Evaluating International Water Treaty Impacts & Risks: The Albufeira Convention and the Spanish Experience

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Abstract

Most river treaties specify quantities of water allocated between the riparians according to long-term mean flows. However, as the value of water increases due to shortages, it raises the incentive to violate treaty provisions. Climate Change may exacerbate the causes of non-compliance and hinder the ability of river treaties to manage riparian conflicts. This paper develops a theoretical model to estimate the accepted level of risk premium associated with signing an international treaty and to derive the general conditions under which a riparian would choose to retract from an existing treaty. The model is then applied to the Spanish part of the Tajo basin, to evaluate the effect of an existing river treaty (the Albufeira Convention) between Spain and Portugal on riparian welfare. Subsequently, it explores the sustainability of the above treaty under extreme surface flows using satellite data on several water availability indices.

1 Introduction

Water that is shared by two or more states riparian to a water body may be governed by treaties. These treaties are mostly based on long term mean flows. However, global climate change models linking climate with hydrology predict large-scale fluctuations in the water cycle both spatially as well as temporally (Ellis et. al. 2008, Seager et. al. 2007). Such changes could lead to extreme events like droughts and floods, changing sea-level dynamics, precipitation patterns and so on. The imprecise and ambiguous terms of the water agreement, makes it difficult for riparians to achieve compliance of treaty specifications even under the best circumstances as it leaves room for multiple interpretations. This problem is further exacerbated as climate change complicates both the willingness and the ability of the parties to adhere to a river treaty. As the value of water increases due to shortages, it raises the incentive to violate treaty provisions that limit unilateral development of infrastructure or limit water withdrawals for consumption. The overall result could be a breakdown of the treaty as well as international tension and conflict.

In order to address this issue we estimate the risk faced by each riparian state from extreme surface flows (droughts and floods) and explore whether this risk inflicts on the treaty, the risk of breaking down as one or more parties retract from it. The central objective of this study is the assessment of two types of risks. First, the assessment of economic risk borne by an individual riparian country. Second is the estimation of risk to the stability of the existing agreement between the riparians. These risk estimates are then compared under differing risk aversion parameters.

Previous literature has attempted to find the factors that lead to conflict or co-operation and has estimated the agricultural risk from climate change. However none of these studies have estimated the nationwide risk from volatile surface flows nor have the corresponding risk of the breakdown of a treaty been derived. Nevertheless, in order to avoid national as well as international strife, ensure a sustainable co-operative environment and better adapt to future uncertainties through well designed disaster mitigation strategies, it is imperative that the riparians have an unambiguous notion of the individual risks awaiting them if they are planning to defect from an existing treaty in the face of future hydrological uncertainties. This is what this paper attempts to accomplish.

This paper has five main research objectives. First, to develop a theoretical framework, in order to analyze the impact of a treaty and to assess the risk of dissolution of a treaty under changing climatic conditions and resulting likely fluctuations in water availability. Second, to empirically conduct an impact analysis of the treaty by a comparative analysis of the benefit and risk scenarios before and after the treaty was implemented. Third, to simulate drought-like conditions of the 1992-95 period in the Tajo Basin and explore the implications of suffering the same kind of drought under the negotiated treaty. Finally, to compare the welfare distributions and risk premiums under the 1995 drought in the pre-treaty period to those under simulated conditions of water scarcity in the post treaty scenario.

The paper is organized as follows. Section 2 provides an overview of the related literature on several dimensions of the impact of climate change. Section 3 constructs the theoretical framework. Section 4 applies the theoretical model to the Tajo basin that would be studied in our analysis. It offers a general description of the basin, provides a background of the evolution of cooperation between Spain and Portugal and describes the data sources and manipulations made. Section 5 develops the empirical strategy to be adopted. Section 6 provides the descriptive statistics and the results obtained from the analysis. Section 7 summarizes the paper and discusses the policy implications.

2 Literature Review

2.1 *Impact of climate change on the economy and the environment:*

Mimikou et. al. (2000) assesses the impacts of climate change on the quantity and quality of water resources. Caselli and Malhotra (2004) conclude that fatalities and damage depend on the country's stage of development and not on the disaster per se. More recent studies like Hallegatte and Dumas (2009); Hallegatte and Ghil (2008) are of the opinion that these results are sensitive to the elasticities of substitution in the production function and also to its coincidence with upturns or downturns of the business cycle. Miller and Yates (2005) suggest that changes in global climatic patterns affect the hydrological cycle. Rising temperatures and decreasing soil moisture could induce forest fires, change vegetation patterns and alter the region's water balance. Mc.Donald et. al. (2010) adopt a detailed hydrologic model to predict that by 2050, highly populated urban centers would experience difficulties in maintaining ecological processes due to insufficient flows. They also find that freshwater fish populations would be impacted and that cities would need to make significant investments in order to secure functioning of freshwater ecosystems for future generations.

Tubiello and Rosenzweig (2008) conduct an extensive review of the literature studying the agricultural impacts of climate change. McCarl, Villavicencio and Wu (2008), Schlenker and Lobell (2010), Mendelsohn, Nordhaus and Shaw (1994) and Mendelsohn et. al. (2007),estimate impacts of fluctuations in climate on crop yields and land values. Hertel, Burke and Lobell (2009) explore the poverty impacts of climate change over different segments of the population.

