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Keywords: Yields, Land, Market, Climate.
JEL Classification: N33, N34, N53, N54.

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Explaining wheat yields in eighteenth-century Spain.[1]

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Abstract

From an extensive dataset of wheat yields at municipal level in mid eighteenth-century Spain, a detailed statistical analysis indicates that the differences in wheat yields were mainly a consequence of different natural conditions, and that demand did not have a significant influence. Counterfactual exercises show that improvements in rainfall, altitude or roughness of terrain would have a significant impact on average yields. The paper concludes that, although grain markets in the mid-eighteenth century were well integrated, producers addressed the growing demand not by investing in increasing yields, but by extending the area of cultivated land using the still abundant pastures. The low grain yields in Spain were in part a consequence of the rational behaviour of producers who faced an economic environment characterized by an elastic supply of land.

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1. Introduction

Although the debate concerning the timing and the intensity of the agricultural revolution in Britain is still open in academia, there is little doubt about the benefits that the rest of the economy was able to obtain from increasing agricultural productivity. The role of the primary sector as a supplier of labour for the secondary and tertiary sectors, or as a market for the manufactured goods and services that they provided, is a generally accepted fact. The main drivers of the increases in productivity have also been the subject of an intense debate, with some authors pointing to the importance of market forces as an incentive to improve yields and therefore to increase production (Postel-Vinay, 1991; Wrigley, 1985). Kopsidis and Wolf (2012) also indicated that incentives from the demand side were the key drivers of agricultural productivity in nineteenth-century Prussia. Grain has traditionally been the most important agrarian product in European agriculture. Therefore the study of grain production and yields is basic for an understanding of the mechanisms that allowed countries like England to increase productivity in the way that that they did during the industrial revolution.[2] Although there are several studies about grain yields and their determinants in the countries of north-western Europe, we do not find the equivalent amount of literature in the case of Spain (Brunt, 2004).

In the mid-eighteenth century, grain yields in Spain were clearly disappointing, with an average of 4.7 quintals per hectare. This was far below the levels reached in countries like England, Belgium or France. Authors like O'Brien and Keyder (1978) suggest that the advantage of countries like England is based on more favourable natural conditions, and Spanish economic historians also tend to blame unfavourable natural conditions as the main reason for the low levels of agricultural productivity (Espejo,1879; Llopis, 2002; Tortella, 2003). Brunt (2004), on the other hand, suggests that, in addition to natural conditions, English farmers were able to increase grain yields by intensifying their farming with the introduction of new techniques. We know that the eighteenth century was a period of demographic growth in Spain, and according to Llopis and Sotoca (2005) the integration levels in grain markets in the mid-eighteenth century were higher than was traditionally thought. If that was the case, did Spanish farmers respond in the same way as their English counterparts to the increasing demand? This paper will address this fundamental issue in the light of new quantitative evidence.

As in the rest of Europe, grain was by far the most important crop in Spanish agriculture. It was estimated that, in Castile, more than 80 per cent of the land was often dedicated to the cultivation of cereals (Llopis, 2002, p.28). This paper estimates regional grain yields in mid eighteenth-century Spain, and attempts to explain the forces that affect them. To that end we will use a wide range of variables, from natural conditions such as temperature, rainfall and land quality, to demand-side factors like population density, economic integration and market potential. The first part of the paper presents the sources and the methodology employed to estimate grain yields in 362 municipalities in the Crown of Castile during the early 1750s. The Crown of Castile was the main political entity of Spain, and represents around 80 per cent of her territory. We later quantitatively explore the

[2] Several articles have considered the study of grain yields in Europe. See Allen and O'Grada (1988), Allen (1988), Broadberry et al. (2011), Clark (1991), Chorley (1981), Dejongh (1999), Mironov and A'Hearn (2008), Overton (1979, 1990) or Turner (1982).

variables behind the provincial differences. The analysis shows that natural conditions seem to be the most important factors explaining the different levels of yields, while demand does not play a significant role. Finally, the paper offers an explanation of this result, and suggests that producers responded to the growing demand by increasing the amount of arable land instead of intensifying their existing cultivation.

2. Estimating grain yields in mid eighteenth-century Spain

The source that we used for estimating grain yields at local level is the Catastro de la Ensenada, a survey ordered by King Fernando VI for fiscal purposes. The Catastro was a monumental study that was made possible through the work of around 1,000 judges, 6,000 men and 90,000 local experts whose responsibilities included, among other things, measuring every single piece of land and estimating the wealth and income of every family in more than 14,000 municipalities. The survey was so detailed that it cost more than 40 million reales, an amount that would have been enough to pay an army of around 300,000 professional soldiers for a three month campaign.[3] We used the information contained in the "general answers", which were given in response to a list of forty questions concerning a wide range of geographic, demographic and socio-economic aspects for each municipality.

In order to estimate grain yields in each municipality, we used the information contained in numbers 9, 10 and 12 of the *general answers*. Question 10 asked how land was divided by use in the municipality, and the answers include a detailed description of the areas of each type of land that were used for every product cultivated.[4] Question 12 asked about the average yield of each product that could be reaped depending on the quality of the land. However, this information was not enough to obtain standardised yields, because the units of measurement changed not only between the different regions but also often within the same provinces. In the Crown of Castile and especially in the interior and the south, the fanega was used as a unit of dry volume and a unit of area. However, as we have explained before, the fact that the name of the unit is the same does not guarantee a standardised measurement. For example, in the village of Getafe located in the province of Madrid, one fanega of land contained 3,441 square meters, while in Cenicientos, also located in Madrid, one fanega contained 5,161 square meters. We can also find different units in Madrid where, together with the fanega, we can find the obrada. We also found a wide range of units for measuring capacity; the fanega was the most common unit, although in areas like the north other units such as the ferrado were frequent. In order to standardise the measurements, we used the information for question 9, which offers a precise description of the units of measurement in each municipality and their equivalent in nationwide standard units like the Castilian varas. We transformed all capacity units to quintals and all surface units to hectares, obtaining yields for all the municipalities in quintals per hectare.
To calculate provincial grain yields we followed the methodology set by Bringas (2000), where the final yield in each location is calculated as a weighted average of the yields in

[3] The daily salary of a professional soldier in mid eighteenth-century Spain was set at 52 maravedis or 1.53 reales.

