**The demographic impact of irrigation projects: a comparison of two case studies of the Ebro basin, Spain, 1900–2001**

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Abstract

Water management and population issues have always been particularly important in Spain, a country historically characterized by severe environmental constraints on agricultural growth and intense rural depopulation. This paper evaluates whether irrigation projects in Spain over the course of the twentieth century have achieved one of their main objectives, which was to reduce rural population decline. This paper makes two contributions. First, we compare the evolution of population in two of the earliest and most ambitious irrigation projects in Spain, the *Riegos del Alto Aragón* (Upper Aragon Irrigation System) and the *Canal de Aragón y Cataluña* (Aragon and Catalonia Canal System), both located in the Ebro basin. Second, the time period of the study spans an entire century. This long-term approach is crucial if we accept that irrigation requires time to consolidate its effects and, therefore, its impact on population may be long delayed. We show that the evolution of population in each of the two projects has been substantially different. We also analyze the factors that have caused or prevented population growth. We argue that financial, economic and environmental limitations have been significant, but also that political and geographical factors have played a major role.

Keywords: Irrigation projects; demographic impact; Spain; long-run study; comparison of two cases

Abbreviated article title: The demographic impact of irrigation projects

## Introduction

As they developed in the nineteenth and twentieth centuries, modern irrigation systems were aimed, among other objectives, at resettling population and reducing migration to the cities and abroad.[1] Population allocation projects based on water diversion and storage schemes accompanied colonial expansion, contributed to the 'interior colonization' of large and thinly populated countries, such as the United States, Canada and Australia, and, more recently, they have formed part of development strategies in Africa, Asia and Latin America.

Although the economic and environmental effects of irrigation projects have received considerable attention, there is little literature on their demographic impact. Research into the effects of irrigation on population has focused on two main areas: North America and the developing countries. Studies of the United States usually refer to the settlement of the irrigated West during the late nineteenth and early twentieth centuries, and to the impact of later irrigation projects on alleviating rural depopulation in the Midwest.[2] A recent study analyzes irrigation projects in the Canadian Prairie West in the early twentieth century.[3] Assessments of irrigation projects in developing countries as tools to reduce, or redirect, internal migration during the twentieth century, includes case studies for Bangladesh, India, Kenya, México, Nepal, Nigeria, Sri Lanka, Somalia and Thailand.[4]

This literature has produced mixed results. Studies are difficult to compare because of differences in methodology. Nevertheless, Matthew Evenden refers to three main problems that are common to irrigation projects around the world.[5] First, irrigation programs are costly. They often involved large infrastructure works and proved incapable of generating sufficient revenues to enable settlers, private capital or even governments to pay expenses. Second, environmental constraints prevented the expected outcomes. Third, models from abroad, particularly those imported from the US, tended to produce undesired results in different natural and socio-political environments.

Issues of water management and population distribution have been particularly important in Spain, a country characterized by severe environmental constraints on agricultural growth and intense rural depopulation. Scarce, irregular rainfall coupled with seasonal drought is a major factor explaining the relatively poor performance of Spanish agriculture in the nineteenth and twentieth centuries, compared to other European countries.[6] Rural depopulation began in the late nineteenth century and intensified sharply in the mid-twentieth century.[7] Rural-urban migration and its subsequent effects on the demographic system, namely the reduction of numbers of women and young people, have been described

as two of the main causes for the dramatic decline in rural and agricultural populations.[8] The proportion of the Spanish population living in towns of 5,000 or fewer declined from 71 per cent to 29 percent.[9] During the same period, the population employed in agriculture fell from approximately 66 per cent in 1900 to 5 percent in 2001.[10] Thus, the existence of large, depopulated regions, particularly rural areas, has become a serious socio-economic problem in modern Spain. Depopulation poses a severe threat to local economies, not only limiting the opportunities for economic growth and complicating the provision of public services, but also causing environmental problems and endangering the very existence of villages.[11]

This paper analyzes whether twentieth century irrigation projects in Spain have achieved one of their main objectives, which is to reduce rural population decline. This issue has been widely debated in political and academic forums.[12] Despite the intensity of the debate, however, there is no great consensus. Furthermore, only a few studies have produced quantitative estimates and comparisons. Irrigation projects in the north-eastern province of Huesca have received particular attention.[13] José María de Ureña has estimated population growth for 122 villages (some of them located in the adjacent province of Lérida) between 1920 and 1975, and Angel Paniagua has done the same for selected villages between 1940 and 1991.[14] Both authors concur that population in irrigated areas grew during early peaks in irrigation activity, but that growth was often minor and always short-lived. Other studies analyzing shorter periods (less than 25 years) during the second half of the twentieth century show similar results.[15]

This paper makes two contributions. First, we compare the evolution of population in two of the earliest and most ambitious irrigation projects in Spain, the *Riegos del Alto Aragón* (Upper Aragon Irrigation System) and *the Canal de Aragón y Cataluña* (Aragon and Catalonia Canal System), both located in the Ebro basin. Second, we consider an entire century.[16] This long-run approach is crucial, because time is required for the effects of irrigation to become apparent; the effects of irrigation initiatives on population may be long delayed.

The paper is organised in six sections. First, we show that the idea of introducing irrigation to sustain rural populations has persisted over time, at least in the inland regions of Spain, although it has been adapted to changes in the economic and social context. In the second section, we describe the two irrigation projects; the third section discusses the sources used and the methodology adopted. In the following two sections, we show that the evolution of population in each of the two projects differs substantially. We also analyze the

factors that caused or prevented population growth. We argue that financial, economic and environmental constraints were significant, but that political and geographical factors have played a major role. Thus, in a context of poor agriculture and inequality of access to land, irrigation projects were implemented as politically-acceptable substitutes for more ambitious agrarian reforms. As has been argued with regard to developing countries, however, 'the evidence suggests that land settlement programmes alone cannot be expected to solve agrarian problems'.[17] Proximity and good access to markets are key factors in understanding the demographic success of irrigation projects. The paper ends with a review of the main conclusions.

