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ABSTRACT

This working paper discusses how natural resource scarcity (aridity, in the case of Spanish agriculture) encouraged the process of frontier expansion defined by Barbier, meaning the exploitation of new, relatively abundant resources (water) for production purposes. Water for irrigated agriculture was obtained from both ground sources, identified as 'vertically downward' sources (i.e. wells, which were mainly funded by private initiative), and 'horizontally extensive' surface sources, such as dams and canals, primarily paid for by the public sector. Although the processes involved in obtaining water can be traced back over the centuries, it was really not until the 20thcentury when they became truly important. The growthof agricultural production was deeply influenced by this process. The main result is the mismatch between areas of high current agricultural productivity, and better initial endowment of natural resources.

Keywords: Natural resources and economic growth, Irrigated agriculture, Spanish economic history, Spanish agricultural history.

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RESUMEN

En este documento de trabajo se analiza como la escasez de recursos naturales (aridez, en el caso de la agricultura española) alentó el proceso de expansión de la frontera definido por Barbier, es decir, la explotación de nuevos recursos, relativamente abundantes (agua), para fines productivos. El agua para la agricultura de regadío se obtuvo del subsuelo (*vertically downward sources*, es decir la perforación de pozos, que fue financiada principalmente por la iniciativa privada), y de las fuentes superficiales (*horizontally extensive sources*, tales como presas y canales, pagados principalmente por el sector público). Aunque el aprovechamiento de agua para regadío se remonta mucho tiempo hacia atrás, no fue realmente hasta el siglo XX cuando se convirtió en verdaderamente importante. El crecimiento de la producción agrícola se vio profundamente influenciado por este proceso. Su resultado principal es la falta de coincidencia entre las zonas de alta productividad agrícola actual, y las que tienen una mejor dotación inicial de recursos naturales.

Palabras clave: Recursos naturales y crecimiento económico, Agricultura de regadío, Historia Económica de España, Historia Agraria de España.

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Water scarcity and agricultural growth in Spain: from curse to blessing?*

1. Introduction

Natural resource scarcity can be a major drawback for economic growth. When we consider pre-industrial economies, where the agricultural sector is the basis of most productive activities, environmental conditions are essential to explain the level of production, its composition, and the pace of growth. The climate, soil, and ruggedness of landscape are the main constraints to agricultural activities. In traditional economies, human beings have adapted to these environmental conditions by developing crops - or other activities –as close as possible to their ecological optimum (Grigg 1982: 51-53). Nevertheless, history also shows that there have also been conscious and deliberate attempts to change these conditions. The use of the natural resource of water has been the most important way to increase land productivity and to ensure crops in arid and semi-arid regions.

This process has been conditioned by the particularities of water, such as its transformation following water cycles (naturally circulating resource, constantly recharged) and its irregular distribution over time and across geographies, which create shortages locally (Oki and Kanae 2006). Among the features that influence the economic characterization and management of water, we find the essentiality of water

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as an element for life, its mobility, and its heterogeneity in terms of location and quality, variability, etc. Despite the fact that water is widely regarded as the most essential of natural resources, freshwater systems are – paradoxically - directly threatened by human activities (United-Nations-Water 2009; Vörösmarty et al. 2010), transformed through land cover changes, industrialization, urbanization, dams and other engineering works, irrigation and interbasin transfers, all of which aim to increase human access to water (Meybeck 2003; Vörösmartyet al. 2004). The benefits of water provision to productivity improvements (UNDP 2006; United-Nations-Water 2009) often go along with harm to the environment and to biodiversity, with potentially serious costs (Abell et al. 2008; IUCN 2009), and all of these effects further shapewater's relative scarcity and the environmental, economic, political, and social responses to that scarcity.

In this context, the objective of this work is to analyse the process of frontier expansion, meaning the exploitation of new relatively abundant resources (water) for production purposes (Barbier, 2011). Water for irrigated agriculture was obtained from ground sources identified as 'vertically downward' sources (i.e. wells), and from 'horizontally extensive' surface sources (such as dams and canals). The characterization of water as 'new' is due to the fact that, although the use of this resource is very old, traditional technologies offered limited possibilities for its extraction and development. However, crucial technological changes in engineering, the use of new materials, and the utilization of fossil fuel to power engines created significant expansion of ready access to water from the early decades of the 20thcentury, making it possible to construct large reservoirs with a capacity to store, and therefore to regulate, large volumes of water. Furthermore, the introduction of steam (and, later, fossil fuels) to power machines to pump water, allowed the extraction of water from underground.

The case study chosen is Spain, a predominantly semi-arid country, with a long tradition of water 'management', dating back to the Roman period. From the 19th century on, there was an intensification of effort to expand irrigation on a much larger scale. However, the effects of these efforts did not begin to be felt until the first decades of the 20th century, coming to fruition after 1950.

Water use grew notably when economic growth accelerated after the Industrial Revolution. Population growth, of course, increased the demand for water, but the primary underlying factor was the great increase in per capita income. Growing per capita income not only increased the demand for food, but also modified consumption patterns. Consumption of water-intensive goods increased sharply, resulting in a significant increase in water use. However, the most serious strain on freshwater resources comes now from the mounting weight of meat in the consumption package(Duarte et al., 2013 and 2014a).

To cope with the increase in demand, agriculture has substantially increased its production throughout the past century. The expansion of irrigation has contributed significantly to this increase in production; the global irrigated area jumped from approximately 48 million hectares in 1900 to 235 million in 1989 (Gleick 1993). The development of modern irrigation systems has also been identified as a necessary condition for the efficient use of the agricultural technologies that emerged in the second half of the 20th century (Hayami and Ruttan 1985). In the case of the Green Revolution, the new high-yield crop varieties worked best where irrigation infrastructure was already available, and chemical fertilizers were widely used (Federico 2005). A great investment in dams and irrigations canals became necessary and, accordingly, food supply more than doubled and water withdrawal grew by 2.81% annually during this period. It was the intensification of agriculture that made water withdrawal figures soar, as agricultural water use is the most important (Duarte et al., 2014a).