2.2 *Climate Change and Conflict:*

Among researchers investigating water and international relations, one group namely the Neo-Malthusians are of the opinion that water could end up being a source of violent conflict. Homer-Dixon (1994,1999) Gleick (1993) and Rogers (2002) provide similar views that water scarcity could be a national security issue. Burke et. al. (2009) find strong historical linkage between civil war and temperature in Africa with warmer years leading to increases in the likelihood of war. Miguel, Satyanath and Sergenti (2004) attempt to understand the factors behind civil strife and emphasise the role of economic fluctuations in shaping conflict risk. Based on accumulating evidence on potentially disruptive effects of climate change on human enterprise, like possible declines in global food production, Barnaby (2009); Hendrix and Glaser (2007) claim that climate change will worsen instability in already volatile regions. Institutionalists like Keohane and Ostrom (1994), Wolf (2002), Kalpakian (2004), Brochmann and Gleditsch (2006) on the other hand share a more optimistic view stating that the nature of water resources makes armed conflict counterproductive and hence co-operation is a more likely outcome through trade and joint membership in international organizations. Tir and Ackerman (2004), Homer and Dixon (1999) find how the level of economic development, joint membership into international organizations and water rights issue and relative capabilities between upstream and downstream riparians affect treaty formations. Dinar (2009b) suggests that scarcity and co-operation follow a hill shaped relation. There are other studies that employ game theory and experimental techniques to explore the effects of climate change and variability on treaty stability like Ansink and Rujis (2008), Dinar (2009a), Abbink et. al. (2010).

2.3 *Climate Change and Risk Assessment:*

Understanding risk is important on one hand for helping producers make better decisions while on the other hand, it provides policymakers with essential information that aids them to evaluate the potency of various risk protection measures. Harwood et. al. (1999) in their report provide a detailed description of risks and risk management tools and strategies at the farm level. It compares the alternative risk management strategies taken by farmers based on their assessment of the risk faced by them and their response to financial difficulties. According to the Stern Review “climate change is the greatest externality the world has ever seen.” It analyzes climate changes by converting future cost and benefits into present discounted values. It essentially adopts the expected utility theory accounting for risk averseness. However there remains the controversy regarding conceptualizing probabilities as objective frequencies or subjective beliefs. Critics of the paper point out that as one moves towards the tails of the probability distributions, one is increasingly moving towards subjective uncertainty where the probability estimates of probability distributions themselves become obscure since it is impossible to pin down the frequencies of rare events by past occurrences or through computer simulations. Weitzman (2007) discusses the theme of catastrophe insurance and develops the motivation for treating structural uncertainty as tail thickening of posterior predictive distributions.

The literature provides three types of quantitative risk analysis methods or probabilistic assessment methods (Vose 1996; Cullen and Frey 1999;). The first are the analytical methods that calculate mathematical exact solutions for the model outcome but are difficult to implement with complex models. Secondly, there are the approximation methods based on Taylor series expansion, which provide statistical moments of the model outcome variables (Manfredo and Leuthold 1999). This method usually requires strong statistical assumptions and calculates only some parameters of the distribution. The third method is the statistical simulation method, which involves randomly sampling the probability distributions of the random variables (a possible scenario) and then running the model for each scenario. The analytical and statistical methods are known as "full valuation" methods in the risk analysis literature as they enable us to derive a probability distribution of the model outcome. This paper employs the statistical simulation method as it allows for complex mathematical functions within the model and it is easy to implement from a computational point of view.

3 Theoretical Background:

The theoretical model lays the foundation for analyzing the cooperative behavior of an upstream riparian. It proposes certain conditions under which an upstream country would be willing to comply with the treaty specifications.

3.1 *Basic Model* *(Incorporating Uncertainty in Water Supply):*

We confine our analysis to the agricultural sector and recognize the uncertainty caused by fluctuations in water availability, which is an input in the agricultural production function. There have been several studies exploring the behavior of farmers under uncertainty. Antle (1983) argues that risk affects risk-neutral farmers when they make sequential production decisions subject to random shocks. Letey et al. (1984) show that risk can lead to adaptation that increases optimal irrigation water use by up to 50%. Estimating the effect of climate change on production decisions entails including the uncertain nature of water availability into the modeling framework. To do this we follow Babcock and Shogren (1995) who incorporate uncertainty into agricultural decision making. For our analysis, we consider a national production function with an aggregate output y which can be sold at a price p ,

$$y = q(A) \qquad (1)$$

The output is stochastic due to the presence of a stochastic input A which is water availability or the water allotted to the country by an agreement. The input A cannot be controlled directly by the decision maker due to random events. However, the decision maker can influence the distribution of A to a considerable extent by investment in x units of infrastructure to control the stochasticity of A (e.g. construction of dams, expanding capacity of a reservoir, investment made in order to be better informed of the weather conditions etc.) with a per unit cost of c. Thus the conditional density of A is defined as;

$$g(A|\,x); \qquad \underline{A} \leq A \leq \overline{A} \qquad (2)$$

The national welfare as a function of net profits is given by,

$$U(\pi) = U[p \cdot q(A) - c \cdot x] \;\; U' > 0,\; U" \leq 0 \qquad (3)$$

The expected national welfare is,

$$E[U(\pi)] = \sum_{A=\underline{A}}^{\overline{A}} U\{p \cdot q(A) - c \cdot x\} \cdot g(A|\, x) \qquad (4)$$

Let $\lambda(x)$ be defined as the premium that represents the country's willingness to resolve the uncertainty regarding A for a given level of x. Thus $\lambda(x)$ is the level of risk premium that a country is willing to pay in order to stabilize water availability at its mean level. Then,

$$U[p \cdot q\{E(A)\} - c \cdot x - \lambda(x)] = \sum_{A=\underline{A}}^{\overline{A}} U[p \cdot q(A) - c \cdot x] \cdot g(A|\, x) \qquad (5)$$