## Irrigated agriculture as a response to population decline in rural Spain

Irrigation techniques have been used in Spain since Roman times.[18] Large irrigation projects, sometimes as part of no less ambitious fluvial transportation plans, appeared in the late-eighteenth and the earliest years of the nineteenth centuries.[19] However, lack of sufficient private capital, technological difficulties, and the minor role played by the state in the largely unregulated economy of nineteenth-century Spain, delayed construction of large-scale irrigation projects until the twentieth century.[20] The construction of the new hydrological infrastructure was not possible without the financial support of a state that had become readier to intervene. Behind this turn-of-the-century shift in irrigation policy were the ideas of the Regenerationist movement.[21]

Regenerationists stressed the environmental difficulties facing Spanish agriculture.[22] They referred to poor soils and climate conditions, and water supply problems such as evaporation, floods, and scarce, irregular rainfall.[23] They saw hydraulic policy, particularly irrigation, as a tool to overcome these environmental constraints.[24] State intervention in water issues, furthermore, was seen as a solution to economic and social problems in rural Spain, such as poverty, inequality of access to land, social conflict, and migration.[25]

Regenerationism's call for state intervention gained much attention during the end-of-century agricultural depression, as the integration of the world economy and competition from the New World put pressure on European farming.[26] Both rural-to-urban migration and emigration to Latin America and North Africa accelerated in Spain from the end of the nineteenth century to the early 1930s.[27] Lucas Mallada, one of the first and leading Regenerationists, pointed out the weakness of unirrigated agriculture and its inability to retain the local population.[28] The idea of irrigation as a prophylactic against migration was

defended enthusiastically by Joaquín Costa, the most influential Regenerationist, particularly in his celebrated work *Oligarquía y Caciquismo* (Oligarchy and Bossism).[29] Irrigation, according to Costa, could sustain or augment employment requirements by increasing crop areas and yields, and by substituting labour intensive crops, such as fruit, vegetables and forage plants (which enabled the maintenance of livestock), for cereals.[30]

The first national Hydraulic Plan was adopted in 1902. However, lack of public (and private) funds, technical problems, inadequate planning and the failure of different branches of government to cooperate with one other delayed the execution of many projects.[31] Hydraulic policy became more integrated with regional interests during the 1920s, when the *Confederaciones Hidrográficas* (River Authorities) were created. Some of the most important projects took shape in this decade. In 1933, a new and more comprehensive Hydraulic Plan was enacted. Manuel Lorenzo Pardo, the engineer who directed the plan, identified the retention of the rural population as one of the main goals of these efforts.[32] The hydraulic plan also conceived of irrigation as a means to facilitate rural colonization.[33] However, such colonization programs, debated in Spain since the end of the eighteenth century, did not begin until the 1950s.

In the years following the Spanish civil war (1936-1939), the Franco dictatorship became concerned about water policy. The main elements of the national hydraulic infrastructure, comprising water regulation schemes (basically dams) and irrigation projects, were built between 1950 and the 1970s.[34] The new hydraulic plan of 1940 adopted the main population objectives and tools of the two former plans with minor changes.[35] The state also tried to foster the irrigation of colonized lands with financial and technical assistance, but pursued a conservative option of 'land settlement' rather than promoting thorough-going 'agrarian reform'.[36] As conceived before the civil war, agrarian reform implied some kind of land confiscation and redistribution. Land settlement, by contrast, did not require change of ownership, since it was based on the voluntary offer of land by owners. The early colonization efforts faced serious difficulties obtaining private land for settlement, and, as a result, the extent of irrigation remained modest. The law was reformed in 1946, permitting confiscation, and compensation, under certain conditions. However, the expansion of irrigation in the 1950s and the 1960s took place in a different economic context.

As Spain opened up to trade in the early 1950s, economic policy changed, transforming the inward-looking and categorically unsuccessful development model that had characterized the early years of the regime. Spain underwent an intense process of economic growth,

accompanied by industrialization and urbanization, especially in the 1960s.[37] These developments encouraged the design of new objectives for irrigation policy, which echoed the former intend to maintain the rural population. Despite fascist rhetoric about rural life and values, the recently founded *Instituto Nacional de Colonización* (National Colonization Institute, 1939) did little to provide landless peasants with irrigated land.[38] Certainly, the main objective of many land-settlement programs was to stabilize the rural population. According to one estimate, 44 per cent of land-settlement programs referred to the potential demographic impact of irrigation.[39] The *Instituto* tended to favour the interests of (often large) landowners, whose economic and political hegemony had been threatened in the early 1930s.[40] Although scholars debate the figures, the number of settlers was probably in the range of 15,000-25,000, all in all a fairly low figure.[41] Evidence for specific irrigation programs also points to limited demographic effects.[42] On the other hand, the development of hydroelectric infrastructure, a key condition for economic and industrial growth, as well as the increase in agricultural output and productivity, based on irrigation, became priorities for water policy.[43]

Economic expansion and the new industry-oriented policy model had a clear impact on rural areas. From the 1950s onwards, agriculture, now much more mechanized, became a source of unskilled labour for both the domestic and the international market.[44] In comparison with earlier and later periods, the 1960s were the high point of unskilled migration from rural areas to industrial and urban destinations.[45]

The territorial reorganization of the state after the end of the dictatorship (1975) implied regional decentralization of irrigation policies, which also had to be adapted to the European Common Agricultural Policy and the Regional Development Programmes after Spain's accession to the European Union in 1986. However, agriculture was no longer a driver of economic growth in the advanced European countries. The objectives of European and Spanish rural policy were reoriented from production to maintaining the population and improving living standards.[46] This change in orientation was included in the Spanish Water Act of 1985 and other water policy plans during the 1990s.