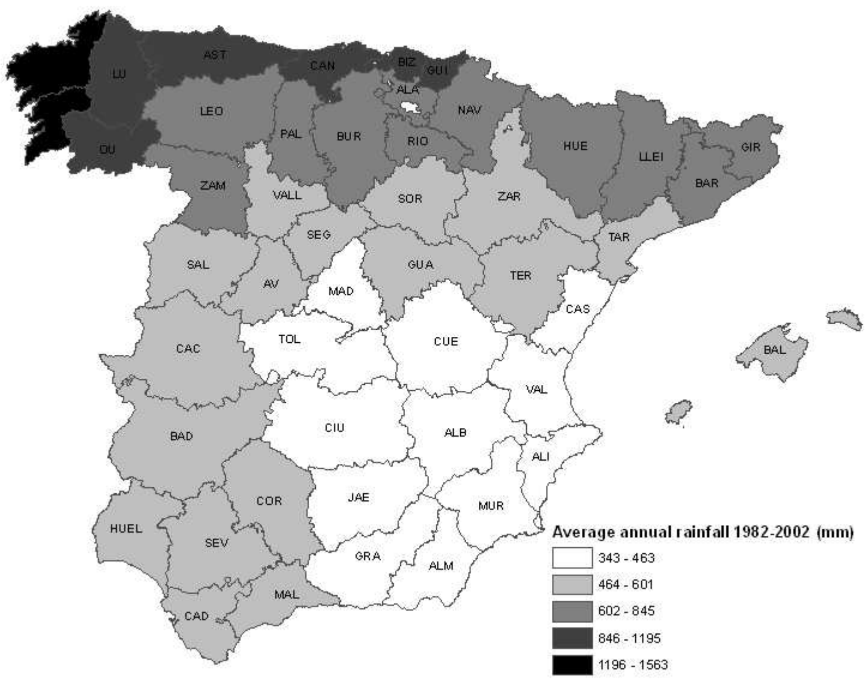
In this working paper we first explain why water scarcity is so important in Spain to understand its relative agricultural backwardness in the European context until late in the 19thcentury. It was not until the 20thcentury that irrigation spread significantly. We then analyze the result of the increase of water use on agricultural crop production for the period 1935-2005.Subsequently, we focus on the compositional changes in agricultural production stemming from the greater availability of water. In addition, we examine the impact of the expansion of irrigation on the regional distribution of agricultural crop production. The last section deals with the negative effects generated by greater water availability: the development of irrigation could have caused significant environmental damage, and there were important conflicts over the control of, and access to, water resources, particularly from 1977 onwards.

2. Water as a constraint for agricultural growth

In pre-industrial Europe, the most significant agricultural innovations consisted of a sequence of changes introduced in England, and then in the Netherlands: changes in crop rotation and the introduction of forage pulses that fixed nitrogen to the soil were crucial, allowing for the elimination of fallow and a greater integration of farming and agriculture, largely thanks to the greater availability of feed for cattle. At the same time, these changes led to greater access to organic fertilizers, and agricultural yields and production increased (Allen, 1994; Clark, 1987).

Spain is a semi-arid country characterized by variable and unequal rainfall, together with higher levels of evapotranspiration compared to the European average(González de Molina, 2001). Spain stands out, not only for its semi-arid character, but also for its irregular distribution of water resources, both over time and in space. Figure 1 shows the average long-term precipitation for the period 1982-2002 (in mm) in the various Spanish regions, and clearly displays significant disparities in terms of water endowment. The Northwest of Spain is the most humid area in the country, followed by the Cantabrican coast. Other regions in the north of Spain, particularly those in the Pyrenees and the Cantabrican mountains, also show important amounts of rainfall. However, as can be seen, most regions in Spain are arid or semi-arid, with low average annual precipitation. These differences have, historically, had a clear effect on regional grain yields (Santiago-Caballero, 2013).

Figure 1: Long-term average annual rainfall (mm), 1982-2002.



Note: The list and codes of provinces are shown in the Appendix.
Source: Own elaboration with data from Goerlich (2012)

Aridity was one of the primary limiting factors of the adoption in Spain of the English mix of farming techniques, and hampered the introduction of fodder crops into the crop rotation system and the addition of nutrients to the soil (Garrabou, 1994, Clar and Pinilla, 2009, and Tortella, 1994).Throughout the 19thcentury, many European countries followed the English agricultural innovations, and thus increased productivity (Bairoch, 1999; Chorley 1981; Lains and Pinilla, 2009; Van Zanden 1991). Production per hectare was significantly lower in Spain than in the rest of Europe, where these innovations were introduced (Pinilla, 2004).

By the end of the 19th century, a political movement, Regenerationism, led by the thinker Joaquín Costa, viewed irrigation as a panacea for the serious problems affecting rural areas, especially the problem of poverty. The expansion of irrigation during the 19th century was limited, for two reasons. First, the economic liberalism propounded by Adam Smith gave the state a very limited economic role; thus, large waterworks must be privately funded, and the cost of the initial investment, and its long amortization period, limited the increase in irrigated area - although with some regional differences (Pinilla, 2008a; Ramón, 2013). Second, from a technological viewpoint, the materials used and the development of engineering did not allow for the construction of large reservoirs. Thus, even the irrigation canals that were built did not have the ability to maintain a supply of water when, and where, it was most needed.

Both drawbacks were overcome in the early years of the 20th century. Costa's ideas broke with the tradition of economic liberalism and instead granted the state a role in encouraging the economic development of the country. Consequently, from 1895 on, the state funded some hydraulic plans already under construction and notably boosted the expansion of irrigation.

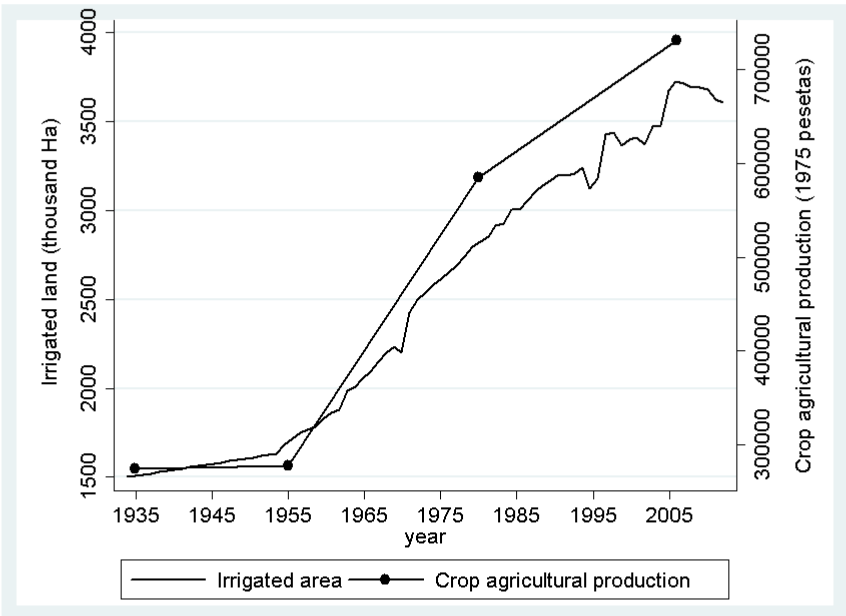
Second, the new technologies that had recently appeared, as engineering techniques and new materials like reinforced concrete were introduced, allowed Spain to overcome these technological disadvantages. Furthermore, since the middle of the 19th century, the use of steam power to pump water from wells had spread, although the high costs involved considerably limited the process. This became less of a problem with the introduction of pumps driven by petrol, gas, or electricity (Calatayud and Martínez-Carrión, 2005).