Let RP be the level of risk premium that a country is willing to pay to stabilize productive activities at its mean level,

$$U[p \cdot E[q(A)] - c \cdot x - RP] = \sum_{A=\underline{A}}^{\overline{A}} U[p \cdot q(A) - c \cdot x] \cdot g(A|\, x) \qquad (6)$$

By equating the L.H.S. of the last two equations (5) and (6) we get,

$$\lambda(x) = p\{q[E(A)] - E[q(A)]\} + RP \qquad (7)$$

Thus $\lambda(x)$ has two parts, the production premium and the risk premium. The production premium is the change in expected profits obtained by fixing A at its mean level. It plays a significant role in the valuation of new technologies or investments. For example, if yields are concave in irrigation water, expected yields would be higher under a more uniform sprinkler technology that reduces variability of applied irrigation water (Bernardo, 1988)

RP is the Arrow-Prat risk premium which measures the willingness to pay to fix income at its mean level. A Taylor Series expansion around both sides of equation (7) provides a second order approximation to the premium.

$$\lambda(x) = p\{q[E(A)] - E[q(A)]\} - \frac{1}{2} \cdot \frac{U"}{U'} \cdot p^2 E\{q(A) - q[E(A)]\}^2 \qquad (8)$$

Thus $\lambda(x)$ is a measure of the value that would be derived from investment aimed at reducing risk targeted at the water availability, A. It is evident from equation (8) that $\lambda(x)$ is influenced by risk preferences. If production function is concave, this premium is positive, even under risk neutrality. On the other hand, if production function is linear, the premium comprises solely of the risk preferences. In the context of an international treaty, this term $\lambda(x)$ could be viewed as the total premium that a riparian would be willing to pay by signing the treaty in order to stabilize the fluctuations in water supply. Thus the following hypothesis can be made about compliant behavior by a riparian country.

3.2 Hypothesis

It is expected that signing a treaty would likely reduce the uncertainty in water allotments and consequently the variability in basin level welfare, especially for an upstream country. Since $\lambda(x)$ is the amount that a country is willing to pay to resolve the uncertainty in A, we can also view this as the amount of profits a riparian country will be willing to let go in the process of signing a treaty in order to reduce the uncertainty. Thus, from a cooperative outcome would be sustainable under any of the following conditions:

I: If national welfare post-treaty is higher than or equal to the national welfare pre-treaty, $\pi_1 \geqslant \bar{\pi_0}$

II: Even if national welfare post-treaty is less than the national welfare pre-treaty $\pi_1 < \bar{\pi_0}$, the riparian will be willing to comply with the treaty provisions as long as, $\pi_1 \geqslant \bar{\pi_0} - \lambda(x)$, so that,

$$U(\pi_1) \geqslant E[U(\pi_0)].$$

This implies that a country will be willing to give up a part of their profits (equivalent to the total risk premium) in any period as long as it can stabilize water availability at the mean level and thus reduce uncertainty of supply as a result of likely climatic changes. From the above hypothesis, we can derive the risk of breakdown of a treaty. It can be viewed as the likelihood of non-compliance by a riparian and is given by,

$$Risk\, to\, treaty \; = P[\pi_1 < \pi_0 - \lambda(x)]$$

4 Application to the Tajo Basin

The hypothesis of the above theoretical model is tested using the case of the Tajo Basin that spans across the border between Spain and Portugal. It is examined from the perspective of Spain, which is the upstream country. The existence of the AC treaty (the Albufeira Convention) that was signed between the two countries in 1998, provides the opportunity to explore the reasons for an upstream country to abide by treaty regulations and thus test our hypothesis. The objective is to estimate and compare national welfare functions before and after the AC .

4.1 Description of the Tajo Basin

The Tajo river emerges from the Sierra de Albarracín (Montes Universales, Spain) at 1,600 m above sea level. The tajo river basin is an international river basin encompassing Portugal and Spain. The basin's socio-political relevance lies in the fact that it joins the capitals of both countries, namely Lisbon and Madrid which is home to over 9 million people. Lying on the Iberian Peninsula, the Tajo River Basin District (RBD) covers an area of 81,310 km^2, 25,666 km^2 in Portugal and 55,644 km^2 in Spain. The RBD is 1,100 km long (230 km in Portugal) and has a mean width of 120 km. The main tributaries merging into the river from the Spanish part of the RBD, are the Jarama and its tributaries (11,600 km^2), Alerche (4,100 km^2), Tietar (4,500 km^2), Alagón (5,400 km^2), Guadiela and Almonte (3,000 km^2). The main tributaries joining from the Portugal side are the Sorraia (7,611 km^2) and Zêzere (5,029 km^2). The rivers within the RBD have a quite irregular flow regime, reflecting rainfall variations both in terms of annual and seasonal values. Flood episodes are commonly observed during autumn and winter due to periods of intense precipitation. On the other hand, during summer, most of the smaller rivers dry up due to lack of rainfall and increased evaporation. The annual precipitation ranges within 2744 mm and 524 mm as measured in Penhas da Saúde and Cabo da Roca, respectively. (UNESCO 2011)