A number of geographers and other social scientists have pointed out that a more exhaustive territorial examination on the part of authorities would have been appropriate in a context of acute rural depopulation in some areas from the 1950s onwards.[47] The main debate concerning water policy in recent times, in fact, has been over the transfer of water from the north-eastern Ebro basin to the southern coastal regions, which have followed a

growth strategy that has been heavily based on urban growth, tourist resorts and water-intensive agricultural production in recent decades. In the preliminary inquiries leading up to the latest Hydraulic Plan of 2000 (now stalled), experts advising on socio-economic matters warned the authorities that the relocation of key resources like water from depopulated areas to developed regions could aggravate territorial imbalances.[48]

Irrigation still has a role to play in sustaining rural populations and promoting balanced territorial development in inland Spain, according to a number of scholars.[49] The current minister of Agriculture, Elena Espinosa too has said that 'irrigated agriculture is [a key factor] in fixing population in the countryside'.[50] Aragon is probably the region in which this position is most widely accepted. This is, of course, where one of the case studies analyzed here, the *Riegos del Alto Aragón,* is located. The *Canal de Aragón y Cataluña* project is also partly in Aragon. It is also a region that has suffered intense rural depopulation, that began in the late nineteenth century and accelerated in the second half of the twentieth century.[51] The demographic losses of two of its provinces, Huesca and Teruel, were among the greatest for the whole of Spain in the period, and population growth in Aragon's third province, Zaragoza, has been almost insignificant beyond the capital city.[52] Various geographers, economists and sociologists have argued that a well-designed irrigation policy could help sustain rural population in this region.[53] César Trillo, the president of the *Riegos del Alto Aragón*, has also demanded more irrigation to prevent out-migration and to keep people on the land.[54]

**Two major irrigation projects in the Ebro Basin**

Almost the whole of the *Riegos del Alto Aragón* irrigation system (hereafter RAA) and 60 per cent of the *Canal de Aragón y Cataluña* system (hereafter CAC) are located in the province of Huesca (Aragon) [Fig. 1].[55] The remaining 40 per cent of the CAC is in the neighbouring province of Lérida (Catalonia), and a very small part of the RAA is in the province of Zaragoza (Aragon). Both systems lie in the Ebro Basin, which cuts right across the northeast of the Iberian Peninsula. The area under the influence of the RAA is located in the north part of the basin, between two affluents of the Ebro (the Gállego and Cinca rivers), and the CAC occupies southern parts of the basin, irrigated by two Pyrenean rivers (the Ésera and Noguera Ribagorzana).

Average annual precipitation in both systems is around 400 mm, and rainfall is highly irregular, whether measured on an annual or monthly basis.[56] Frequent extremely dry years

and summer droughts occur, when the water requirements for some crops are higher than can be met from the available precipitation. Furthermore, dendroclimatic reconstructions (based on tree rings) for the period 1500-2000 suggest that annual precipitation decreased in the second half of the twentieth century.[57] Projections, although tentative, point to a further decline and even greater irregularity.[58]

[Figure 1]

The pace of infrastructure construction differed for each project, as shown in Table 1. Significant work in, and expansion of the RAA continued through the twentieth century, but the CAA was largely completed in the 1930s. The main difference between irrigated and non-irrigated lands lies in yields. A lack of systematic data makes it impossible to calibrate the improvement in yield produced by the irrigation schemes. However, data from the province of Huesca for the late 1980s show that yields from cereals irrigated land were 4.4 times higher than those from unirrigated areas. Fruit grown on irrigated land in the 1960s in the provinces of Huesca and Lérida were almost six times greater than those from unirrigated orchards.[59]

[Table 1]

**Data sources and methodology**

Population Census data, which report *total* population at the village level every ten years, have been used for both the irrigated and non-irrigated areas of RAA and the CAC. In each irrigation system, we chose villages in which the population remained below 10,000 inhabitants throughout the twentieth century in order to avoid the inclusion of urban areas. Villages are considered to be 'irrigated' if more than 25 per cent of their cultivated land (in 1981 in the province of Huesca, and 2001 in the province of Lerida) was irrigated. Among irrigated villages, we distinguish between those in which 25 to 75 per cent of all cultivated land is irrigated and those in which more than 75 per cent of the cultivated area is irrigated. On the other hand, a village is considered to be 'non-irrigated' if the irrigated area represented less than 10 per cent of the total cultivated area in the same periods.[60]

The chosen thresholds are somewhat arbitrary, particularly with regard to the sharp distinction between irrigated and non-irrigated villages. In our analysis, we drop villages in which 10 to 25 per cent of all cultivated land is irrigated. However, the literature does not offer any clear guidance on this issue. Our criterion that at least a quarter of cultivated land be irrigated ensures that irrigation has a significant impact on the local economy. Likewise, it seems reasonable to treat a village as 'non-irrigated' if the irrigated area does not account for a minimum 10 per cent of total cultivated land.[61] Table 2 reports descriptive statistics for each group of villages.[62] In the case of the CAC, we also distinguish between villages located in the provinces of Huesca and Lerida, because of the substantial differences in their demographic evolution, discussed below.