As a result of such technological improvement, and a substantial increase in public investment, the construction of hydraulic infrastructure accelerated, especially from the second half of the 20th century, and Spain's irrigated area increased substantially (Herranz, 2004). The new reservoirs entailed an improvement in the quality of irrigation; it was now possible to go from irregular irrigation, when water could be harnessed only in the months of higher rainfall and snowmelt, to a permanent irrigation, when it was possible to supply water when, and where it was needed for crop growth. The productivity of the land increased and new irrigated crops were introduced that would not have been feasible under rainfed conditions. In those places where it was possible to alleviate water scarcity by constructing waterworks, water went from being a limiting factor for agriculture to being essential, especially in combination with the Mediterranean climate characterised by high levels of sunshine hours.

The irrigated area increased rapidly between 1935 and 2006. As we can see in Figure 2, this growth was particularly intense from 1955. It seems quite clear that the development of the Spanish agricultural sector entailed large pressures on water resources, necessitating the construction of irrigation infrastructure and the expansion of irrigated land (Duarte et al, forthcoming). The former phenomenon, together with abundant sunshine, compared to other Western European countries, gave Spain a significant advantage in the production of certain agricultural goods.

During Franco's dictatorship, the construction of water infrastructure became an outstanding agricultural policy. Spain moved towards becoming a high-income country, and the development of the domestic market, together with integration in international markets as an exporter of high-value agricultural and food products, put increased pressure on domestic water resources and made it necessary to intensify the change from rainfed to irrigated agriculture.

Figure 2: Trajectory of irrigated area in thousand ha (left axis) and agricultural production(in pesetas at 1975 prices) (right axis), 1935-2006.



Source: Data from 1935 to 1953 were not available. We linearly interpolated information between 1935 and 1954 (Irrigated area). Own calculation from Gallego (1993) and MAGRAMA (2005) (Agricultural production).

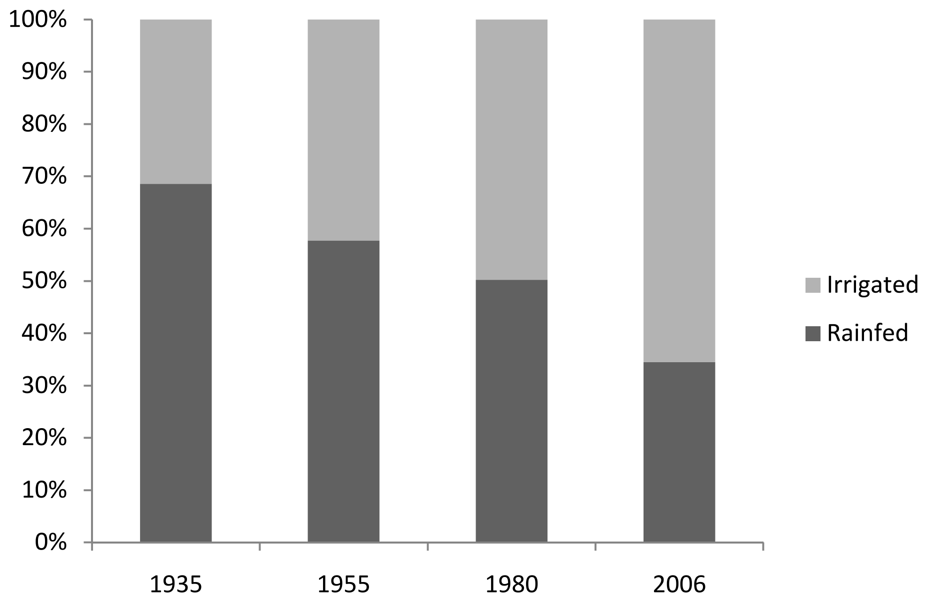
3. The increase in agricultural production

Spanish agricultural production, following the depression at the end of the 19th century, grew at a significant pace during the next three decades (Clar and Pinilla, 2009). This growth was based on Spain's growing presence in international agricultural markets, and on the development of the domestic market for both traditional and new products. In the first case, the success of Spain as an exporter of horticultural products was remarkable, with a notable increase in trade (Pinilla and Ayuda, 2009 and 2010), but this success was dependent on the expansion of irrigation, since the most important products, such as oranges and fruit and vegetables, required more water than could be supplied by the rain. It has been estimated that 32.4% of the increase in irrigation water consumed in Spain between 1900 and 1935 was devoted to export products(Duarte et al., 2014b: 103).

Growth in Spanish agricultural production was halted from the beginning of the civil war in 1936 until the mid-1950s, but more important than the effects of the war itself, was the post-war situation; the autarkic policies of the Franco regime (a crude intervention in the markets that discouraged the production of key commodities such as wheat) and the difficulty in obtaining inputs such as fertilizers and machinery, led to a decline in production and a hiatus in agricultural modernization (Barciela,1986; Christiansen, 2012).

The turnaround in agrarian policies from 1951 and the end of the international isolation of the Spanish economy allowed the resumption of agricultural transformations and a very rapid growth in production, both in the European context, and in absolute terms (Martín-Retortillo and Pinilla, forthcoming). If we only consider crop production, it increased at 3% annually, on average, from 1955 to 1975, and irrigated land grew at a 2.25% annual rate. Finally, during the democratic period (1975-2006) agricultural production and land under irrigation continued to increase, but at a slower pace, 0.8% and 1.1% respectively. Accordingly, during these years, Spanish agriculture went from being a traditional sector in which production was allocated mostly depending on climatic characteristics to a modern sector, highly conditioned by the strong development of irrigation.