4.1.1 Evolution of Conflict and Co-operation:

As pointed out by Garrido and Llamas (2010), Spain and Portugal have had a longstanding history over the Tajo marked by both conflict and cooperation. Portugal, being the smaller downstream country with fewer dams and waterworks than Spain always claimed to have been the vulnerable party subjugated by Spain. On the other hand, Spain being the more arid upstream country would claim her right to build more dams to compensate for its semi-arid environment, while contending that it provided Portugal with free flood prevention service. However, eventually with the formation of the European Union, significant steps were taken in terms of bilateral cooperation in the field of trans-boundary river basins. It culminated in the signing of the Convention for the Protection and Sustainable Use of Water in the Shared River Basins of Portugal and Spain (Albufeira Convention) in 1998.[1] The flow regimes established by the AC came into force in November 2000. The main principles laid down by the Convention included co-ordination of actions to ensure the sustainable use of waters; to promote and protect the good status of surface waters and ground waters within the international river basins; and for contribution towards the mitigation of water scarcity events. Under the Albufeira Convention, the proposed regime in the Cedillo dam section (Spain) and in the Ponte de Muge gauge station section (Portugal) is shown in the Table 1. The proposed annual flow regime would not apply if the year is considered as an exceptional year. A year could be classified as an exceptional year if reference precipitation for that year is less than 60% of average precipitation or if the reference precipitation for that year is less than 70% of average precipitation and precipitation in previous year is less than 80% of average precipitation. The flow regimes were agreed upon at the Conference of the Parties (CofP), composed of representatives from the respective riparian governments and chaired by Minister from each State. So far the CofP has met twice; the first time in Lisbon on July 27, 2005 and the second time in Madrid on February 19, 2008. As seen in Table 1, in the second CofP meeting, the earlier negotiated flow regimes were changed and the minimum flows were set up on a weekly basis.

Table 1 about here.

4.1.2 Water Usage in Spain and the Tajo

Total water abstractions in Spain represent 34.7% of available surface and groundwater resources, whereas the average intensity of water abstractions over available resources is 14.2%. Of all the water users in the Spanish economy, irrigated agriculture stands out as the main water user. It takes up more than four of every five cubic meters of total water abstracted. According to the Water Satellite Accounts 1997-2001 published by the Spanish National Institute of Statistics (INE), agriculture's share in water demand represented 85% of total water consumption in 1997 and 80% in 2001. The urban sector, though uses only about one eighth of total water consumption, is second in importance, as it is growing at an annual rate of 4.7%. The manufacturing industry is third in importance to activities demanding water using less than 2.5% of the total and has a growth rate of 3.6%. The rest of the

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[1] This was inspired by the 1997 UN Convention and by the Water Framework Directive (WFD).

water abstractions are distributed to other uses like the tertiary sector and the building industry (less than 4% of total usage) and consumptive uses for power generation (less than 0.3% of the total). More specifically, for the Tajo basin, urban water supply, agriculture and hydro-power are the three most important sectors in order of water use priority considered by the Hydrological Plan of the Spanish part of the Tajo basin. In terms of water demand, agriculture has the highest demand of about 2048 hm^3 per year, followed by hydro-power, which has a yearly demand of about 1397 $hm^3$and the urban sector with a yearly demand of 971 hm^3[Manasi et. al. (2006)]. As such, we focus our analysis to the agricultural sector.

4.2 Data (Sources & Variable Creation)

We use panel data over the period 1981 to 2010 that includes 8 provinces namely Teruel, Cuenca, Guadalaraja, Madrid, Toledo, Avila, Salamanca and Caceres that comprise the Tajo basin in Spain. For the estimation procedure we use crop yield data for the five main crops namely, Wheat, Barley, Olive, Grapes for Wine and Sunflower.[2] Crop yield (kg/ha), land use (in hectares) and price of each of these crops were obtained from the Statistical Yearbook of the Ministry of Agriculture, Food and Environment in Spain.[3] Data on prices obtained from the Statistical Yearbook provides the average farm gate prices or the prices received by the farmers for each crop. They are taken from different markets and represent average prices. All prices are expressed in Euros.[4] For converting the previous year prices from Peseta to Euros, we use the exchange rate prevailing at the time of the formation of the European Union.[5] Due to non-availability of disaggregated data on water use for each crop within each province, some alternative measures of water availability and variability are used that are known to affect crop yields as found in the existing literature. These proxies for water availability include satellite data on precipitation, drought index (SPI), soil moisture index and soil wetness index. Data on these four hydrological variables were collected at a relatively detailed spatial distribution from Aghakouchak (2012). It combines remote sensing techniques and physically based and statistical approaches to develop reliable models of large scale hydrologic systems. The source for the hydrological data is NASA MERRA-Land data. The soil moisture content data has a resolution of 2/3 x 1/2 degrees and it is measured in m^3/m^3. It measures the fractional content of water in a volume of wet soil. The Soil Wetness Index (SSI) identifies deficits in soil moisture at various time scales during the year (1, 3, 6 and 12 months). We use the SSI that is based on 1-month standardized soil moisture index. It represents the amount of soil moisture with respect to climatology in a normalized scale and over a given time period. Both SPI and SSI are unitless and are normalized indices between -4 to +4, where negative values indicate drought, while positive values indicate wet periods. The values, -1 to -2 is typically interpreted as moderate (-1) to severe (-2) . Drought values below -2 are considered to be extreme droughts. A one month SPI refers to precipitation deficit during the past one month, while a 6-month SPI indicates precipitation deficit in the past 6 months. The longer the duration, the more extreme would be the situation. The precipitation and SPI data have a resolution of 0.5×0.5 degrees. Precipitation is measured in mm/month. Spatial distributions of each hydrological variable across the Spanish part of the basin are shown in the descriptive statistics section. [6]

These geocoded hydrological variables were obtained at a monthly frequency. They had to be converted

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[2] Crop importance is based on the total land used for cultivation.