[Table 2]

Because Spanish statistics do not provide village-level data for the population directly or indirectly employed in the predominant agricultural sector until very recent times, this paper focuses on *total* population in rural areas. We believe this is still very useful. As we argue below, one of the keys to the success of irrigation programmes has been their connections to post-primary economic activities (*forward linkages*), such as agro-industry, and to export-led strategies. These employment opportunities, however, are not properly reflected in the agricultural figures provided by the census data. As shown in Table 3, village-level data on the percentage of the active population involved in agriculture, based on recent censuses, suggest that differences between the areas studied are not large, especially if we also take into account the provincial totals, which are clearly lower. Differences between the areas under study narrowed further at the beginning of the twenty-first century. As we show below, there are substantial differences between the economic structure of irrigated and non-irrigated areas, as well as between different irrigated areas.

[Table 3]

To compare the year-by-year growth of total population in irrigated and non-irrigated villages, we consider the percent change in compound annual growth (the geometric average growth rate) between selected dates. We also consider the percentage change in compound annual growth for the provinces of Huesca and Lérida, which is used as a reference. The closest (census) years to the start of infrastructure works are taken as baseline years: 1910 and 1900 for RAA and CAC, respectively. The second benchmark is 1930, the census year

prior to the outbreak of the Spanish civil war (1936). Our next points of reference are 1950 and 1981, the census years that approximate the beginning and the end of the most intense period of structural change and rural-urban migration in Spain. The study period ends in 2001, when the last available census was carried out. Aside from population data, this paper also makes use of secondary sources to supplement the information obtained from the censuses.

**The development of Riegos del Alto Aragón**

The earliest irrigation projects in this area were initiated in the middle of the nineteenth century, but the idea of irrigating the area did not seize the attentions of social reformers and local politicians until the end of nineteenth century when the impact of the agricultural depression dramatically reduced exports of cereals, the main crop in the area.[63] Wine production, the second most important crop, also fell because of rising French trade protectionism and the spread of the *phylloxera* plague to the province of Huesca.[64] As working and living conditions in rural Huesca became difficult in a context of extreme inequality of access to land, even small landowners had to supplement their income with seasonal work on larger estates.[65] Irrigation was expected to increase the number of days worked per year, not only by extending cultivated land and introducing new crops, but also by providing jobs in infrastructure works.[66] Fear of change, and preservation of the status quo, however, ensured that early support from landowners was by no means enthusiastic or unanimous.[67] It has also been argued that politicians mainly supported the CAC project, which had greater economic potential, and this may have delayed works in other parts of the province.[68]

Civil engineers did not finalise their designs for the project until 1911, and they were not approved by the state until 1915.[69] Because of high costs, the pace of construction was slow during the following two decades, as shown in Table 1. At the outbreak of the civil war, in 1936, only 10,000 of the planned 300,000 hectares had been irrigated. Deficiencies in the infrastructure meant that a significant part of this irrigation was temporary.[70] Even large-scale irrigation (more than 75 per cent of total cultivated land) was unable to offset the enduring consequences of the agricultural depression, as shown in Table 4. The already difficult agricultural labour market, in fact, worsened during the early decades of the twentieth century because of falling prices and limited access to credit. As a result, many agricultural labourers and small landowners migrated during this period.[71]

[Table 4]

Intended to increase the number of irrigated hectares, the project was included in the hydraulic plan of 1939. New infrastructure works to expand the area under permanent irrigation may have slowed depopulation in largely irrigated villages [Table 4]. However, the extent of irrigated land was still modest by the early 1950s. Moreover, half the area under irrigation was used in the production of cereals, a low-value crop.[72]

The construction of main and subsidiary hydraulic works accelerated between 1950 and 1981, but deficiencies in the implementation of irrigation, as well as changes in the local (and national) agricultural sector and the economy as a whole over these decades meant that only large-scale irrigation projects achieved any significant effects [Table 4]. First, the lack of sufficient water and other environmental constraints, such as the poor quality of soils, limited the introduction of crops other than cereals.[73] The province of Huesca, moreover, became one of the main sources of basic food supply in the Franco dictatorship's agrarian policy.[74] In short, irrigation in the RAA was used, in this period, to ensure regular harvests of the same main low-value crops (cereals) as were grown on non-irrigated lands. However, specialization in such a non labour-intensive crop was a strong incentive for mechanization when this option became available to a number of landowners.[75] In a context of growing opportunities in urban areas, a vicious circle of mechanization and out-migration developed.

The strong economic growth and structural change achieved in Spain in the 1950s and 1960s generated abundant, stable jobs and relatively high wages in nearby urban areas such as Zaragoza and Barcelona. Migrations from rural Huesca intensified as a result [Table 4].[76] The early migrants were mainly agricultural labourers. Scholars have argued that this was the consequence of the Dictatorship's irrigation policy, which did not seriously consider limitations on access to land.[77] Certainly, many irrigation policies in the 1950s and 1960s aimed at increasing agricultural output and ensuring the availability of water for hydroelectricity generation, rather than at providing irrigated land for landless peasants. Moreover, early migration meant that the price of labour increased, which reinforced incentives to mechanize. This provoked further out-migration of small landowners, who faced difficulties both in hiring seasonal labour and in being hired in larger estates.[78] The intense out-migration from the area during this period included social groups other than small landowners, such as the labourers employed on hydraulic infrastructure projects.[79]