Figure 3: Percentage of crop production, ratios of rainfed to irrigated production



Source: Own elaboration based on MAGRAMA (1935, 1955, 1975, 1980 and 2007)

Irrigation played a key role in the growth of agricultural production. As we can see in Figure 3, rainfed agricultural production had a decreasing share from 1935 to the beginning of the 21stcentury. In fact, during these years it went from being around 70% of total crop production in 1935 to slightly more than one third of the total output in 2006. Although the problem of Spanish aridity was partially overcome, the development of the agricultural sector led to greatly increased pressure on water resources (Duarte et al., forthcoming).

An important aspect of this analysis is the quantification of the factors driving the growth in agricultural production during the period 1935-2006. Following a decomposition approach (Dietzenbacher and Los, 1998), we assess to what extent changes in irrigation and rainfed crop yields, as well as variations in irrigated and rainfed area, contributed to the increase in agricultural production. Thus, we conduct the decomposition shown below:

$$\Delta P = \Delta Y_R(A_{R0} + A_{R1}) + \Delta A_R(Y_{R0} + Y_{R1}) + \Delta Y_I(A_{I0} + A_{I1}) + \Delta A_I(Y_{I0} + Y_{I1})$$

Changes in agricultural production (ΔP) between the periods t=0 and t=1 are explained on the basis of changes in the rainfed crop yield ($\Delta Y_R(A_{R0} + A_{R1})$), where Y is yield and R is rainfed; changes in the rainfed area ($\Delta A_R(Y_{R0} + Y_{R1})$), where A indicates area; changes in the irrigated crop yield ($\Delta Y_I(A_{I0} + A_{I1})$), where I indicates irrigation, and changes in the irrigated area ($\Delta A_I(Y_{I0} + Y_{I1})$).

Table1: Decomposition of agricultural production

	1935-1955*	**1955-1980**	**1980-2006**	**1935-2006**
Change in rainfed yield	-409%	48%	17%	**33%**
Change in rainfed area	-281%	-4%	-46%	**-19%**
Change in irrigated yield	501%	24%	58%	**41%**
Change in irrigated area	289%	32%	71%	**45%**
Change in production (million pesetas at 1975 prices)	3,968	307,561	145,643	**457,172**

Source: own elaboration.*As the change in production was insignificant between 1935 and 1955, the percentages of the effects of the explaining factors rise rapidly due to simple calculations.

As we can see in Table 1, three factors underlie the increase in agricultural production between 1935 and 2006. The increase in irrigated area accounted for 45%, and from 1980 to 2006, it accounted for 71% of the increase in agricultural production. The growth in the irrigated crop yield was 41% of the total change in agricultural production. Great technological improvements occurred throughout this period, together with an important compositional change towards water-intensive crops. Technological development during this period also contributed to the increase in the rainfed crop yield, accounting for 33% of the growth in agricultural production.

4. Changes in the crop mix

During the first third of the 20thcentury, the Mediterranean regions tended to substitute traditional rainfed crops by irrigated production, with much of this being destined for export (Pinilla and Ayuda, 2009; Duarte et al.,2014b). This was possible thanks to the use of new technologies (petrol engines, electric pumps, etc.), and private funding of irrigation was supplemented by state financing of the construction of waterworks (Pinilla, 2006).

In fact, as we can see in Table 2, the distribution of agricultural production changed significantly from 1935 to 2006. Firstly, there was a marked increase in the share of horticultural crops and fruit trees, while tubers -and to a lesser extent cereals and pulses -lost importance in the production structure. That is, there was a substitution from traditional crops to high value-added Mediterranean horticultural products. This compositional change could be related to economic development, the associated dietary changes, and the orientation of these products to foreign markets. Without the greater water availability that came from the expansion of irrigation, these changes would not have been possible. Furthermore, changes in the crop mixture on irrigated land (especially in fruit trees) led to an increase in irrigation productivity.

The most striking changes took place between 1980 and 2006. The entrance of Spain to the European Economic Community, and thus the Common Agricultural Policy(CAP), was a significant factor. The growing integration of European markets encouraged specialization in certain products (fruit trees, olives) while the production of others (tubers, cereals, fodder crops)was discouraged(Clar et al., 2014; Pinilla and Serrano, 2009).

Table 2: Crop production(millions pesetas at 1975 prices) and percentage of group products in agricultural crop production

	1935	1955	1980	2006	1935	1955	1980	2006
Cereals	77,364	70,674	162,756	168,107	28.25	25.44	27.80	23.00
Legumes	7,514	13,542	9,414	5,515	2.74	4.87	1.61	0.75
Industrial crops	12,980	19,115	40,657	35,820	4.74	6.88	6.95	4.90
Tubers	32,921	31,835	43,130	18,971	12.02	11.46	7.37	2.60
Horticultural	39,723	44,443	103,026	179,082	14.50	16.00	17.60	24.50
Fruittrees	38,127	34,980	82,731	147,253	13.92	12.59	14.13	20.14
Vineyards	20,450	20,112	50,867	44,810	7.47	7.24	8.69	6.13
Olives	32,474	19,519	35,443	87,981	11.86	7.02	6.05	12.03
Fodder crops	12,331	23,631	57,388	43,515	4.50	8.51	9.80	5.95
Total Crop	273,882	277,851	585,412	731,055	100.0	100.0	100.0	100.0

Source: Own elaboration based on MAGRAMA (1935, 1955, 1975, 1980 and 2007)

In this regard, changes in the distribution of agricultural production had profound impacts on natural resources, especially in the case of water. In fact, the growing importance of horticultural and fruit products involved increasing pressure on water resources, which were particularly intense during the Franco dictatorship, but also in the subsequent democratic period. This marked compositional change towards water-intensive products, in a semi-arid country like Spain, came with a cost: the development of irrigation and therefore of an increase in the irrigated area.