[3] Figure 4 shows major crops in the basin selected on the basis of cultivated area.

[4] The conversion rate at the time of the formation of EU was 1 Euro =166.386 Pesetas.

[5] Figure 14 shows the crop prices all converted in terms of Euros/100kg.

[6] Table 9 in appendix shows the correlation matrix for each of the hydrological variables.

to yearly values by averaging the values over the crop cycle, which is from September to October. Since the Albufeira Convention came into force in November 2000 , we perform our comparative analysis of the benefit functions before and after the year 2000. The yearly values geocoded at various grid resolutions for each of the variable were then converted to obtain data at the provincial level. This was done by identifying the grids that were within the boundaries of the provincial polygons. Due to the uneven number of data points within each polygon, we take the average value to reflect the water availability corresponding to each polygon for a particular year. The entire procedure was done using the ArcGIS 10 software by converting points to polygons and then taking the average value within each polygon. The standard deviation of these points were also taken in order to measure the variability in water availability within each province. One period time lags of these variables were generated since water availability at the initial stages of the cropping cycle are crucial for a good harvest. Spatial lags were also generated for these variables, since water use in the previous upstream province is expected to affect the water availability in terms of soil moisture and soil wetness in the next downstream province. We use the log of yield and land use variables, in order to smooth out outliers. Moreover, since there exists non-linearities between the dependent and the independent variables,[7] taking log values makes it possible to maintain the non-linear relationship while preserving the linear model and also allows us to easily interpret the regression estimates as elasticities. In order to estimate the yield differences between rainfed and irrigated lands, a dummy variable was created that took a value of 1 for cultivation on irrigated land whereas it assumed a value of 0 for cultivation on rainfed land.

5 Empirical Methodology

The goal of the empirical model is to use the available data to derive the social benefit functions before (from year 1981-2000) and after the AC (from 2001-2010). In order to simulate the welfare function, the sectoral production functions need to be generated. We confine our analysis to the agricultural sector, as was justified earlier. This will provide a good proxy to the benefits accrued by Spain. These hydrological variables also help us in deriving the yield response functions for each province and for each type of crop separately. These yield response functions are aggregated over the provinces to obtain the crop response function, which in turn is aggregated over the three major types of crops in Spain (Wheat, Barley and Olive) to obtain the national gross revenues from the agricultural sector. We then simulate the welfare distributions for different levels of risk aversion, which enables us to compute and compare risk premiums for the pre and post treaty scenarios. The estimation procedure uses panel data with the time period ranging from 1981 to 2010 and takes into consideration 8 provinces (Cuenca, Guadalaraja, Madrid, Toledo, Avila, Caceres, Teruel and Salamanca) within the Spanish part of the Tajo basin.

5.1 Identification of Treaty Effects & Estimation of the Pre & Post Treaty Yield Response Functions

In order to evaluate the impact of the treatment (in this case, the AC treaty) on the outcome variable i.e. crop yields over a spectrum of crops and across the provinces within the Spanish part of the Tajo River Basin, and to derive the yield response functions to water availability in each of the cases, we use the difference in differences (DD) approach. This methodology is employed since crop yields are

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[7] See Figure 12

observed over the two groups of crops: those grown on irrigated land and those that are grown on rainfed land over the two time periods (before and after the implementation of the treaty). Further, the effect of the treatment is observed only in one of the groups and for one of the periods. This is because crop yields from the irrigated land group (in this case the treatment group) is affected by the treaty only in the second period, as the restrictions imposed on water flow affect the water available for irrigation and thereby affect the resulting yields. On the other hand, the rainfed land group (the control group) is unaffected by the treatment, since the treaty specifications do not affect the climatic conditions. Hence it is possible to identify the impact of the treaty by utilizing the variation in crop yields between the two groups.

Figure 1 about here.

Let the two groups be indexed by the treatment status, thus the Type of Land Dummy (Land) = 0, 1 where 0 indicates the rainfed land group unaffected by the treatment (control group) and 1 indicates the irrigated land group that is affected by the treatment (treatment group). Also let the Post Treaty Dummy = 0, 1 where 0 indicates the pre-treatment time period i.e. before the implementation of the treaty and 1 indicating the post-treatment period i.e. after the treaty was implemented. Thus the outcome variable for each observation ($i = 1, ..., N$)can be modeled as:

$$Y_i = \alpha + \eta X_i + \beta Land_i + \gamma Post - Treaty + \delta(Land * Post - Treaty)_i + \varepsilon_i \quad (9)$$

where,

X_i = Covariates affecting yield of crop i (e.g. water availability)

$Land_i$= Dummy variable indicating rainfed vs. irrigated land

$Post - Treaty$ = Time Dummy indicating pre vs. post treaty time period

α = constant term

η= coefficient of covariates affecting Y_i

β = treatment group specific effect

γ = time trend common to treatment and control group

δ= true effect of the treatment

ϵ= unobserved error term

Thus β can also be interpreted as the possible difference between the two groups prior to the policy change (the implementation of the treaty) and γ can be thought of as capturing the aggregate factors that could cause changes in the outcome variable, yield, even in the absence of a policy change. The impact of the treatment is evaluated by the difference in difference estimator $\hat{\delta_{DD}}$ which is obtained by estimating the difference in average outcome in the treatment group T (cultivation on irrigated land), pre and post treatment minus the difference in average outcome in the control group C (cultivation on rainfed agriculture), pre and post treatment.