Out-migration slowed in the late 1970s, but the population in rural Huesca kept falling during the 1980s and 1990s.[80] This has been the case even in irrigated villages [Table 4]. Scholars agree that age- and sex-selection in previous migrations has contributed greatly to the erosion of demographic stability in Huesca and neighbouring provinces in recent decades.[81] Data for the RAA area at the end of the century reveal strong imbalances in sex and age ratios in both irrigated and non-irrigated villages.[82] The predominance of indivisible inheritance encouraged non-inheritors to migrate, which contributed to the ageing of rural society.[83] Meanwhile, the area has continued to specialise in low labour-intensive crops. The importance of cereals declined during the 1980s, when new hydraulic works allowed the introduction of higher value crops such as maize, rice and forage. As in the case of cereals, however, the cultivation of these crops is highly mechanized and the demand for labour has remained relatively low.[84]

The emergence of the agro-food industry may also have played an important role in retaining population in irrigated areas by exploiting potential complementarities between the local production, transformation and distribution of high-value crops. Sugar beet was once a high-value, labour-intensive irrigated crop in the province of Huesca and, indeed, Aragon as a whole.[85] However, production in the region began to decline in the mid-1920s and shrank fast from the 1960s onwards, because higher returns could be obtained in other parts of Spain.[86] The switch to other alternatives in the agro-food industry has been difficult to consolidate in the area under the influence of the RAA. An intense specialization in the promising but then failed beet crop and the existence of comparatively high labour costs, have constrained the development of other agro-food industries, such as canning and cattle.[87]

**The development of the Canal de Aragón y Cataluña**

Although private projects to irrigate this area date back to the sixteenth century, lack of capital delayed the development of a major irrigation project in this part of the Ebro basin until 1896, when the state undertook construction.[88] Again, it was the impact of the agricultural depression on the profitability of cereals, problems affecting the production and export of wine, and the frequency of droughts that accelerated the process.[89] As in the case of the RAA, politicians and social reformers regarded irrigation as a way to reduce out-migration in a context of poverty and inequality of access to land.[90] In contrast with RAA, however, expectations created through trade with nearby urban and industrial areas may have encouraged the construction of hydraulic infrastructure, and its subsequent expansion.[91]

The demands of landowners, farmers and traders coincided with support for irrigation in the area. As a result, construction of hydraulic infrastructure in the CAA began earlier and was more intense than in the RAA, even though the economies of both areas (and provinces) shared relatively similar interests.[92]

The first part of the project was opened in 1906, and work proceeded rapidly. Three decades later, 83 per cent of the total was irrigated, as shown in Table 1. In the early decades of the twentieth century irrigated villages benefited from a process of market integration, in which agricultural areas acted as food suppliers to the growing industrial towns and cities in the northeast, one of the most advanced parts of Spain at that time. Exports to the metropolitan area of Barcelona and to medium-sized towns like Zaragoza, Lérida, Monzón, Binéfar and Almacellas intensified considerably before the civil war.[93] Population in irrigated villages increased during this period, as shown in Table 5. Trade was based on cereals, and, in the early 1930s, this crop still accounted for 71 per cent of total irrigated land. The early hydraulic infrastructure, in fact, was designed mainly to facilitate cereals production, which does not require as much water as other crops.

[Table 5]

A shift in cropping patterns, beginning in the late 1910s, may have contributed to population growth in largely irrigated villages and particularly in the province of Lérida [Table 5]. Although cereals remained the main crop in the province of Huesca for decades, labour-intensive and more profitable crops, such as forage and later maize, fruit and vegetables, were gradually introduced in irrigated villages in the province of Lérida.[94] Better railway and road infrastructures facilitated exports, as in the case of forage sold to the city of Barcelona during World War I. New hydraulic works in the 1920s also permitted a greater intensification in land use. Agricultural cooperatives encouraged this process, spreading technical information and demanding the rapid construction of hydraulic infrastructure and better communications.[95]

Irrigation infrastructure was almost complete by the middle of the twentieth century. Increasingly thereafter valuable crops, particularly fruit and maize, replaced cereals in the province of Lérida.[96] Population in irrigated villages in this area increased during the period 1950-1981 [Table 5].[97] In a period of rapid urbanization and industrialization, during which there important changes in the diets of Spaniards, the demand for new crops grew in the cities of Lérida, Barcelona and Zaragoza. Meanwhile, technological innovations, such as

chemical fertilizers and new crop varieties, made it possible to respond by increasing productivity.[98] Although large estates did not disappear, agricultural production in irrigated areas was largely based on small- and medium-sized family-owned farms.[99] Family labour was supplemented with wage-labour on large estates or, as we will see below, in agro-industries. In this regard, it has been argued that small and medium-sized farmers adapted successfully to changing demand patterns through labour intensification, specialization and integration with the export sector and the agro industry.[100] Specialization in labour-intensive crops, furthermore, hindered the introduction of mass mechanization. This structure helped raise family incomes in rural areas and, in the end, reduced rural-urban migration in the 1960s and 1970s.[101]

Differences between irrigated villages in Lérida and Huesca widened from the 1980s onwards [Table 5]. The growing importance of agro-food industries in Lérida is an important factor in understanding population growth in a significant part of the irrigated areas in the province in recent decades. For example, canning and cattle industries developed strongly in the province of Lérida from the 1960s onwards.[102] Farmers in irrigated villages, meanwhile, provided the necessary inputs. Early specialization in forage plants, on the one hand, allowed irrigated areas to feed the local cattle industry, a main centre for the production of pig and bovine meat in Spain.[103] The later introduction of fruit (apples, pears and peaches) and vegetables meant irrigated villages were also able to become the suppliers for a growing canning industry.[104] Again, it was the existence of a well-functioning hydraulic infrastructure, experience in the cultivation of high value crops, proximity to urban markets, and relatively high population densities, that allowed irrigated villages to become the basis of the new development strategy.[105]