Table 3: Percentage of rainfed production by group of products on total agricultural crop production

	1935	1955	1980	2006
Cereals	84.26	79.60	74.72	62.40
Legumes	99.00	78.94	74.51	71.94
Industrial	53.02	31.21	31.13	28.68
Tubers	66.50	52.00	43.30	13.39
Horticultural	22.74	17.19	11.18	1.32
Fruit trees	54.65	41.89	22.83	10.12
Vineyards	93.86	93.91	89.54	66.73
Olives	92.91	92.54	88.62	69.84
Foddercrops	58.04	49.58	46.50	50.63
Total	68.57	57.74	50.22	34.52

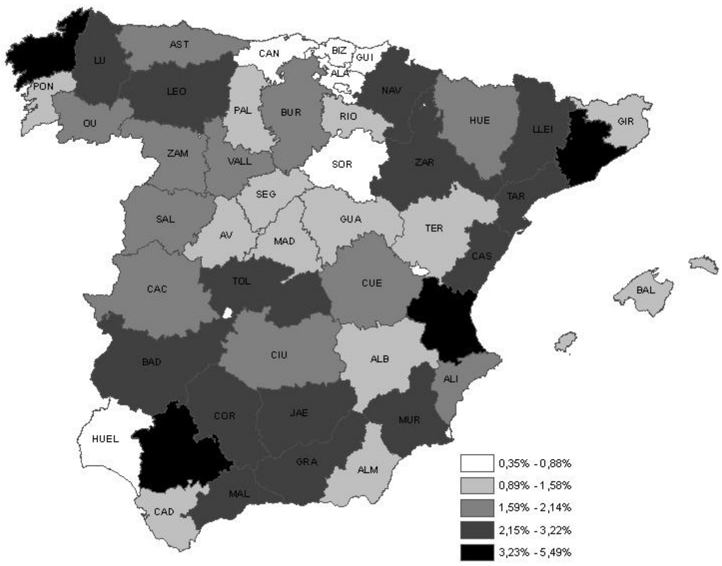
Source: Own elaboration based on MAGRAMA (1935, 1955, 1975, 1980 and 2007)

As Table 3 shows, the percentage of rainfed agriculture dropped in all groups of products. Nonetheless, there are interesting differences among them. Fruit trees, tubers and vineyard products are the groups with a larger decrease in their share of rainfed production. The case of fruit products is notable since, in 2006, only 10% were cultivated under rainfed conditions, having declined from almost 55% in 1935. On the other hand, cereals, fodder crops and horticultural products had a lesser decline. However, an abrupt change in cereals grown under irrigation occurred; maize replaced wheat as the main cereal crop on Spanish irrigated land. As for horticultural products, despite that they show a smooth decrease, their weight during the whole period was the lowest, and rainfed production only accounted for 1.32% by 2006.

5. Changes in the spatial distribution of agricultural production

In Figure 4, it is possible to distinguish that, in 1930, the value of agricultural production varied sharply from region to region The dispersion of agricultural production was significant, and it is important to highlight areas such as Valencia (center east), Barcelona (the darkest in the northeast), A Coruña (the northernmost on the west) and Sevilla (the darkest in the southwest); these regions accounted for 5.8%, 4.1%, 4.13% and 3.7%, respectively, of the value of total agricultural production in 1930.

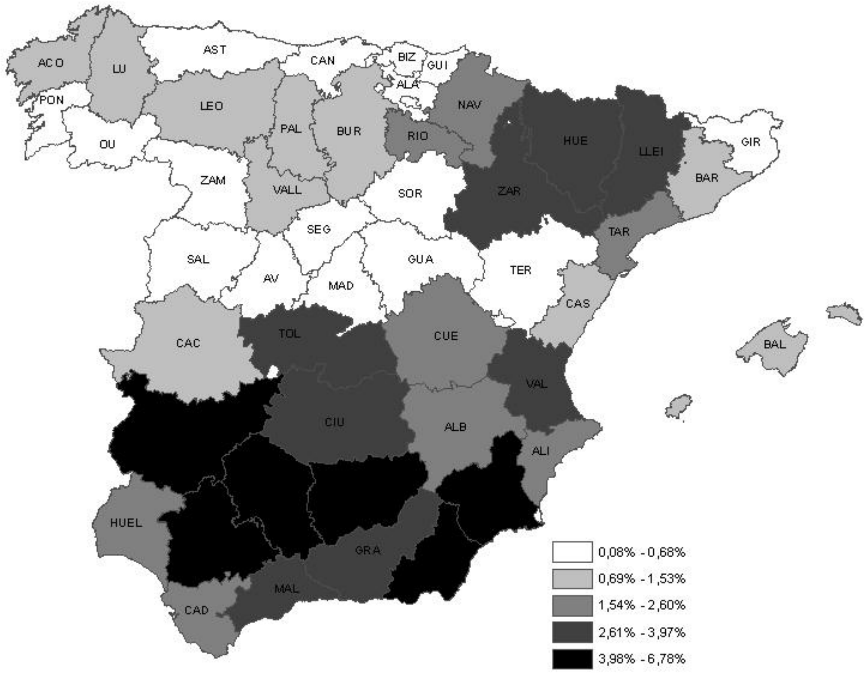
Figure 4: Regional distribution of agricultural crop production as percentage of the total, 1930.



Note: The list and codes of provinces are shown in the Appendix.
Source: Own elaboration from Gallego (1993).

The picture is very different when we consider the regional distribution of agricultural production in 2005 (Figure 5). From 1930 to 2005, a clear trend can be found. A re-allocation of agricultural production took place, from humid to arid and semi-arid areas. Whereas in 1930 those areas with an average value of annual precipitation lower than 846 mm represented around 64% of the value of agricultural crop production, these regions accounted for over 80% of crop agricultural production in 2005. Humid areas in the North of Spain lost importance, mostly in favour of the arid regions in the South. The provinces in the South, and in the Ebro Valley in the North-East increased their proportion of total crop production. In other words, agricultural production became concentrated in certain provinces, especially those with the most arid climates.

Figure 5: Regional distribution of agricultural crop production as percent of total, 2005.



Note: The list and codes of provinces are shown in the Appendix.
Source: Own elaboration from MAGRAMA (2005).

The arid and semi-arid provinces of Badajoz, Sevilla, Almería, Jaén, Murcia, Córdoba and Ciudad Real doubled their share of national production between 1930 and 2005; they comprised 18.69% of total Spanish production in 1930, rising to more than 40% in 2005. Average annual rainfall in these seven provinces was 442 mm 1982 and 2002, while the national average was 650mm (as indicated above). On the whole, these regions specialized in Mediterranean agricultural products, and these products experienced significant declines in rainfed production, especially in the period 1980-2006†. Hence, the role of irrigation in the development of the agricultural sector in arid regions in the South of Spain was essential. During these years, important investments in water infrastructure were carried out, which allowed an evolution from a traditional agriculture based on rainfed crops to a modern and productive irrigated sector.