[4] The Catastro normally distinguished between three types of land, first quality (the best), second quality (medium) and third quality (the lowest). The output produced by each type of land in the municipality was reported to the national authorities.

each one of the three types of land (good, medium and bad quality). However, the use of this estimate as a measurement of yields is not entirely accurate. If a province uses all its first quality land to produce fruit, and therefore relies on the second and third quality lands to produce grain, then the average grain yield in the province underestimates the real level of grain yields. Therefore, as a better measurement of yields we decided to use the yield obtained from the first quality lands, since we believe that to be a more precise estimator because it compares yields from the same type of land. In any case, our estimates indicate that the differences between the average yield and the yield from the first quality land are minimal, suggesting that the substitution between different products did not play a significant role and that grain was cultivated all over the country in the same type of land.[5]

The final sample includes 362 municipalities from 33 provinces in the Crown of Castile. The list of municipalities includes both large urban centres and small rural villages, is well spread through the territory and includes a wide variety of locations from municipalities in the mountains to locations at the coast.[6] Therefore we believe that the sample is representative, with a geographical coverage of close to 20 per cent of the territory of the Crown.

3. Factors explaining grain yields

There is a wide range of variables which can affect yields, and which should therefore be taken into account as possible drivers. From the many plausible causes, climate has often been cited as the main reason for the low productivity figures suffered by Spanish agriculture (Carreras and Tafunell, 2003, p.5; Tortella, 2003, p.9). Climatic differences could explain the north/south east geographical pattern, and also why the rankings of the most productive regions hardly changed until the modernisation of the second half of the twentieth century. Brunt (2004) showed that temperature and rainfall play an important role in explaining the differences in grain yields in eighteenth-century England. For example, apart from its obvious role as a nutrient, rain is important because it helps to generate vegetation that can be transformed into compost (Simpson, 1995, p.107). With an average precipitation of 660 mm per year, Spain's rainfall levels are far below those of other European countries such as France with nearly 900 mm or the United Kingdom with more than 1,200 mm.[7] However, the low national average also hides more dramatic differences within the country, with regions in the south where average precipitation does not exceed 300 mm per year.[8]

Unfortunately, provincial climatic records for the eighteenth century are not available. However, and although the climate has changed over time, we have good reason to believe that the regional differences in climatic terms have remained stable. In other words, from time to time the climate in Spain has become drier or wetter, but it has done so consistently over the whole country and therefore the regional differences have remained

[5] The adjusted and unadjusted yields present a correlation of 93%.
[6] See appendix for a detailed description of the sample.
[7] See World Bank Database 2009 (http://data.worldbank.org/).
[8] Instituto Nacional de Estadistica (INE) database INEBase (http://www.ine.es/inebmenu/indice.htm).

stable. We checked the validity of this argument by taking the first reliable weather records that exist for Spain at a provincial level, from the early twentieth century, and comparing them with the latest ones which are available. Figure 1 compares the average rainfall in the 33 provinces of the Crown of Castile in the early twentieth and twenty-first centuries, and shows a strong correlation. Therefore, and although the climate became warmer during the twentieth century, the results prove the argument of stable inter-regional climatic conditions. Different studies have shown that similar regional patterns can also be followed back in time. Estimates of rainfall for Catalonia and Andalusia during the eighteenth century also reveal a strong correlation, proving that although climate changes have affected Spain in the past, the regional disparities remained stable (Barriendos, 2003; Rodrigo, 1999). Other studies like Brunt (2004) accepted the extrapolation of modern meteorological measurements to earlier centuries to measure the effect of climate on grain yields.

[FIGURE 1 AROUND HERE]

The values of the climatic variables used in the regression are an average over the period 1971-2000. There are several reasons for using this modern data. First of all, the first records at provincial level, mentioned above, do not include information for the 33 provinces. Only modern records include meteorological stations in all the provinces and therefore provide information for all of them. Secondly, as we explained above, the differences between provinces did not change over time, and therefore the use of modern data does not significantly change the results. We used the information from the 47 stations run by the Spanish meteorology state agency that are in the territory covered by our study, and the data provided by the Spanish National Meteorological Agency.[9] In order to allocate the most reliable data to each one of our municipalities, we calculated the distance of each of them to each of the stations, and assigned the climate values of the closest station. We introduced the average yearly rainfall (Rainfall) and temperature (Temperature) into our models. Given the lack of precipitation in most of the country, we would expect a positive correlation between yields and rainfall. The case of temperature is not so straightforward. Although a rise of temperature is usually associated with an increase in the growth rate of a plant, after an optimum point is reached further increases of temperature have a negative impact with *rapid declines of reaction rates and cytoplasmic streaming* (Rosenzweig, 1998). For that reason the relationship should be positive until a threshold is reached beyond which increasing temperatures reduce yields.

Another key variable that can explain low yields in Spain is the low quality of the soil. In terms of fertility, most of the terrain of Spain is considered marginal (IIASA, 2002). High altitude is closely correlated with marginal soils, and gradients make the cultivation of land difficult and reduce the yields that can be obtained. With an average altitude of 660 meters, Spain is the second highest country in Europe (coming after Switzerland), a fact that limits the productivity of the soil that is used for agricultural production. Higher altitude is usually associated with marginal lands, and authors like Parry have indicated that the probability of a harvest failure increases with altitude (Parry, 1975). We gathered information about the altitude of the 5,179 municipalities in the Crown of Castile and used

[9] Data obtained from Ministerio de Medio Ambiente (2005).

the average altitude of each municipality (Altitude).[10] We expect to find a negative correlation between the variables, with those municipalities located in areas of higher altitude producing lower yields than those located in more fertile areas. We also controlled by roughness of the terrain, using the coefficient of variation of the altitude within a radius of 50 kilometres of each location (Roughness). The terrain in areas with high levels of roughness also tended to be more marginal than those on the plains. Therefore the correlation that we expect between this variable and yields is also negative. We also should take into account another variable that measures the quality of the land used for cereal production, which we can extract from the Catastro. The survey offers information about the amount of land used to produce grain divided into three categories; first (good quality), second (medium) and third (low).We used the percentage of good quality land as a proxy for the fertility of the terrain in each municipality included in the analysis (Good Land), expecting a positive correlation with yields.

The quantity of livestock can also be important for explaining the different levels of yields, because more animals imply a higher abundance of organic fertiliser. Artificial fertilisers were not used in the production of grain in Spain until the first decades of the twentieth century. Therefore any improvements in yields based on fertilisers had to rely on organic material, especially manure from livestock (Simpson, 1995). We used the information provided in the *Censo de Ganaderia* from 1865 to quantify the amount of livestock in Spain at a provincial level.[11] There are no surveys at provincial levels closer to the eighteenth century, and for that reason this study is the first study of these characteristics which is available and has good quality data.[12] We found the number of horses, donkeys, mules, cows, sheep, goats and pigs and then estimated the amount of manure that they could produce.[13] Finally we calculated the potential amount of manure per square kilometre available in each province and included the results in our models (Manure). We understand the difficulties of using the levels of livestock in 1865 to explain 1750s grain yields. However, data show that the distribution of manure per square kilometre in the 33 provinces was stable over time, and that the use of the information from the 1865 census is acceptable.[14] In fact other authors have indicated that the regional distribution of livestock remained stable between 1750 and 1865, and have explained that the data extracted from the census are highly reliable (Garcia Sanz, 1994). We expect a positive correlation between the amount of manure per square kilometre and yields.