## Conclusions

This study has analyzed the demographic impact of two of the earliest and most important irrigation projects in Spain. Differences between the two outcomes are considerable. The percent change in the compound annual growth rate in the population of irrigated villages in the area of *Riegos del Alto Aragón* in the twentieth century is slightly less than zero in the best case [Table 4]. By contrast, the rate of population growth in irrigated villages located in the area of the *Canal de Aragón y Cataluña*, particularly the section located in the Catalan province of Lérida, has exceeded of the provinces of Huesca and Lérida, as a whole, whether or not urban centres are included [Table 5]. Different rates

of population growth led to different population densities, as shown in Figures 2 and 3. At the beginning of the twenty-first century, population density in irrigated areas on the Catalan side of the *Canal de Aragón y Cataluña* is outstandingly high [Fig. 3], while population density in irrigated areas located in the *Riegos del Alto Aragón* area is similar to or lower than what it was a century ago [Figs. 2 and 3].

[Figure 2]

[Figure 3]

Initial costs and discord contributed to the delay in the construction of hydraulic works in the *Riegos del Alto Aragón*. A further problem was that even the parts of the hydraulic network that were completed had only limited impact on agricultural performance, since irrigation was often impermanent and environmental constraints limited the introduction of crops other than cereals. Construction of more and better infrastructure accelerated in the second half of the twentieth century, precisely when the agricultural sector lost its role as a driver of economic growth, and rural out-migration increased dramatically. In this context, the area of the *Riegos del Alto Aragón* was particularly exposed, because of its specialization in a low-value crop (cereals) susceptible to intense mechanization, and the unresolved problem of access to land.

The chain of interactions has had more positive effects in the case of the *Canal de Aragón y Cataluña*, particularly in its Catalan section. The basic infrastructure was almost finished by the 1930s. This meant that some areas were well irrigated when agriculture was still the most important economic sector in Spain. Commercial expectations played an important role here. Since the beginning of the twentieth century, different social groups have coincided in demanding better irrigation and transport infrastructure, in order to become the main suppliers of the nearby and expanding urban and industrial centres. Irrigated villages in this area responded quickly to changes in demand. Exports of cereals gave way, first, to exports of more valuable crops such as forage and fruit and, then, to the consolidation of a local agro-industry. Furthermore, specialization in labour-intensive crops helped slow rural out-migration when it was at its peak between approximately 1950 and 1980.

As has been argued by leading scholars, these results seem to confirm that the hope that irrigation projects might solve demographic problems should be treated with caution and on

a case-by-case basis.[106] Irrigation projects may have contributed to population growth in certain historical contexts, especially when the agricultural sector played a major role in the economy. Even in the successful case of *Canal de Aragón y Cataluña* studied here, however, the capacity to retain rural population may have lost part of its strength in recent decades [Table 5]. An important issue here, in any case, is what is produced on irrigated lands, and where this production will be sold. Further options in rural policy, such as tourism and the conservation of nature, may also be considered in particular situations - even more so if we consider that greater water scarcity appears to be a possible feature of future scenarios.

## Notes

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[4] A. S. Oberay, *Migration, Urbanisation and Development*, Geneva, 1987; F. I. Ude and A. T. Salau, Rural development planning and labour requirements in Nigeria: a case study of small-scale irrigation projects, *Applied Geography* 7 (1987), 333-342; B. Martens, *Economic Development that Lasts: Labour-Intensive Irrigation Projects in Nepal and Tanzania*, Geneva, 1988, 47-49 and 145-146; A. S. Oberay, *Assessing the demographic impact of development projects. Conceptual, methodological and policy issues*, London, 1992, 29-37; T. Brabben, C. Angood, J. Skutsch and L. Smith, *Irrigation can sustain rural livelihoods: Evidence from Bangladesh and Nepal*, London, 2004; Y. Tsur, T. Roe, R. Doukkali and A. Dinar, *Pricing Irrigation Water. Principles and Cases from Developing Countries*, Washington, DC, 2004.

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[9] X. Tafunell, Urbanización y vivienda, in A. Carreras and X. Tafunell (Eds), *Estadísticas Históricas de España. Siglos XIX y XX,* Vol. I, Madrid, 2005, 455-499.

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[13] For a discussion of the importance of irrigation in the province of Huesca in relation to the national total, see V. Pinilla, The development of irrigated agriculture in twentieth-century Spain: a case study of the Ebro basin, *Agricultural History Review* 54 (2006) 122-141.

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[16] In their valuable book on Riegos del Alto Aragón, *Agua, tierra y paisaje. Complejidad y diversidad en el territorio de Riegos del Alto Aragón*, Zaragoza, 2003, 93, J. M. García-Ruiz, T. Lasanta and F. Biarge include a graph showing the long-run evolution of population for irrigated and non-irrigated areas (index numbers). The baseline year, however, refers to 1900, well before the beginning of hydraulic works (1915). The authors do not report figures, nor do they explain criteria defining irrigated and non-irrigated areas (number of inhabitants and extent of irrigation in each village, changes over time, creation of new colonization villages, etc.). M. A. Bouzada, S. Elfkih and M. L. Feijoo, El regadío del Alto Aragón como factor de desarrollo en la comarca de los Monegros, *Economía Aragonesa* 34 (2007) 103-118, follow a similar approach to the study of twelve villages located in the area under the influence of the Riegos del Alto Aragón.