$$\delta_{DD} = (\bar{Y_1}^T - \bar{Y_0}^T) - (\bar{Y_1}^C - \bar{Y_0}^C) \qquad (10)$$

where, $\bar{Y_i}$ is the mean observed yield in period i, $i = 0, 1$

This estimator turns out to be an unbiased estimator of the treatment impacts, under the condition that the underlying trends in the outcome variable is the same for both the treatment and the control group (a.k.a. the parallel trends assumption). It eliminates biases that result from the permanent differences between the treatment and control groups while undertaking a comparison of the two groups in the second period. It also removes biases arising as a result of time trends while comparing the treatment group over time. This allows us to estimate the impact of the treaty as well as obtain the pre and post treaty yield response functions for each crop. We use these yield response functions to obtain the gross profit functions and the welfare functions. The following section illustrates how we obtain the basin welfare distribution using these functions.

5.2 Simulations of the Welfare Distributions (Incorporating Stochasticity of Uncertain Inputs)

To obtain the simulated agricultural welfare distributions, we begin by estimating the yield response function for each crop. In order to incorporate stochasticity and estimate the effects of the uncertain input variable, we first fit distributions to the uncertain input (i.e. water availability) based on the available data. These distributions as well as the regression estimates for the crop response function, enables us to obtain the simulated yield response distributions and thereby the gross revenue distributions for each crop. Aggregating these crop revenues across the provinces within the basin, we derive the simulated basin gross revenues for the agricultural sector. We then compare the welfare functions before and after AC for Spain. Finally, we derive simulated welfare distributions for specified conditions, for instance a prolonged drought or for possible future climatic conditions.

In order to find how the crop yields respond to water availability, the yield response functions or the water production functions are estimated over a spectrum of crops and across the provinces within the Spanish part of the Tajo River Basin. Both in the pre and the post treaty period, we use the Cobb Douglas Production functions[8], for each crop i separately as shown below:

$Q_i = AX^a \qquad (11)$

The above production function is transformed into its log-linear form for estimation purposes. Thus the estimating equation is given by:

$Y_{it} = \alpha_0 + \alpha_1 log(X_{it}) + \alpha_2 Land_i + \alpha_3 (Land_i \,.\, log(X_{it}) + \sum_{j=2}^{8} \beta_j Province_j + \varepsilon_{it} \quad (12)$

where,

X_{it} = Water availability in time t for producing crop i

$Land_i$= Dummy variable indicating rainfed vs. irrigated land

$Province_j$= Dummy variable indicating the different provinces, $2, ..., 8$

α_0 = Constant term

α_1= Coefficient on water availability index

α_2 = Coefficient on a type of land dummy. Land = (0, 1) where 0 & 1 indicates the rainfed and irrigated lands respectively

α_3 = Interaction between water availability index and type of land dummy

$\beta_2, ... \beta_8$= Coefficients on the Province Dummies

ε_{it}= unobserved error term

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[8] Section 6.3 explains the use of the Cobb Douglas as the yield response function

The yield response function is used to obtain the profit function for each crop:

$$\pi_i = P_{yi} \cdot Y_i - P_1.X_1 - FC \qquad (13)$$

where,

π_i = profit function for crop i.

P_{yi} = crop prices

Y_i = yield response function for crop i

P_1 = price of water

X_1 = water input variable

FC = fixed costs

We obtain the basin agricultural profit function by aggregating the crop profits across the provinces. The basin agricultural welfare as a function of basin agricultural profits is given by:

$$U(\Pi, \theta) = (\tfrac{1}{1-\theta}) \cdot \Pi \qquad (14)$$

where,

Π= basin agricultural profits

Following Lien and Hardaker (2001), the utility function selected in (13) is a special form of the power utility function. Here θ is the coefficient of relative risk aversion. The utility function exhibits Constant Relative Risk Aversion (CRRA) and Decreasing Absolute Risk Aversion (DARA) since $U^{'}(\Pi) > 0$ and $U^{''}(\Pi) < 0$.[9] Using equation (13) we transform the basin gross revenue distribution to the basin welfare distribution. Since the welfare distributions are influenced by risk preferences, we compare the welfare distributions for several levels of risk aversion. Thereafter, we compute the risk premiums before and after the treaty for each of the risk aversion parameters.

For this utility function given in (14) the coefficient of absolute risk aversion is:

$$R_a(\Pi) = -\frac{U^{''}(\Pi)}{U^{'}(\Pi)} = \frac{\theta}{\Pi} \qquad (15)$$

and the coefficient of relative risk aversion is,

$$R_r(\Pi) = \Pi \cdot R_a(\Pi) = \theta \qquad (16)$$

Following Freund (1956), the approximate risk premium (RP) is given by:

$$RP = 0.5 \cdot R_a \cdot V(\Pi) \qquad (17)$$

Thus for different values of the relative risk aversion, θ we can obtain the RP as shown above. We can also obtain from RP, the proportional risk premium (PRP). The PRP represents the proportion of the expected payoff of a risky prospect that a decision maker is willing to pay in order to trade risk in

---

[9] This implies that higher profits are associated with higher levels of welfare and the welfare function exhibits diminishing marginal utility from additional wealth.

return for a sure thing.

$$PRP = \frac{RP}{E(\Pi)} \qquad (18)$$

We compare the welfare for the following different values of the relative risk aversion coefficient:

$\theta = 0$, risk neutral

$\theta = 0.5$, hardly risk averse

$\theta = 1$, somewhat risk averse

$\theta = 2$, rather risk averse

$\theta = 4$, extremely risk averse

6 Results

6.1 Descriptive Statistics

Table 6 shows the pre and post treaty descriptive statistics for the important variables.