Several authors have also pointed to the influence that demand can have on land productivity. Postel-Vinay argued that provincial differences in grain yields in nineteenth century France were a consequence of the lack of economic integration (Postel-Vinay, 1991). According to the author, those areas that were more integrated and could therefore export to urban areas for high prices, had more incentives to invest to improve productivity

[10] Instituto Nacional de Meteorologia (http://www.aemet.es/es/eltiempo/prediccion/municipios).
[11] Junta General de Estadistica, (1868), available online at http://www.ine.es/inebaseweb/hist.do.
[12] Several authors agree on the good quality of the data available from the census. See for instance Garcia Sanz (1994, p.89).
[13] The production of manure per animal was obtained from the North East Recycling Council (NERC) http://www.nerc.org/documents/manure_management/manure_generation_calculator.xls
[14] The correlation between manure per square kilometer in the 1860s and the 1960s was 0.9. Therefore we believe that it is a reasonable assumption to believe that there were also only small differences between the 1750s and the 1860s, given that the rural economy was more static than in the twentieth century.

and achieve higher yields. To check this hypothesis, our regression included variables that measure the effects of markets, like the spatial integration of the grain market around each location. We consulted 5,179 books of manuscripts from the Catastro (one for each municipality in the Crown) to obtain the price of wheat in every municipality studied in the survey. We used the prices to estimate the coefficient of variation of the price as an estimate of the spatial economic integration. We measured the coefficient of variation of the prices of all the municipalities within a 50 kilometres radius from the location as an estimation of market integration (Integration).[15] We also included a dummy for those provinces located on the coast, assuming that cabotage could also lead to an increase in the ability of those provinces to transport grain and therefore to increase the levels of economic integration (Coast). Kopsidis and Wolf (2012) proved that, in nineteenth-century Prussia, markets had a strong and significant influence on the levels of agricultural productivity. To check if this was also the case in eighteenth-century Spain, we introduced market forces that could have an influence on the incentives to improve exploitation and consequently on yields. We estimated the potential market through population density in each province (Density), using information from the Catastro. The higher the density, the higher the pressure on land and therefore, according to authors like Boserup, the higher the incentive to improve yields (Boserup, 1965). However, the use of demographic density could have some problems. We could observe a region with a high population density but where all the inhabitants lived in villages cultivating grain for self-consumption. In such a case, the potential market for grain would be small, and therefore the incentives to increase yields beyond the level required for self-consumption would be small. For that reason we decided that the market potential in each municipality would be a better measurement of potential urban demand. As Kopsidis and Wolf (2012) did, we estimated market potential as the sum of potential urban demand weighted by the distance to the municipality (Market Potential).[16] The role of Madrid in the interior of the country was also taken into account, with the inclusion of several dummies that controlled whether the municipality was within a 50km, 100km or 200km radius from the capital. Finally, also following Kopsidis and Wolf (2012), we considered the increasing yields consequent on more capital, including in the analysis the number of horses per square kilometre as a proxy for physical capital (Horses/Km2). In the case of all the variables related to market forces, we expect a positive correlation with yields, except in the case of Integration, which is measured as the coefficient of variation of prices, where we expect a negative correlation, with those areas with a higher volatility of prices (and less integration) presenting lower yields.

4. Estimating wheat yields in mid eighteenth-century Spain

Table 2 presents the results of three regressions that were generated In order to explain the differences in yields, using simple OLS regressions with robust standard errors. In Model I we included as explanatory variables the natural factors that have traditionally been associated with the low productivity levels of Spanish agriculture, and that we would expect to be closely correlated with grain yields. The variables that are connected to

[15] Most of the trade in mid eighteenth-century Spain took place within very small distances; see Llopis and Sotoca (2007)

[16] We considered urban centres to be locations with more than 1,000 inhabitants.

natural conditions are Rainfall, Temperature, Manure, Good Land, Altitude and Roughness. We called this regression *nature*, as it will identify the effect that the traditional natural constraints have on yields. The results show that the most important of the explanatory variables driving yields was Rainfall, which was also highly significant. The relationship also shows the expected sign, with a positive correlation with yields, indicating that those municipalities which enjoyed higher rainfall were also those which obtained higher yields. The result was expected, as lack of rain has persistently been mentioned in the literature as the most important handicap faced by agriculture in Spain (Tortella, 2003). The relationship with the other variables is less intense and in some cases is not statistically significant. The role of average temperatures does not seem to be statistically significant, and shows a negative sign. We are not surprised by this result, given that, as explained before, the most important natural limitation faced by the Spanish farmers was not low temperatures but lack of rain. We also believe that the results and the lack of significance could be related to the extreme characteristics of the continental climatic regime, which are especially dominant in the centre and south of the country, with very cold winters and hot summers. The areas with higher temperatures in Spain are also those that have traditionally been more affected by climatic shocks like droughts which have a negative impact on yields. Good Land shows the expected positive sign, indicating that those municipalities with better soils also tended to have higher yields. Roughness also shows the expected negative correlation, implying that locations with more irregular terrain presented lower average yields. However, although the signs are correct both variables are not statistically significant. Manure is statistically significant and also shows the expected positive sign. Finally, the variable Altitude is highly significant and shows the expected negative correlation.

Model II was the result after the extraction one by one from Model I of the variables that were less significant. The results for all the variables are robust with the first estimation, and maintain their coefficients practically unchanged. In addition, the variable Roughness gains statistical significance. In Model III we added, as controls, all the variables that recent studies have suggested are significant for agrarian productivity from the demand side. The coefficients of the four variables associated with natural conditions included in Model III show practically the same coefficients again, and are all, except Manure, statistically significant. However, in this case the variable is close to being statistically significant at the 10 per cent level with a p-value of just .107. On the other hand, none of the variables linked to market forces appear to be significant drivers of wheat yields. Density, Madrid 50, Madrid 200, Horses/Km2 and Integration (measured as the coefficient of variation of wheat prices) all show the expected signs. The coefficient for Market Potential is 0 while Madrid 100 presents a negative coefficient. The small increase in R2 and the persistence of the coefficients for the natural variables seem to indicate that the role of market forces was not equally significant. The results show that Rainfall is the most influential variable on the variation of yields, and that an increase in Rainfall equivalent to one standard deviation appears to increase average wheat yields by 12.5 per cent. Altitude also seems to be a significant force in explaining wheat yields, with an increase in this variable equivalent to one standard deviation reducing average wheat yields by 7.8 per cent. The other two variables are also significant, although their influence on wheat yields is smaller. An increase in Manure and Roughness equivalent to one standard deviation increases average wheat yields in the first case by 6.2 per cent while reducing them by 4.7 per cent in the latter case.