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[18] A. Gil-Olcina and A. Morales-Gil (Eds), *Hitos históricos de los regadíos españoles*, 1992, Madrid; C. Barciela and J. Melgarejo (Eds), *El agua en la historia de España*, Alicante, 2000.

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[27] B. Sánchez-Alonso, Those Who Left and Those Who Stayed Behind: Explaining Emigration from the Regions of Spain, 1880-1914, *The Journal of Economic History* 60 (2000) 730-755; J. Silvestre, Internal migrations in Spain, 1877-1930, *European Review of Economic History* 9 (2005) 233-265.

[28] S. L. Driever, Lucas Mallada, 41.

[29] J. Costa*, Oligarquía y Caciquismo*, Madrid**.**

[30] J. Costa, *Política Hidráulica. Misión social de los regadíos*, Madrid, 1911, 6-8.

[31] J. I. Jiménez-Blanco, Introducción, in R. Garrabou, C. Barciela and J. I. Jiménez-Blanco (Eds), *Historia agraria de la España contemporánea. Vol. III, El fin de la agricultura tradicional (1900-1960)*, Barcelona, 1986, 9-141, 87-89; N. Ortega, El Plan Nacional, 346-348; J. Simpson, La agricultura española, 181-183; M. González de Molina, Condicionamientos ambientales.

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[33] F. J. Monclús and J. L. Oyón, De la colonización interior a la colonización integral (1900-1936). Génesis y destino de una reforma agraria técnica, in R. Garrabou, C. Barciela and J. I. Jiménez-Blanco (Eds), *Historia* agraria, 347-380; A. Paniagua, *Repercusiones sociodemográficas de la política de colonización durante el siglo XIX y el primer tercio del XX*, Madrid, 1992, 91-103.

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*Geographers* 32 (2007) 9-28. See also E. Fernández-Clemente, *Un siglo de obras hidráulicas en España*, Zaragoza, 2000; and J. Melgarejo, De la política hidráulica a la planificación hidrológica. Un siglo de intervención del Estado, in C. Barciela and J. Melgarejo (Eds), *El agua en la historia*, 275-321.

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[38] E. Swyngedouw, *Technonatural revolutions*, 15-16; A. Paniagua and V. Rodríguez, Agrarian Reform, 99-101; N. Ortega, Algunas orientaciones; C. Barciela and M. I. López-Ortiz, La política de colonización, 351-353.

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[41] See A. Paniagua and V. Rodríguez, Agrarian Reform, 95-96; E. Swyngedouw, *Technonatural revolutions*, 16, and the works cited therein.

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[56] P. Ibarra, F. Pérez, I. Rabanaque and V. Rodrigo, Condicionantes ecológicos para el desarrollo de la agricultura, in V. Pinilla (Ed.), *Gestión y usos del agua en la cuenca del Ebro en el siglo XX*, Zaragoza, 2008, 39-96.

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[60] In the case of the RAA, we did not consider the sixteen newly-colonized villages established from the 1950s onwards. We deal with this issue below.

[61] The number of villages excluded from the analysis is eight for RAA, and five for CAA. Initially, we considered including them in the non-irrigated group, but some doubts arose about their precise classification. Preliminary estimates including these thirteen villages show similar results.

[62] The complete list of villages is available from the authors upon request.

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[67] A. Sabio, La incidencia del regadío, 144-192.

[68] C. Frias, Los regadíos en el siglo XIX, 191-192.

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[74] A. Sabio, Herencia de preguerra, fachada de postguerra: regadío y obras públicas en Huesca, 1938-1960, en C. Laliena (Ed.), *Agua y progreso social*, 215-250; E. Clar, Del cereal alimento al cereal pienso. Historia y balance de un intento de autosuficiencia ganadera: 1967-1972, *Historia Agraria* 37 (2005) 513-544.

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[76] J. Recaño, Una aproximación a la dinámica demográfica y territorial de la emigración aragonesa en el siglo XX, in Gobierno de Aragón (Ed.), *Despoblación y políticas públicas en Aragón*, Zaragoza, 2002, 51-83; M. I. Ayuda, V. Pinilla and L. A. Sáez, La despoblación en Aragón.

[77] J. I. Jiménez-Blanco, Introducción, in R. Garrabou, C. Barciela and J. I. Jiménez-Blanco (Eds), *Historia agraria de la España contemporánea*, 9-141; Paniagua, *Población y colonización*.

[78] J. M. Naredo, *La evolución de la agricultura*, 203-206; A. Sabio, La incidencia del regadío, 185-186.

[79] A. Sabio, La incidencia del regadío, 171. The demographic evolution of the sixteen colonization villages established between 1946 and 1968 was very negative. In this regard, see A. M. Martínez-Cordón, Los poblados de colonización en el sistema de Riegos Bardenas-Alto Aragón, *Geographicalia* 25 (1988) 145-155; and J. M. García-Ruiz, T. Lasanta and F. Biarge, Agua, tierra y paisaje, 84-90.

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## Tables

Table 1.

Irrigated areas, selected dates

| Riegos del Alto Aragón | | | Canal de Aragón y Cataluña | | |
|---|---|---|---|---|---|
| Year | Hectares | Percentage of final size | Year | Hectares | Percentage of final size |
| 1936 | 10,000 | 8.5 | 1937 | 81,807 | 83.1 |
| 1952 | 30,167 | 25.6 | | | |
| 1980 | 70,731 | 59.9 | | | |
| 2001 | 118,000 | 100 | 2002 | 98,400 | 100 |

Sources: For Riegos del Alto Aragón, L. Germán (Ed.), *Riegos del Alto Aragón. Impacto económico y social*, Huesca, 2006; for Canal de Aragón y Cataluña, J. Mateu and F. García-Pascual, *Conmemoración del Centenario del Canal de Aragón y Cataluña, 1906-2006*, Zaragoza, 2004.