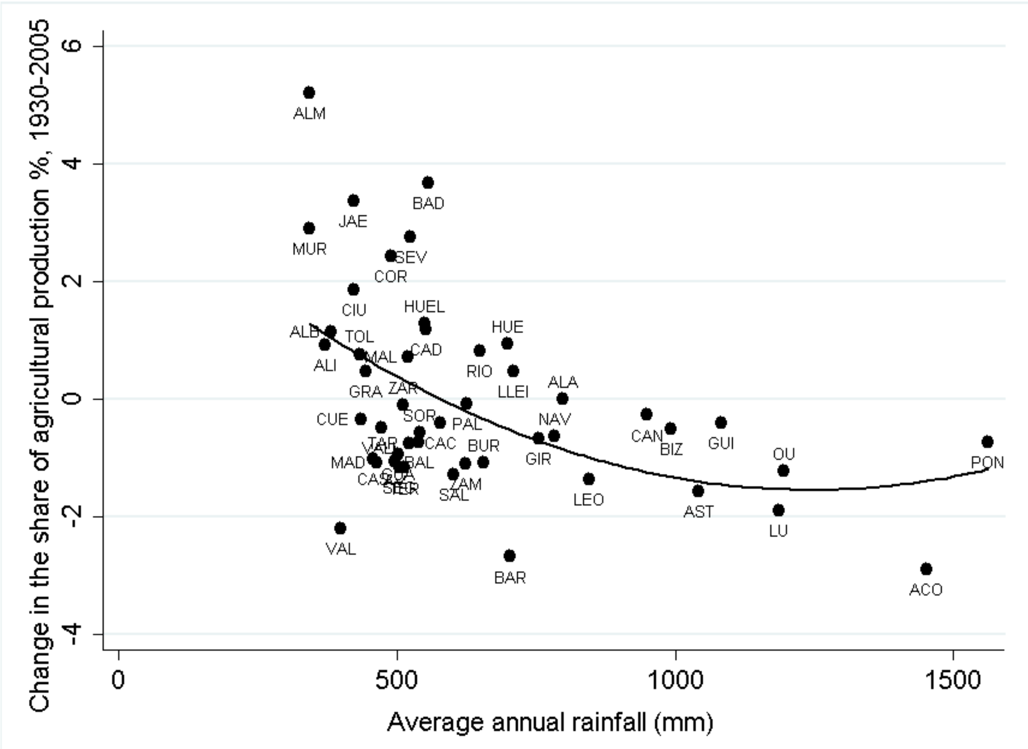
†The provinces of Almería, Murcia and Badajoz had a clear horticultural specialization; in 2005 they produced 43% of total horticultural production. Jaén, Sevilla and Córdoba were specialized in olive products, representing 61% of the production of these crops in 2005. The importance of vineyard products in Ciudad Real is notable, since this province produced 20% of total Spanish vineyard production in 2005.

Only certain regions in the North of Spain, such as those in the Ebro valley, where irrigation infrastructure was intensively developed during the 20th century, display sharesof agricultural production greater than 1.5% (Pinilla, 2008b).

But what is the relationship between aridity and the distribution of agricultural production? As can be seen in Figure 6, throughout the years 1930-2005 there was a de-coupling between precipitation levels and the share of the value of agricultural production. The weight of the most humid areas in Spain in crop agricultural production decreased from 1930 to 2005, with this decline being particularly intense in the case of the provinces in Galicia (ACO, PON, LU and OU). Nevertheless, the most remarkable aspect is the large increase in the share of agricultural production of those arid areas located in the south of Spain. This is the case, for example, of the southeastern provinces of Almeria and Murcia, two Mediterranean areas with the lowest levels of rainfall in Spain that have experienced a large rise in their weight of agricultural production, with shares of 5.2% and 2.9%, respectively. That is, whereas the dry provinces in the southern half of Spain and those in the (northeastern) Ebro Valley gained share in agricultural production, in a large part of humid Spain, agriculture was losing importance.

This de-coupling would not have been possible without the key role of irrigation. The largest increase in the percentage of irrigated production took place between 1980 and 2006, jointly with the increase in the share of horticultural, fruit trees, and olive products. In this sub-period, the existing trends were reinforced. It seems paradoxical that, in one of the driest countries in Europe, water resources have such intensive use.

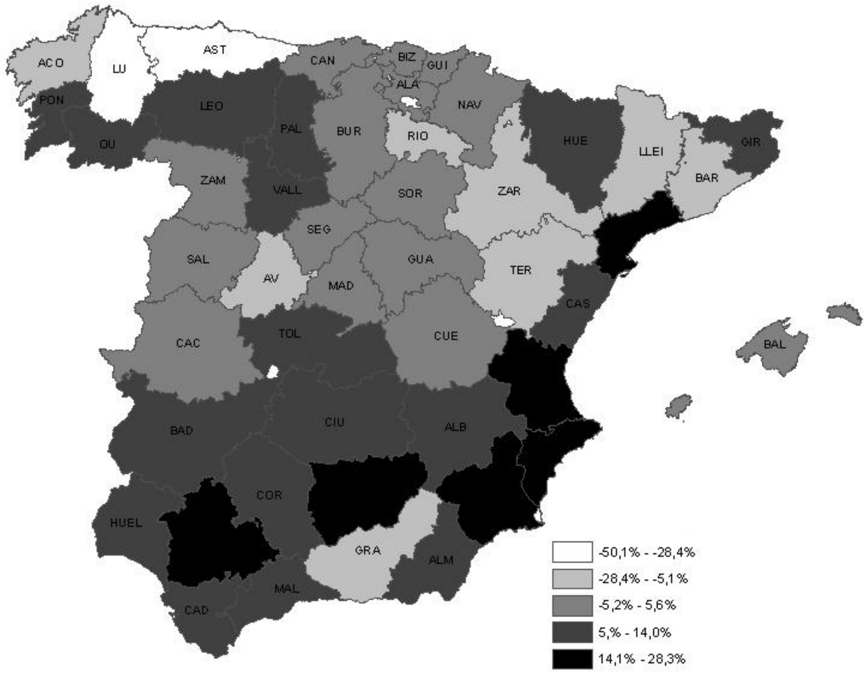
Figure 6: Average annual rainfall in Spain vs. changes in the share of agricultural crop production (%)



Note: The list and codes of provinces are shown in the Appendix.
Source: Own elaboration from MAGRAMA (2005), Gallego (1993) and Goerlich (2012).