[TABLE 1 AROUND HERE]

Following Brunt (2004), using the information provided in Model II we can also estimate the effects of changes in the natural conditions on average yields. Table 2 presents several counterfactuals based on improvements and deteriorations of natural conditions from the average levels estimated in the model. The results are obtained from including in the model the best and worst values found in the sample of municipalities for each one of the natural variables analysed. For instance, if all Spain enjoyed a rainfall level of 1,734 mm per year (the maximum observed in several municipalities in the province of Pontevedra), then average yields would increase from 6.4 to 9.3 quintals per hectare, an improvement of 45 per cent. On the other hand, if all the country suffered an average rainfall of 185 mm per year, as do several municipalities in the province of Almeria, then average wheat yields would decrease to 4.9 quintals per hectare, a reduction of 23 per cent. As in the case of the regression analysis, out of the many plausible changes in natural conditions, variations in rainfall are the ones that have the most significant impact on average yields. Altitude also seems to be an important factor, with yields increasing by 31 per cent if all municipalities were assumed to enjoy the minimum altitude presented in the sample. If all the locations were situated in the highest observed altitude, average yields would decrease by 8 per cent. Increasing the amounts of manure per square kilometre to the maximum levels obtained in our sample would increase average yields by 17 per cent, while its reduction to the minimum values would reduce them by 11 per cent. Roughness seems to be the least significant factor, although improvements and deteriorations in its levels would still increase and reduce yields by 9 per cent. In a situation where all the natural conditions were the ideal ones, average yields in Spain would increase from 6.4 to 15.4 quintals per hectare, an increase of 141 per cent, while the worst possible conditions would reduce them to 3.6, a decrease of 44 per cent. In other words, if all the country had enjoyed the best plausible natural conditions, yields would reach similar levels to those achieved in England during the same period.[17]

[TABLE 2 AROUND HERE]

However, a perfect natural environment is far from being realistic. None of the provinces in Spain was able to achieve a nearly perfect score for all natural conditions. Those closest were the provinces in the north of the country, which enjoyed high rainfall levels, and therefore were also able to grow enough pasture to maintain the livestock required to increase the availability of manure. On the other hand, they were also characterized by high levels of roughness in consequence of the mountain chains that distinguish their landscape. As an example, while the average roughness levels in our sample were around 40 per cent, the figure increased to 61 per cent in Galicia, 95 per cent in Asturias and 105 per cent in Cantabria. In contrast, those areas in the interior that enjoyed a more homogeneous landscape were located in two huge internal plateaus that increased the average altitude, and they also suffered lower rainfall levels and a more extreme continental climate.

[17] See Allen (1988), Broadberry et al. (2011), Clark (1991), Overton (1979, 1990) and Turner (1982).

Therefore, the analysis of the determinants of wheat yields in mid eighteenth-century Castile reveals that the region was living under a regime where climatic factors and natural conditions played a very significant role with respect to yields. Demographic pressure and economic integration, on the other hand, did not seem to be significant factors for the variability of yields. However, we believe that there was room to improve the productivity levels of Spanish agriculture despite the natural conditions. Allen showed that, in the English case, increasing yields were a consequence of changes in cultivation practices that increased the amount of nutrients in the soil (Allen, 1992, p.204). In a similar way, although Spain faced an important climatic handicap, it is also true that there were ways of improving grain yields with the resources that were available to producers. In some cases, the answers to the Catastro concerning local yields included information about the increase that could take place with the use of fertilisers. Records from the province of Cuenca indicate that the use of fertilisers allowed the cultivation of moorlands that otherwise would not produce anything. Even more importantly, with fertilisers medium quality land could produce as much as high quality land, an increase in yields of roughly 30 per cent.[18] The population also increased in Spain during the eighteenth century, offering incentives for increasing production (Llopis, 2002, p.123). If there was a strong and increasing demand, why did Spanish producers not intensify their cultivation by using these techniques? We believe that the answer to this question lies in the structure and development of grain markets in eighteenth-century Spain.

5. Markets and the elastic supply of land

The most obvious way to explain the absence of the effect of demand would be to argue that economic integration levels were simply too low. If grain markets in the mid-eighteenth century were not integrated, then the effect of demand would have been limited and producers would have had to rely on isolated markets. Following Grantham (1999), the isolated producer would not have had any incentive to invest in his cultivation and therefore grain yields would not have improved. Was this the case in mid eighteenth-century Spain? If producers had to rely on the state of the transport network, the prospects for the development of internal trade connections could not have been worse. The lack of navigable rivers in Spain reduced the possibilities of commercial exchanges within the country, and the internal geographical barriers increased transport costs by land and made the construction of canals costly. The main impression of contemporary writers showed these difficulties; an employee of the Spanish court in the eighteenth century noted that *"Because there cannot be neither navigable rivers nor canals everywhere, this deficiency has to be compensated with good roads"* (Uriol, 1978, p.626). However, the lack of maintenance had significantly reduced the extent of the main roads from around 19,000 kilometres in the sixteenth century to slightly more than 11,000 kilometres in the early eighteenth century (Uriol, 2003). Several studies have pointed out that the creation of a national grain market coincided with the development of the railway, which overcame the constraints of the deficient road network (Sanchez-Albornoz, 1974; Peña and Sanchez-Albornoz, 1984). If this was the case, then we would have to wait until the mid-nineteenth century to see a true process of economic integration at the national level.

[18] See, for instance, the answers to the Catastro from Valdemoro-Sierra.

However, an increasing consensus is growing around a different hypothesis, that grain markets were integrated well before the arrival of the railway. Llopis and Jerez (2001) indicated that the levels of economic integration of the grain markets were significant in the middle of the eighteenth century. According to these authors the traditional views that connect the establishment of national markets with the introduction of the railway underestimate the levels of integration achieved in previous periods. In a similar study, Reher (2001) maintains that grain markets developed in Spain during the eighteenth century, when the volatility of grain prices decreased, especially in areas of the interior like Segovia and Leon. Reher concluded that the connection between the prices in different cities and the harvests in the provinces of the interior revealed the existence of a market in the eighteenth century. Llopis and Sotoca (2005) reached similar results, showing that the levels of economic integration in the grain market were especially high during the period 1725-1765. The authors found intense levels of integration of the grain markets in Spain between locations that were separated by very long distances. However, they explained that this did not imply that grain was moved hundreds of kilometres, but that the correlations were mainly consequent on exchanges over small distances (Llopis and Sotoca 2005, p.18).