Table 2.

Irrigated and non-irrigated villages

| Project and irrigated area as percentage of total cultivated land | Number of villages | Average population, baseline year | Average population, 2001 |
|---|---|---|---|
| Riegos del Alto Aragón | | | |
| More than 75 per cent | 9 | 579 | 575 |
| Between 25 and 75 per cent | 15 | 1249 | 880 |
| Less than 10 per cent | 12 | 839 | 310 |
| Canal de Aragón y Cataluña | | | |
| *Huesca (Aragón)* | | | |
| More than 75 per cent | 10 | 1347 | 2245 |
| Between 25 and 75 per cent | 9 | 1312 | 804 |
| Less than 10 per cent | 13 | 1134 | 367 |
| *Lérida (Cataluña)* | | | |
| More than 75 per cent | 7 | 1274 | 2837 |
| Between 25 and 75 per cent | 6 | 1696 | 2352 |
| Less than 10 per cent | 9 | 973 | 484 |

Note: Baseline years are 1910 for Riegos del Alto Aragón and 1900 for Canal de Aragón y Cataluña.

Sources: For population data, Censuses of Population, various years, Madrid; For percentage of irrigated land, A. Ibarz, *El canal d'Aragó y Catalunya: Cent anys d'esperança i de progrés*, Huesca, 2005, and unpublished data provided by the Regional Government of Aragón (*Gobierno de Aragón*), Department of Agriculture.

Table 3.

Percentage of the active population involved in agriculture

| Project and irrigated area as percentage of total cultivated land | 1981 | 2001 |
|---|---|---|
| Riegos del Alto Aragón (Huesca) | | |
| More than 75 per cent | 58 | 26 |
| Between 25 and 75 per cent | 53 | 26 |
| Less than 10 per cent | 51 | 29 |
| Canal de Aragón y Cataluña (Huesca) | | |
| More than 75 per cent | 55 | 28 |
| Between 25 and 75 per cent | 55 | 23 |
| Less than 10 per cent | 66 | 28 |
| Canal de Aragón y Cataluña (Lérida) | | |
| More than 75 per cent | 47 | 22 |
| Between 25 and 75 per cent | 49 | 21 |
| Less than 10 per cent | 64 | 31 |
| Provinces | | |
| Huesca | 29 | 11 |
| Lérida | 29 | 9 |

Source: Censuses of Population, Madrid.

Table 4.

Riegos del Alto Aragón: Percent change in population compound annual growth rate, 1910-2001

| | 1910-1930 | 1930-1950 | 1950-1981 | 1981-2001 | 1910-2001 |
|---|---|---|---|---|---|
| Irrigated area as percentage of total cultivated land (average of villages) | | | | | |
| More than 75 per cent | -0.3 | 0.1 | 0.8 | -1.1 | -0.01 |
| Between 25 and 75 per cent | -0.1 | -0.3 | -0.4 | -0.7 | -0.4 |
| Less than 10 per cent | -0.1 | -1.1 | -1.8 | -0.9 | -1.1 |
| Provinces | | | | | |
| Huesca | -0.1 | -0.1 | -0.2 | -0.3 | -0.2 |
| Huesca, rural | -0.2 | -0.5 | -1.2 | -0.6 | -0.7 |

Note: The compound annual growth rate, or the geometric average growth rate, represents the year-by-year growth rate. It can be explained using the following calculation: Percent change in population compound annual growth rate = [(Ending Date Population /Starting Date Population)$^{1/n}$ – 1] x 100; where n refers to the number of years from start to end. Rural Huesca refers to the average of villages below 10,000 inhabitants.

Source: Censuses of Population, various years, Madrid.

Table 5.

Canal de Aragón y Cataluña: Percent change in population compound annual growth rate, 1900-2001

| | 1900-1930 | 1930-1950 | 1950-1981 | 1981-2001 | 1900-2001 |
|---|---|---|---|---|---|
| Irrigated area as percentage of total cultivated land (average of villages) | | | | | |
| *Huesca (Aragón)* | | | | | |
| More than 75 per cent | 0.8 | 0.8 | 0.3 | -0.2 | 0.5 |
| Between 25 and 75 per cent | 0.1 | -0.1 | -0.1 | -1.0 | -0.6 |
| Less than 10 per cent | -0.5 | -1.1 | -1.8 | -0.9 | -1.2 |
| *Lérida (Cataluña)* | | | | | |
| More than 75 per cent | 0.9 | 0.8 | 0.8 | 0.7 | 0.8 |
| Between 25 and 75 per cent | 0.8 | -0.1 | 0.4 | -0.1 | 0.3 |
| Less than 10 per cent | -0.1 | -0.6 | -1.3 | -0.7 | -0.7 |
| Provinces | | | | | |
| Huesca | -0.03 | -0.1 | -0.2 | -0.3 | -0.2 |
| Huesca, rural | -0.1 | -0.5 | -1.2 | -0.6 | -0.6 |
| Lérida | 0.5 | 0.2 | 0.3 | 0.1 | 0.3 |
| Lérida, rural | 0.2 | -0.2 | -0.6 | -0.01 | -0.2 |

Note: For the percent change compound annual growth rate, see Table 4. Rural Huesca and rural Lérida refer to the average of villages below 10,000 inhabitants.

Source: Censuses of Population, various years, Madrid.