Table 6 about here.

An initial glance at the table demonstrates higher means and lower standard deviations in the post-treaty period relative to the pre-treaty period for the crop yields as well as area under cultivation. It also shows a higher mean and standard deviation for variables indicationg water availability such as precipitation, SPI and the indeces for soil wetness and soil moisture.

The figure below shows the variability in water availability as measured by precipitation across the provinces.[10]

Figure 2 about here.

The above graph is obtained using krigging techniques in GIS using the geocoded data on precipitation values for the year 2000. In the figure, the area shaded in brown marks the Spanish provinces enclosed within the Tajo basin. It is evident that the southern part of Spain receives much less rainfall compared to the northern parts. Also average precipitation falls as we move from west to east along the basin.[11].The figure below shows the yearly standard deviation of precipitation values for each of the 8 provinces during the post treaty period.

Figure 3 about here.

From the figure 3, we can observe that the provinces located in the western part, such as Caceres, Salamanca and Toledo have a higher variability in water availability over time.

In order to observe the differences in mean and variability in crop yields between the pre and post treaty period we look at the box plots as shown in the figure below.

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[10] Spatial maps throughout this paper were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com

[11] Figures for the other hydrological variables can be found in Appendix (Figures 10 & 11).

Figure 5 about here.

An initial glimpse at the data shows that the median of rainfed crop yields rises for all crops as we move from the pre-treaty to the post treaty scenario. The right side of the graph shows a similar trend for the yields of irrigated crops. [12]

Now, in order to check if these differences in mean and standard deviations between the pre and post treaty scenarios, for land use and yields of irrigated crops are significant, we conduct Anova and t-tests. The one-way anova with the Bartlett's test is used in order to test for the equality of variance. In those cases where the standard deviation is significantly different, we use the ttest with unequal variance to test for the difference in means. When the standard deviation is not significantly different, the F statistic from the anova is used to test for the difference in means. The positive differences in average yields for all crops except for sunflower indicate a higher average yield in the post treaty scenario that is stastically significant in all cases. The negative values of the differences in standard deviation reflect the fact that variation in yields have fallen in the post treaty scenario. The difference in standard deviations are negative for all crops except for Barley, reflecting the fact that crop production stabilized compared to the pre-treaty case for most cases. It is also evident that for all crops except sunflower, the average as well as the standard deviation of Gross Revenues in the post treaty scenario are significantly higher than those in the pre-treaty period[13].

6.2 Estimation of Treaty Impacts

Prior to obtaining the results for the estimation of treaty impacts through the difference-in differences estimator, we look at the validity of the research design. This is done by checking if the parallel trends assumption holds true. In order to verify the validity of the parallel trends assumption we need to ensure there is no significant difference in trend between irrigated and rainfed yield in the pre-treaty period. For this we need the coefficient of the interaction of Irrigated land Dummy and Pre-Treaty Time Dummy to be non-significant.

Table 2 about here

Table 2 shows regression estimates to check the parallel trends assumptions for performing the DD analysis. For each of the crops mentioned above, we find that the coefficient of "Land & Pre-Treaty Time_Interaction" is not significant implying that parallel trends assumption holds in the pre-treaty period. [14]. As such we can expect to obtain unbiased estimates for the treaty impacts through the difference-in-differences approach.

In order to estimate the impact of the treaty and thereby obtain the pre and post treaty yield response function, the Difference-in-Differences (DD) analysis is performed as explained by the regression equation (9) in section 5.1. This analysis is performed twice, once to estimate the impact of the treaty implemented in the year 2000 and again for the modified treaty in the year 2008, which insisted frequent monitoring of the flow regimes as illustrated in Table 1. The results obtained are shown in the table below.

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[12] The histograms of yields for crops grown both on rainfed and irrigated land shown in Figure 13 indicate that for most cases the means appear to be higher in the post treaty scenario.

[13] Table 7 in appendix, shows the anova and t-test results for land usage pre and post treaty both for rainfed as well as irrigated lands. Table 8 shows anova and t-test results for crop yields and gross revenue for cultivation on irrigated lands.

[14] We exclude Grapes and Sunflower from our analysis as we were unable to get a proper distribution for the two crops due to data issues.

Table 3 about here

Table 3 compares the DD estimates for Barley, Wheat and Olives under the initial and the modified treaty specifications. The DD estimate is given by the coefficient of the interaction between the Land Dummy and the Post Treaty Time Dummy. A positive coefficient of the interaction dummy would imply that the difference between irrigated yields and rainfed yields have gone up in the post treaty period. Thus it shows the impact of the treaty, more precisely the average treatment effect of the treaty on irrigated yields. From Table 3 it is clear that though no significant impact is observed for the initial treaty specifications for the above crops, we do observe significant treaty impacts for the modified treaty specification for Barley and Wheat. The sign of the coefficient of the interaction term mentioned above is positive for Wheat and Olive implying that crop yields were favorably impacted, while for Barley it is negative, implying that it has been adversely affected by the implementation of the treaty. The non-significance of the treaty impacts for Olives can be explained by their relative resistance to water scarce conditions.