Therefore, if the levels of market integration were not low, why was the role of market forces so weak? To answer this question we must first have a look at the main agents in the commercialization of grain, and the choices that those agents had for increasing production. In Spain the unequal land distribution meant that local landlords and ecclesiastical authorities were able to extract a significant percentage of the production through taxes like the tithe or rents.[19] Therefore, during the eighteenth century and most of the modern age the sale of grain was usually limited to the highest social and economic classes who controlled most of the territory (Simpson, 1995, p.78). The wide inequality in land and high extraction rates meant that around one third of the gross production of grain was sent to the market (Llopis and Sotoca, 2005). The population increased from 7.7 to 9.4 million between 1715 and 1750, the most intense growth in recorded history until the mid-nineteenth century (Llopis, 2002, p.123), and therefore the demand for grain also increased during this period. The two main alternatives to address this increase in the demand side were an increase in national output by local producers or the import of grain from outside.

The increase of supply by means of international trade was not a realistic possibility for the vast majority of the country. The lack of infrastructure in the interior, and the high transport costs, diluted the influence of international trade in those areas that did not have direct access to the main ports. Even accepting that the supply of foreign cereals increased in some areas of the east of Spain, the increasing demand mainly had to be met by local production (Llopis, 2002, p.442). Therefore, most of Spain had to rely on an increase in national production to feed its growing population. Producers had two alternatives for increasing their production: the first was an intensification of their existing cultivation to increase the productivity of land, and the second was an increase in the amount of land under cultivation. A comparison of the estimates of grain yields by Bringas (2000) for the

[19] Several studies have measured wide inequality in mid eighteenth-century Spain: see Milanovic, Lindert and Williamson (2007), Nicolini and Ramos Palencia (2011) and Santiago-Caballero (2011).

early nineteenth century and by us for the eighteenth century show that these yields remained practically unchanged. Therefore, with yields that stagnated and imports that could only reach some of the coastland areas of the country, the only way to meet the increasing demand for grain was to increase the area of land cultivated. In the eighteenth century significant parts of the country still presented low colonization levels, indicating that land was not a constraint for increasing the production of grain. Alvarez-Nogal and Prados de la Escosura (2011) defined pre-modern Spain as a frontier economy with an abundance of land. In fact, during the eighteenth century 2.5 million hectares were put into cultivation to meet the increase in the demand for grain (Llopis, 2002, p.128). Pastures were transformed into arable land that was fertile thanks to the manure still present, but the nutrients in the land disappeared with time, and this caused diminished yields (Sanchez Salazar, 1986, p.709). The extensive growth could meet the increasing demand during the first half of the century, when the price of wheat grew at similar rates to those of other products. This extension model was maintained in Spain until the mid-twentieth century, when grain yields began to increase at a considerable rate (Simpson, 1995).

Was the intensification of cultivation a realistic alternative to extending the area of land used? Our opinion is that the incentives to intensify cultivation were low at first and costly later. First of all, the low levels of rainfall in most of the country meant that the possibilities for livestock were limited as was the use of manure as a fertiliser (Llopis, 2002, p.127). Therefore, although the use of organic fertiliser was a possibility, in many places in Spain it was an expensive one. In addition, there was no constraint on using more land to increase production, especially for the privileged classes. If big landowners decided to produce more for the market, they would have probably done so by increasing the area of cultivated land using cheap labour instead of investing in expensive fertilisers to increase the yields of the land they already cultivated. The power of landlords was especially high in the southern half of Spain, where they managed to control huge *latifundia* supported with an abundant supply of agrarian workers. On the other hand, high rents and major price fluctuations made it difficult for small farmers to accumulate resources, especially livestock, and this explains their over-cultivation and declining cereal yields (Simpson, 2004, p.83) According to Sanchez Salazar, small producers did not own the resources to improve their lands and had to rely on increasing the amount of land they cultivated (Sanchez Salazar, 1986, p.711). The situation got worse during the second half of the century, when the transformation of pastures reduced the supply of manure and therefore the possibilities of intensification (Llopis, 2002). Therefore, we cannot say that producers did not respond to demand, and in fact we observe that they clearly did. However, instead of increasing production with the intensification of cultivation and therefore an increase in yields, they did so by increasing the area of cultivated land at the cost of a reduction in the area used for pasture. Simpson explained that producers in eighteenth-century Spain faced an elastic supply of labour and land that made an increase in the area of their cultivated land the most profitable choice (Simpson, 1995, p.79). The wide inequality in land distribution meant that the institutional framework did not work in favour of the small producers, who, having the incentive to invest in the intensification of their cultivation, could not do so because of the lack of resources at their disposal. This was not an irrational decision when the incentives to change were too low and short term benefits prevailed over long term investment (Clark, 1992).

Another reason for the low incentives from the demand side was the fragility of the grain market itself. The fact that grain markets only worked within small distances meant that the economic integration achieved in mid eighteenth-century Spain was weak. During the second half of the century, the grain markets that had achieved high levels of integration disappeared rapidly. Reher (2001) observes an increase in the volatility of prices during the last third of the century, while Llopis and Sotoca (2007) also observe a disintegration of the grain markets in Spain during the second half of the century. Grantham (1999) explains that these “thin markets” are not stable and that they can move towards a mature and “thick market” or return to a disintegrated one, as in the case of Spain. As explained above, we believe that the main reason behind the lack of investment to increase land productivity was the abundance of land. However, we also believe that a strong or “thick” market would have presented more opportunities and incentives to the producer, incentives that could have overcome the costs of increasing yields through investments like organic fertilisers.

6. Conclusions

A quantitative analysis reveals that differences in grain yields in the mid-eighteenth century were mainly a consequence of different natural conditions. Rainfall, temperature, manure and the quality of the soil played an important part in the different levels of yields achieved, while market forces, on the other hand, do not seem to have had a significant influence. A counterfactual exercise shows that improvements in natural conditions, especially an increase in rainfall levels, would increase average yields significantly, although reaching yields similar to the ones reaped in north-western Europe solely by assuming better natural conditions is highly improbable. We believe that the main reason for the weak influence of market forces on grain yields was the abundance of land at the disposal of the largest producers. Large areas of the country, especially in the centre and the south, still presented low colonization levels in the eighteenth century. The lack of rainfall in most of the country also meant that the availability of manure as a fertiliser was very limited. Therefore, when the population increased rapidly between 1700 and 1750, producers addressed the increasing demand for food by transforming pastures into arable land. Institutions played an important role in supporting the interests of big landowners who controlled significant amounts of land, while small producers often lacked the resources needed to invest in the intensification of their cultivation. Although markets responded well during the first half of the century, increasing their integration, their disappearance during the second half shows that they were still weak and underdeveloped. Had they been more mature, the incentives for the producers to invest in the intensification of their exploitations may have been higher.