In Figure 7, we can see the change in the provincial distribution of irrigated land during the 20th century. With some exceptions (such as certain provinces in the North Meseta, center-north of the peninsula and in Catalonia, north-eastern provinces), the general pattern was that irrigation grew more in the drier provinces. Where water was scarcer, more investments in irrigated land took place and more pressure on water resources was exerted. These resources included both surface and ground water. In some provinces, the exploitation of aquifers was significant, escalating the problems of pressure on water resources (Reig and Picazo, 2002).

Figure 7. Change in the percentage of irrigated land on total agricultural area, 1916-2009



Source: Own elaboration based on Junta Central Agronómica (1918) and INE (2009).

6. Environmental impacts and water conflicts

As mentioned above, agricultural development in the 20thcentury cannot be understood without a grasp of the policies of expansion of irrigated area and the concomitant increase in water capacity, especially from the 1950s on. This was a process of construction of reservoirs, dams, canals, and irrigation infrastructure that allowed for the regulation of the water supply of the main Spanish rivers, and reducing the risks associated with the geographical and seasonal variations of water availability in Spain. However, the construction and extension of this infrastructure, while it has led to the consolidation of irrigated agriculture, greater associated income, and the spread of a new energy source (hydropower), has not been at all conducive to the ecological preservation of the environment. Furthermore, the drilling of wells, many of them illegal, also entailed environmental problems.

As is well known, any river basin contains many natural ecosystems (aquatic habitats, headwaters, riparian areas, groundwater associated with the channel, estuary, wetlands,…) with different ecological and eco-social functions (flood control and storm protection, yield products such as wildlife, fisheries, and forest resources, among others) that are seriously affected by large-scale irrigation infrastructure and dams. These effects mainly come from the required stabilization of runoff and the diversion of surface water for irrigation, implicit in irrigation infrastructures, which alter the natural hydrological cycle.

There is significant evidence of the global impacts of hydraulic engineering on the quantity and seasonal patterns of continental water flows. According to the World Commission on Dams (2000), these are clearly negative, complex, varied, and profound, and include physical, chemical, and geomorphological effects that alter the natural distribution and timing of flows, affect water quality, water quantity, the flow regime and sediment load (first-order impacts). A second group of impacts are changes in the biological productivity of ecosystems of the main channel, and of riparian land and wetlands (second-order impacts). Consequential to these impacts, significant effects on fish, vertebrates, and other wildlife have been reported.

More specifically, problems of degradation of irrigated land (salinization, alkalization, waterlogging, overexploitation of groundwater flows) have been observed in large-scale irrigation schemes (Dougherty and Hall, 1995). Changes in the structure of soils, often with damage and degradation associated with intensive cultivation and improper irrigation management, directly reduce the fertility and productivity of irrigated areas, leading to additional stresses on land and water resources.

In this regard, according to (Amezketa 2008; FAO/IPGRI 1994; European-Commission 2002), 3% of the more than 3.5 million hectares of irrigated land in Spain are severely affected by salinity problems, and 15% are seriously threatened. In the case of the Ebro basin, the acreage affected by salinity exceeds 300,000 hectares, representing around 30% of the total irrigated area (Pinilla, 2006).

Similarly, the overexploitation of water has been drastic along the south-east coast (Doñana, Upper-Guadiana, Upper-Duero), with irreversible damage in some cases associated with wetland water tables. Moreover, over 125,000 hectares should be abandoned to achieve balance among the aquifers affected by over-exploitation (Oñate, 2009).

The development of irrigated agriculture was also responsible for the problems of diffuse pollution, due to intensive use of fertilizers and pesticides, with the greatest impact on the underground areas being due to nitrates. It is estimated that more than 600,000 hectares in Spain are located in areas vulnerable to pollution. Severe impacts of pollution on the surface systems (rivers, wetlands, coastal lagoons) and ecosystems have also been reported for certain areas of the Spanish Mediterranean coast (MAPA, 2002 and Oñate, 2009).

In this regard, the alteration of natural river flows, both spatially and temporally, and the associated impacts on water quality, salinity, and temperature, has led to critical consequences for fish populations and wetland species. Thus, when the natural variability of the river is affected, biological communities in the area are seriously damaged. Moreover, the cut-off of migratory routes along the river associated with the diversion of water flows also contributes to isolate animal populations, impoverishing some ecological relationships. As an example, Ibañez et al. (1999) estimate a reduction in fish catches in the lagoons of the Ebro delta from 300 tonne/year in the 1970s, to 50 tonne/year in the 1990s. Diaz et al (1993) showed, in a study of Castilla-León, how the habitat transformation involved in Diaz et al (1993)the passage from extensive rainfed to intensive rainfed and, subsequently, irrigation, resulted in the replacement of steppe birds, as well as other species common in urbanized environments.

Habitat fragmentation, together with downstream effects, such as loss of floodplains, the reduction of surface water, and the deterioration of river deltas and sea estuaries, have been seen as major ecological impacts of hydrological alterations (Rosenberg et al. 2000). As an example, the construction of the largedams of Ribarroja and Mequinenza, near the delta of the Ebro river, consolidated a slow and gradual process of reduction in sediment inputs to the delta, now discounted by 99% compared to the original flows, from 22 million t/year in the 1940s, before the expansion of irrigation, to the current flow around 0,1 million t/year (Ibarra et al. 2008).

Other effects, such as the occupation of coastal lands, reducing the natural section avenues, and the modification of the natural landscape, also arise as a result of water regulation infrastructures. Finally, according to Vörosmarty and Sahagian (2000), from a global perspective, engineering-based control of drainage basins represents a significant alteration of the quantity and seasonal patterns of continental runoff.

From a socio-economic point of view, water regulation has allowed modernization of agriculture, with an associated increase in agriculture-based income. However, the construction of water infrastructures, and specifically water reservoirs, also left a trail of important socio-economic negative impacts in Spain. Forced population displacements as a consequence of the flooding of villages, and the disappearance of economic activities dependent on the river ecosystem, both upstream and downstream from a dam, can be seen as the most serious social effect of water resource development. The impact on the personal, social, and cultural identity of displaced populations is difficult to measure, even though it may often be irreversible. In Spain, more than 400 villages disappeared due to the building of dams, with compensation and resettlement attempts often being insufficient for the affected populations[‡].

