infante-Amate et al., 2013; Schwarzlmüller, 2009; Tello and Ostos, 2011; González de Molina, 2010; Carpintero and Naredo, 2006).

Irrigation has traditionally attracted the attention of researchers, although the emphasis has been on the development of hydraulic works and the administration and management of water (Fernández-Clemente, 2000; Herranz, 2004; Gil-Olcina and Morales-Gil, 1992; Barciela and López, 2000). The study of irrigation agriculture in the long term has also been widely analysed, particularly from a regional and basin perspective (Garrabou and Naredo, 1999; Pinilla, 2008).

The period considered is crucial for the study of water in Spain, a semi-arid country with significant cyclical water shortages. Thus, it begins in 1860, when agricultural production in Spain was expanding as a result of both domestic and foreign demand, which grew out of the process of integration of Spanish agriculture in international markets. During the 20th century, the sector experienced important changes associated with technological development. The Civil War, and the autarkic policies carried out during the first decades of Franco's dictatorship, put a halt to this process, but it resumed in the mid-1950s. From then, an intense modernization process associated with production and productivity growth took place, entailing the end of traditional agriculture in Spain. Moreover, technical advances from the beginning of the 20th century allowed the construction of a hydraulic infrastructure that evolved from being paid for by private investors to being largely funded by the government. The development of irrigation was essential to set up an intensive agriculture with a marked exporting character.

To go further into these issues, we will obtain the water embodied (also known as virtual water) in Spanish agricultural production, using water intensities from Mekonnen and Hoekstra (2011, 2012) and agricultural production data from *Anuario Estadístico de la Producción Agraria* (MAGRAMA, 1929–2010). First introduced by Allan (1993), the concept of virtual water is defined as the volume of water required for the production of a commodity. Many current studies on water resources focus on agricultural and food products since, as in the case of Spain, the production of these commodities is the main water user in many regions (Chapagain and Hoekstra, 2011; Hoekstra and Mekonnen, 2012; Aldaya et al., 2008, 2010).

Following a bottom-up approach (Hoekstra and Hung, 2005), we obtain the water embodied in Spanish production, studying not only its trajectory in the long run, but also the changes in its composition. We analyse both green water — rainwater evaporated as a result of the production of a commodity, and blue water — surface or groundwater evaporated during a production process (Hoekstra et al., 2011). Although they are interrelated in the hydrological system, the features and implications of using each measure of water are quite different. Blue water is said to have higher opportunity costs than green water, given that it can be reallocated among different users, while green water cannot be easily re-allocated (Yang et al., 2007). Furthermore, increases in the use of blue water have significant economic implications, since they demand considerable investments of capital, both public and private.

In this paper we study the contribution of the economic factors that underlie the changes in the volume of water embodied in production. To that end, a Decomposition Analysis is applied for each period, identifying and estimating the effect that changes in the volume of production, variations in its composition, and yield improvements had on the embodied water in Spanish production. It is important to highlight that this study considers variable and time-dependent water intensities. As explained in the data section, constant water intensities have been traced back, considering long term changes in crop and livestock yields.

We will discuss the implications that increased agricultural production, and therefore in water consumption, had on water resources, especially on the need to construct infrastructure to store and distribute water for irrigation.

Our findings point to a gradual increase since 1860 in the consumption of blue and green water, with a smooth deceleration from 1930 to 1962, the period that covers the Spanish Civil War and the first twenty years of the Franco's dictatorship. The trend resumed during the period 1962–2008, which is characterised by strong growth in agri-food production and exports, and significant increases in demand for water. Although production patterns changed and crop and livestock yields notably improved, their effect was not sufficient to make up for the great increase in production that occurred during those years.

In the following section we review the methodology and explain the data used. In Section 3 the main results are explained. Section 4 discusses our findings, and Section 5 ends the paper with our main conclusions.

2. Methodology and data

2.1. Methodology

As a first step, we estimate the volume of water necessary for the production of Spanish agricultural and food goods, that is, embodied water in production, following the methodology proposed by Hoekstra and Hung (2005) for virtual water trade. For a country c (Spain in our case), in year t, embodied water in production (m^3/year) can be obtained as the sum of embodied water in production in each of its p products, which yields:

$$EWP(c,t) = \sum_p d_p^c(c,p,t) * P_p^c(c,p,t) \quad (1)$$

where $EWP(c,t)$ represents the volume of water necessary for the production of agricultural and food products in c during year t (m^3), $d_p^c(c,p,t)$ represents the water content per unit of good p in the producer country