At first sight, the study of grain yields in mid eighteenth-century Spain, and a comparison with yields in north-western Europe, reveal the existence of a backward agricultural system that fell behind the most advanced countries of the continent. However, this situation could simply be a consequence of the logical reaction of producers in Spain. As some authors see the appearance of steam power in England as a logical substitute for expensive labour, we can observe that farmers in Spain decided to increase production by extending their cultivated land. The characteristics of the agricultural system in Spain created an economic environment where the investment to increase land productivity was a costly and inefficient alternative. For that reason, we believe that, far from being backward, the low yields in Spain were in part simply a consequence of the rational behaviour of its national grain producers.

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Methodological notes:

In order to avoid autocorrelation between the different independent variables, we checked the bivariate correlations among them. If we found significant correlations, we analysed whether the inclusion of the new variables in the models significantly changed their coefficients. The only case in which this happened was in the correlation between Rainfall and Manure, which was expected. However, the inclusion of both variables in the models did not significantly change the coefficients so we decided to retain both.

To estimate the best models we also tried to introduce other variables such as seasonal changes in rainfall or temperature, but found no significant changes from the results estimated and presented in the paper. We also estimated two types of market potential, one that covered the whole territory of the Crown and a second one that was limited to a radius of 200 kilometres around each location, and the results obtained were similar in both cases.

Table 1. *Determinants of wheat yields*

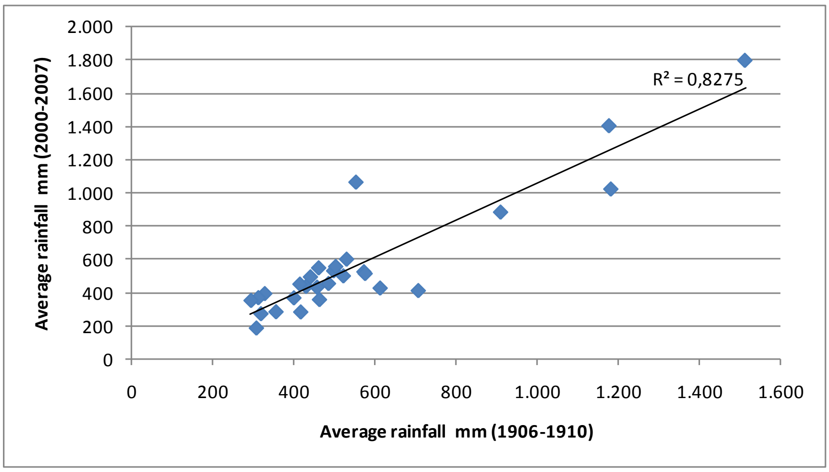
	Model I (nature)	Model II	Model III	Mean	Standard Deviation
Dependent variable: Wheat yields				0.08	0.016
Rain	.28***	.28***	.28***	0.27	0.020
Temperature	-.11			0.11	0.007
Manure	.10**	.11***	.09	0.50	0.026
Good Land	.03			-0.09	0.055
Roughness	-.05	-.06**	-.06**	0.14	0.038
Altitude	-.06***	-.06***	-.07***	0.26	0.053
Integration			-.06	0.10	0.015
Coast			-0,02		
Density			.07	0.06	0.021
Market Potential			.00	0.76	0.350
Madrid 50			0,02		
Madrid 100			-0.04		
Madrid 200			0,01		
Horses/Km2			.02	0.21	0.027
N	348	348	348		
Adj. R2	.30	.29	.30		
F-test	.00	.00	.00		

Note: *, ** and *** denote significance at 10%, 5% and 1% levels, respectively. Values for constant not shown. The variables in logs except for Coast and Madrid 50, Madrid 100 and Madrid 200 that are dummies.

Table 2: *Counterfactual exercises*

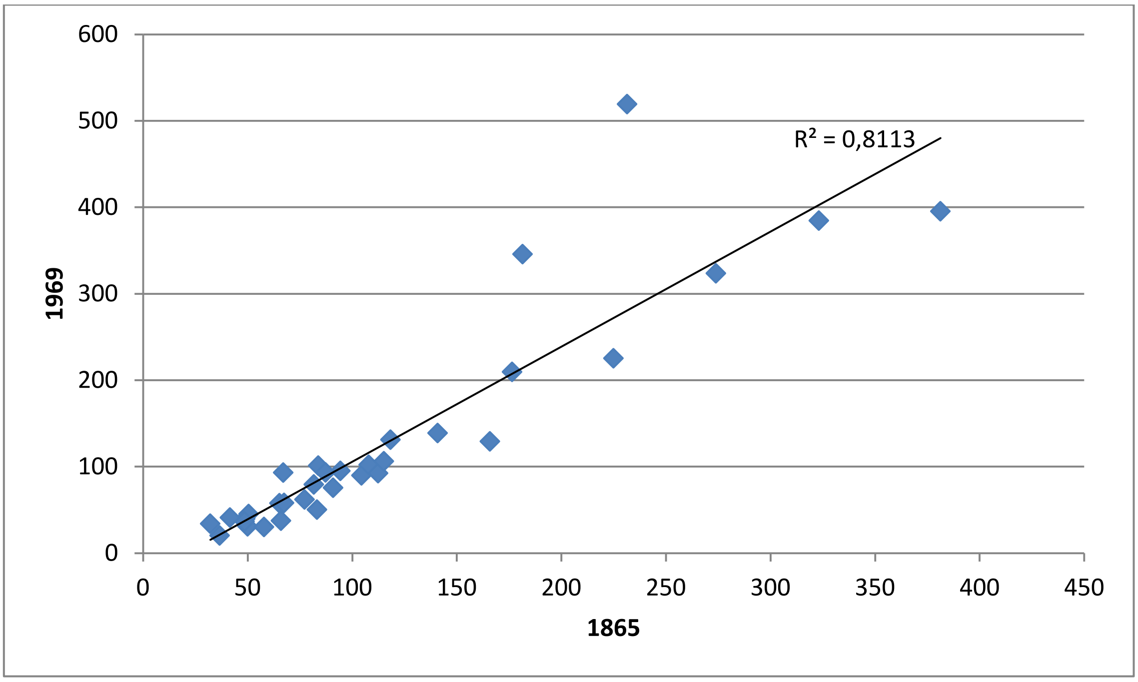
	Yield	Change (%)
Estimated yield	6.4	
Good Rain	9.3	45%
Bad Rain	4.9	-23%
Good Manure	7.5	17%
Bad Manure	5.7	-11%
Good Rougness	7.0	9%
Bad Roughness	5.8	-9%
Good Altitude	8.4	31%
Bad Altitude	5.9	-8%
Bad Nature	3.6	-44%
Good Nature	15.4	141%