The Spanish economic growth model has encouraged, in certain regions, the development of high value-added and high water-intensive activities (recreation, intensive irrigation, urban centers, residential buildings, etc.) in recent decades. In this context, water appears as a newly-valued element in the political arena, and territorial wars for water control within the river basin, or among regions throughout the Spanish rivers system, are exacerbated during periods of severe drought. Two types of conflict have arisen. First, inter-basin conflicts, as a result of the huge needs for water in the export-oriented Mediterranean region that demanded water transfers. Second, in some watersheds, there were disputes between supporters of continuing the implementation of water projects, mainly farmers, and protesters, mostly people living in the affected mountain areas.

Perhaps the most controversial - and most-discussed - regional water conflicts have been those that involve inter-basin water transfers. The Tajo-Segura transfer[§]and the major water transfers drafted in the National Hydrological Plan are the best examples (Arrojo, 2001; Gil-Olcina, 1995;Villarroya, 2006). In the first case, the droughts in the donor basin in Castile-La Mancha(and other conflicts linked to the harnessing of the Júcar) have contributed to struggles between regions for the resource, and to major water transfers. The National Hydrological Plan, especially the planned

[‡] See for the Aragonese Pyrenees, Herranz (1995).

[§]The Tajo-Segura was devised in the I National Plan of Hydraulic Works as the transfer of surplus from the Tajo (Tagus) to correct a hydrographic imbalance, taking almost half a century to complete (in 1979) and creating a 286-kilometre canal.

extraction of 1,000 hm3 per year from the Ebro river to the Mediterranean regions, generated many technical questions, and gave rise to serious concerns about sustainability. In this context, we can cite the claim of Aragon for the right to make use of the Ebro flows, the demands of Catalonia regarding security of supply and environmental flows at the delta, the demands of the Valencia Community to ensure the development of its economic and tourism activity, and those of the Murcia region to develop its horticulture.

7. Conclusions

The objective of this paper has been to illustrate how the scarcity of an essential natural resource can encourage technological change in a process of frontier expansion, allowing the exploitation of new productive sources. On the basis of this debate, the question arises: is the availability of natural resources a blessing, or a curse, for economic and social development.

We consider water resources in a semi-arid Mediterranean country, Spain, as our case study. We discuss how the process of economic growth, and a public policy focused on the expansion of irrigation as a key element in boosting income growth and achieving national food security, encouraged throughout the 20th century the development of technologies and infrastructures to dramatically increase the productivity of agriculture. Substantial public and private investments, sustained over several decades, led to a new geographical distribution of crop production, in which traditional relatively dry regions (though with relative abundance of other natural resources) took advantage of the new resource, regulated water. This reallocation of crop agricultural production, was determined both by the availability of untapped water resources, rivers or aquifers, in drier regions, and its high agricultural potential if existing high insolation was combined with enough water resources. The results can be considered mixed.

On the one hand, the development and expansion of irrigation schemes allowed the Spanish agriculture, mainly during the second part of the 20th century, to experience unprecedented economic growth. Undoubtedly, this allowed the Spanish economy to establish the basis of a more productive sector, better integrated in the production chain (while also facilitating the development of the agri-food industry) and crucially more competitive in international markets. Technological and structural changes inagriculture led to a significant increase in productivity, which supported the rise in agricultural incomes.

On the other hand, the development of this water-intensive agriculture has led to a significant mismatch between those areas with better natural endowments of water, and the areas that currently show higher agricultural productivity. The long-term process of nationwide expansion and intensification of irrigation, and the associated development of irrigation infrastructures (reservoirs, dams, canals, wells) to bring regulated water from its original sources to its users, has left behind important ecological and social impacts that in some cases are already irreversible. The development of irrigation in Spain has been associated with four main ecological problems, namely, salinity and erosion, over-exploitation of water sources, water pollution, and damage to river eco-habitats. The severity of the salinity problem in the Spanish fields (affecting almost 20% of irrigation), the overexploitation of aquifers of major rivers (the cases of Almería, Upper-Duero, and Upper-Guadiana are significant), the reduction of contributions to deltas (almost 100% in the case of the Ebro delta) and the effects on wildlife and vegetation in specific areas (the disappearance of steppe bird species) are clear examples of the other side of the coin of agricultural development in Spain.

Additionally, the process of construction of reservoirs and dams, encouraged as a sort of national economic policy, is problematic. Although it was seen as a source of employment in the short-term (mainly unskilled and sometimes under-paid work), it forced the displacement of rural populations, due to either the direct flooding of villages, or the effect on agricultural areas and pastures on which those populations depended. The negative consequences for those communities are immeasurable.

Finally, the availability of regulated water has been understood in recent decades as a powerful element of regional planning, which allows for the rapid economic growth of recipient regions (through the development of highly profitable and highly intensive water-economic activities), but which condemns other areas that cannot fully take advantage of its use as it passes through their territory. Thus, political promises and territorial expectations have situated water resources in the center of the political debate, further intensifying the dissonance between natural availability and resource use. The project National Hydrological Plan of 2001, with the inclusion of a system of water transfers in the Ebro to supply Eastern Spain (Catalonia, Valencia, and Murcia) and the transfers in the Tajo-Guadiana river system, generated major political and social confrontations among territories, on a scale never before seen regarding a natural resource.

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Appendix

List and code of provinces

ALB: Albacete, ALI: Alicante, ALM: Almería, AV:Ávila, BAD: Badajoz, BAL: Baleares, BAR: Barcelona, BUR: Burgos, CAC: Cáceres, CAD: Cádiz, CAN: Cantabria, CAS: Castellón, CIU: Ciudad Real, COR: Córdoba, ACO: A Coruña, CUE: Cuenca, GIR: Girona, GRA: Granada, GUA: Guadalajara, GUI: Guipúzcoa, HUEL: Huelva, HUE: Huesca, JAE: Jaén, ALA: Álava, LEO: León, LLEI: Lleida, LU: Lugo, MAD: Madrid, MAL: Málaga, MUR: Murcia, NAV: Navarra, OU: Ourense, PAL: Palencia, PON: Pontevedra, AST: Asturias, RIO: La Rioja, SAL: Salamanca, SEG: Segovia, SEV: Sevilla, SOR: Soria, TAR: Tarragona, TER: Teruel, TOL: Toledo, VAL: Valencia, VALL: Valladolid, BIZ: Vizcaya, ZAM: Zamora, ZAR: Zaragoza