Figure 1: Average rainfall by province 1906-1910 and 2000-2007



Source:INE (1906-1910 and 2000-2007)

Figure 2: Pounds of manure per day/ Km2 (thousands) in 33 provinces



Source:INE (1865 and 1969)

Figure 3: Map with the modern provincial boundaries

Municipalities included in the study of grain yields

Municipality	Province		Municipality	Province
Albacete	Albacete		Castuera	Badajoz
Alborea	Albacete		Don Benito	Badajoz
Alcaraz	Albacete		Helechosa	Badajoz
Almansa	Albacete		Hornachos	Badajoz
Hellin	Albacete		Jerez de los Caballeros	Badajoz
Nerpio	Albacete		Merida	Badajoz
Villarrobledo	Albacete		Monesterio	Badajoz
Abrucena	Almeria		Montijo	Badajoz
Albanchez	Almeria		Valdecaballeros	Badajoz
Albox	Almeria		Villanueva de la Serena	Badajoz
Dalias	Almeria		Aranda de Duero	Burgos
Huercal Overa	Almeria		Barbadillo de Herreros	Burgos
Nijar	Almeria		Burgos	Burgos
Sorbas	Almeria		Castrojeriz	Burgos
Velez Blanco	Almeria		Hontoria	Burgos
Cabrales	Asturias		Ibeas de Juarros	Burgos
Cangas de Narcea	Asturias		Lerma	Burgos
Castropol	Asturias		Medina del Pomar	Burgos
Gozon	Asturias		Rublacedo de Abajo	Burgos
Grado	Asturias		Tortoles de Esqueva	Burgos
Lena	Asturias		Villarcayo	Burgos
Oviedo	Asturias		Alia	Caceres
Piloña	Asturias		Caceres	Caceres
Pravi	Asturias		Cilleros	Caceres
Taramundi	Asturias		Jaraicejo	Caceres
Villaviciosa	Asturias		Malpartida de Plasencia	Caceres
Avila	Avila		Miajadas	Caceres
Cabezas del Vilar	Avila		Talayuela	Caceres
Candeleda	Avila		Zarza de Granadilla	Caceres
Cebreros	Avila		Alcala de los Gazules	Cadiz
La Adrada	Avila		Arcos de la Frontera	Cadiz
La Horcajada	Avila		Grazalema	Cadiz
Madrigal de las Altas Torres	Avila		Jerez de la Frontera	Cadiz
Muñogrande	Avila		Jimena de la Frontera	Cadiz
Nava de Arevalo	Avila		Medina Sidonia	Cadiz
Sotalvo	Avila		Olvera	Cadiz
Alburquerque	Badajoz		San Roque	Cadiz
Azuaga	Badajoz		Sanlucar	Cadiz
Badajoz	Badajoz		Tarifa	Cadiz
Benquerencia de la Serena	Badajoz		Vejer de la Frontera	Cadiz
Castilblanco	Badajoz		Agudo	Ciudad Real

Municipality	**Province**		**Municipality**	**Province**
Alhambra	Ciudad Real		Turon	Granada
Almodovar del Campo	Ciudad Real		Velez Benaudalla	Granada
Calzada de Calatrava	Ciudad Real		Alustante	Guadalajara
Daimiel	Ciudad Real		Brihuega	Guadalajara
Piedrabuena	Ciudad Real		Cantalojas	Guadalajara
Retuerta del Bullaque	Ciudad Real		Chiloeches	Guadalajara
Socuellamos	Ciudad Real		Corduente	Guadalajara
Villamanrique	Ciudad Real		Fuentelencina	Guadalajara
Aguilar de la Frontera	Cordoba		Hita	Guadalajara
Carcabuey	Cordoba		Illana	Guadalajara
Cordoba	Cordoba		Miedes de Atienza	Guadalajara
Hinojosa del Duque	Cordoba		Peralejos de las Truchas	Guadalajara
Hornachuelos	Cordoba		Sacedon	Guadalajara
Montoro	Cordoba		Sigüenza	Guadalajara
Posadas	Cordoba		Torija	Guadalajara
Pozoblanco	Cordoba		Uceda	Guadalajara
Carballo	Coruña		Almonaster la Real	Huelva
Cayon	Coruña		Almonte	Huelva
Cesuras	Coruña		Aroche	Huelva
Monfero	Coruña		Ayamonte	Huelva
Ortigueira	Coruña		Calañas	Huelva
Santa Comba	Coruña		Cartaya	Huelva
Toques	Coruña		El Cerro de Andevalo	Huelva
Tordoia	Coruña		Gibraleon	Huelva
Valdoviño	Coruña		Huelva	Huelva
Almodovar del Pinar	Cuenca		Lepe	Huelva
Carrascosa	Cuenca		Niebla	Huelva
Cervera del Llano	Cuenca		Puebla de Guzman	Huelva
Cuenca	Cuenca		Villablanca	Huelva
Huete	Cuenca		Villanueva de los Castillejos	Huelva
Mira	Cuenca		Zufre	Huelva
Moya	Cuenca		Alcaudete	Jaen
San Clemente	Cuenca		Andujar	Jaen
Valdemoro-Sierra	Cuenca		Hornos	Jaen
Villagarcia del Llano	Cuenca		Huelma	Jaen
Villamayor de Santiago	Cuenca		Ibros	Jaen
Baza	Granada		Jaen	Jaen
Galera	Granada		Pozo Alcon	Jaen
Guadix	Granada		Santisteban del Puerto	Jaen
Guejar Sierra	Granada		Segura de la Sierra	Jaen
Iznalloz	Granada		Ubeda	Jaen
Loja	Granada		Villarrodrigo	Jaen
Padul	Granada		Alfaro	La Rioja
Pinos del Valle	Granada		Anguiano	La Rioja

Municipality	Province		Municipality	Province
Bañares	La Rioja		Burgo (El)	Malaga
Cenicero	La Rioja		Campillos	Malaga
Cornago	La Rioja		Cañete la Real	Malaga
Fonzaleche	La Rioja		Cártama	Malaga
Santa Engracia	La Rioja		Málaga	Malaga
Villavelayo	La Rioja		Mijas	Malaga
Villoslada de Cameros	La Rioja		Teba	Malaga
Boca de Huergano	Leon		Blanca	Murcia
Chozas de Abajo	Leon		Caravaca de la Cruz	Murcia
Gradefes	Leon		Cartagena	Murcia
Luyego	Leon		Jumilla	Murcia
Noceda	Leon		Librilla	Murcia
Oencia	Leon		Lorca	Murcia
Riello	Leon		Moratalla	Murcia
Sahagun	Leon		Mula	Murcia
Valdelugueros	Leon		Murcia I	Murcia
Valderas	Leon		Murcia II	Murcia
Villablino	Leon		Yecla	Murcia
A Fonsagrada	Lugo		A Gudiña	Orense
Abadin	Lugo		A Mezquita	Orense
Begonte	Lugo		Amoeiro	Orense
Castroverde	Lugo		Avion	Orense
Cervantes	Lugo		Baños de Molgas	Orense
Chantada	Lugo		Carballeda	Orense
Quiroga	Lugo		Cualedro	Orense
Sarria	Lugo		Lobios	Orense
Viveiro	Lugo		Maceda	Orense
Alcala de Henares	Madrid		Rios	Orense
Brea de Tajo	Madrid		Viana do Bolo	Orense
Cenicientos	Madrid		Vilardevos	Orense
Chinchon	Madrid		Xunqueira de Ambia	Orense
Colmenar de Oreja	Madrid		Aguilar de Campoo	Palencia
Estremera	Madrid		Antigüedad	Palencia
Guadalix	Madrid		Arenillas	Palencia
Lozoya	Madrid		Cervera de Pisuerga	Palencia
Navalcarnero	Madrid		Corvio	Palencia
Pedrezuela	Madrid		Dueñas	Palencia
Puebla de la Sierra	Madrid		Herrera de Pisuerga	Palencia
Robledo de Chavela	Madrid		Osorno la Mayor	Palencia
Valdemorillo	Madrid		Paredes de Nava	Palencia
Valdilecha	Madrid		Velilla del Rio Carrion	Palencia
Villarejo de Salvanes	Madrid		Villarrabe	Palencia
Alora	Malaga		A Cañiza	Pontevedra
Archidona	Malaga		A Estrada	Pontevedra

Municipality	Province	Municipality	Province
A Franqueira	Pontevedra	Armaño	Cantabria
Basadre	Pontevedra	Baro	Cantabria
San Estevo de Basadre	Pontevedra	Cabañes	Cantabria
Abades	Pontevedra	Camargo	Cantabria
Abalo	Pontevedra	Campoo de Suso	Cantabria
Amorin	Pontevedra	Cieza	Cantabria
Angoares	Pontevedra	Comillas	Cantabria
Arcade	Pontevedra	Cueto	Cantabria
Fornelos	Pontevedra	Fresno	Cantabria
Lalin	Pontevedra	Isla	Cantabria
Marin	Pontevedra	Liendo	Cantabria
O Rosal	Pontevedra	Molledo	Cantabria
Vigo	Pontevedra	Noja	Cantabria
Alaraz	Salamanca	Peñacastillo	Cantabria
Alberqueria	Salamanca	Potes	Cantabria
Alconada	Salamanca	Prases	Cantabria
Aldeanueva de Figueroa	Salamanca	Puente Viesgo	Cantabria
Aldeaseca	Salamanca	Riaño	Cantabria
Aldeaseca de Alba	Salamanca	San Vicente	Cantabria
Bejar	Salamanca	Cantabria	Cantabria
Calvarrasa de Abajo	Salamanca	Santillana del Mar	Cantabria
Cantalpino	Salamanca	Santiurde	Cantabria
Carbajosa de la Sagrada	Salamanca	Toranzo	Cantabria
El Cabaco	Salamanca	Torrelavega	Cantabria
Fuenteguinaldo	Salamanca	Villegar	Cantabria
Hinojosa de Duero	Salamanca	Aguilafuente	Segovia
Horcajo Medianero	Salamanca	Ayllon	Segovia
Ledesma	Salamanca	Cuellar	Segovia
Peñaranda de Bracamonte	Salamanca	El Espinar	Segovia
Salamanca	Salamanca	Gallegos	Segovia
San Pedro de Rozados	Salamanca	Montejo de la Vega de la Serrezuela	Segovia
Sancti Spiritus	Salamanca	Pradenilla	Segovia
Santa Marta de Tormes	Salamanca	Santa Maria la Real de Nieva	Segovia
Santiago de la Puebla	Salamanca	Sepulveda	Segovia
Terradillos	Salamanca	Aznalcollar	Sevilla
Topas	Salamanca	Carmona	Sevilla
Villamayor	Salamanca	Ecija	Sevilla
Villares de la Reina	Salamanca	Guadalcanal	Sevilla
Villarino de los Aires	Salamanca	La Roda de Andalucia	Sevilla
Abiada	Cantabria	Lebrija	Sevilla
Ambrosera	Cantabria	Lora del Rio	Sevilla
Aniezo	Cantabria	Moron de la Frontera	Sevilla
Arce	Cantabria	Agreda	Soria
Areas de Iguña	Cantabria	Arcos de Jalon	Soria

Municipality	**Province**		**Municipality**	**Province**
Berlanga de Duero	Soria		Villalba de los Alcores	Valladolid
Deza	Soria		Ayoo de Vidriales	Zamora
Quintana Redonda	Soria		Bermillo de Sayago	Zamora
San Esteban de Gormaz	Soria		Figueruela de Arriba	Zamora
San Pedro Manrique	Soria		Fonfria	Zamora
Vinuesa	Soria		Porto	Zamora
Los Yebenes	Toledo		Tabara	Zamora
Malpica de Toledo	Toledo		Toro	Zamora
Menasalbas	Toledo		Villalpando	Zamora
Nambroca	Toledo		Zamora	Zamora
Ocaña	Toledo			
Oropesa	Toledo			
Santa Cruz del Retamar	Toledo			
Sevilleja de la Jara	Toledo			
Villacañas	Toledo			
Villanueva de Alcardete	Toledo			
Alaejos	Valladolid			
Aldeamayor de San Martín	Valladolid			
Boecillo	Valladolid			
Castroponce	Valladolid			
Castroponce	Valladolid			
Ceinos	Valladolid			
Cogeces de Iscar	Valladolid			
Cogeces del Monte	Valladolid			
Curiel	Valladolid			
Dueñas de Medina	Valladolid			
El Campo	Valladolid			
Foncastin	Valladolid			
Fontioyuelo	Valladolid			
Fresno el Viejo	Valladolid			
Fuensaldaña	Valladolid			
Golosa	Valladolid			
Herrin de Campos	Valladolid			
Iscar	Valladolid			
La Seca	Valladolid			
La Union de Campos	Valladolid			
Mayorga	Valladolid			
Medina del Campo	Valladolid			
Olmedo	Valladolid			
San Martin de Valveni	Valladolid			
Simancas	Valladolid			
Tiedra	Valladolid			
Tordesillas	Valladolid			
Villafrechos	Valladolid			