6.3 Estimation of Yield Response Functions

Table 4 about here.[15]

The table above shows the regression results from the best fitted model. It is assumes a Cobb Douglas (CD) production function[16] and is estimated by taking the log of this function. Thus the log of crop yield for each crop is regressed seperately on log of precipitation, the dummies for different provinces, the land dummy, the treaty dummy and the interaction of the two as discussed in the methodology. The best fitted model was selected after comparing the regression results using OLS, GLS[17] and GLM methods of estimation for each hydrological variable.[18] For each estimation method we test one model including treaty as a dummy variable and the other where regressions are run separately for the two time periods. The later class of models, not only includes the proxy variable, but in addition, a non-linear (or square) term, a one period time lag and two types of dummy variables are included (i.e. the type of land dummy and seven dummy variables for the eight provinces). It also includes an interaction term interacting the type of land dummy with the variable of interest.

The coefficient of Land Dummy is significant across all crops and has a positive value indicating that crops on irrigated lands have a higher yield than those on rainfed land in general prior to the treatment. The Treaty Dummy is significant and positive across all crops except for Sunflower, indicating a positive time trend for all crops in both the treatment and control groups. The interaction of the two treaties, is negative in all crops except for Olive showing that the treaty has an adverse effect on crop yields on irrigated lands as compared to that on rainfed lands. This is expected for the upstream country which has to restrain its water usage as compared to the situation prior to implementation of the treaty. The reason for the exception observed for Olive could be explained by its high resistance to survive even under conditions of water shortages.

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[15] Coefficients are marked significant for the 90% (*), 95% (**)and 99% (***) confidence levels.

[16] The scatter plots shown in the appendix (Figure 12) indicates the non-linearities present in the yield response to precipitation

[17] The GLS fit allows specification of the correlation structure of the residuals. GLS estimates using precipitation as the hydrological variable are shown in Table 11

[18] In a GLM model the distributional assumptions are expanded beyond the normal distribution to the general exponential family. Table 10 shows regression results for CD production function using SPI as the hydrological variable.

Precipitation appears to be the best explanatory variable for almost all crops among the other two variables used as proxies for water availability and this is uniformly observed in almost all of the models tested (see appendix for results). The Adjusted R square value is high compared to the other models, pointing to the higher explanatory power of the model. Additionally, for this model, the coefficient of the variable of interest, the interaction of the two dummies (Land & Treaty) is significant in most cases relative to the other models.

The regression estimates show the differences in slopes and intercepts of the crop yield functions pre and post treaty for the two groups of crops estimated for the five major crops produced in Spain. The coefficient of precipitation shows the percentage change in yield due to a one percentage rise in precipitation. The other models tested using precipitation as the proxy, contain additional regressors including a quadratic term for precipitation and both time and spatial lags of precipitation. The coefficient corresponding to Irrigated Land Dummy represents the difference in intercepts between yield functions for rainfed and irrigated lands.

6.4 Simulation of Basin Welfare Distributions

The coefficients obtained from the regression of the yield function are taken as the fixed parameters of the simulation model. Using information on crop area cultivated and average national crop prices, we calculated the gross revenue of the three main crops (Barley, Wheat and Olive) for each province separately.[19] Precipitation, prices and the area cultivated are taken as the uncertain inputs for the simulation model. We fit distributions to these uncertain inputs using the AIC (Akaike Information Criterion) and obtain the simulated output for gross revenue before and after the implementation of the treaty. Thereafter, the basin welfare distributions are simulated assuming different values of the Relative Risk Aversion (RRA) coefficient. This analysis is confined only to the Spanish part of the Tajo basin.

6.4.1 Comparison of Basin Welfare Pre and Post Treaty

The graphs below show the simulation results comparing the probability densities and cumulative distributions of Basin Welfare Distributions obtained before and after the implementation of the treaty in the year 2000.[20] The blue and red curves represent the welfare distribution functions for the pre and post treaty scenarios respectively.

Figure 6 about here.

Figure 7 about here.

From figure 6 and 7, it is observed that when risk neutrality is assumed (i.e. RRA=0), the mean of the Basin Welfare Distribution in the pre-treaty period is lower than that obtained in the post treaty period by approximately 20 million euros. For all the other risk aversion coefficients, there is a similar rightward shift of the welfare distribution in the post treaty situation.

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[19] Figure 15 - Figure 19 in appendix shows the cumulative ditribution of crop specific Gross Revenues for Caceres, Toledo, Madrid, Guadalaraja and Avila respectively.

[20] Simulations were conducted and graphs were generated using the Decisions Tools Suite 6.

6.4.2 Simulated Basin Welfare Pre & Post Treaty for Drought-like Conditions Prevailing During 1995

The simulation results shown in the graphs below compare the probability densities and the Cumulative Distributions of Basin Welfares under drought scenario in the pre-treaty vs. the post-treaty period. In order to do this we make use of the drought that prevailed in Spain from 1992-1995 as a natural experiment. Parameters of the input distribution of water availability in the simulation model both in the pre and post treaty period are set based on those observed during the year 1995 which faced the most severe conditions.

Figure 8 about here.

Figure 9 about here.

A rightward shift of the Basin Welfare Distribution observed from Figure 8 and 9, indicates that the Basin Welfare values are higher in the post treaty scenario even under conditions of water scarcity as encountered historically by Spain for all assumed values of risk aversion. Under risk neutrality, the mean values for both distributions are lower than the ones under general conditions by approximately 10 million euros. The simulated welfare distributions for all other values of risk averseness indicate that the results are independent of the decision maker's attitude towards risk.

6.4.3 Computation and Comparison of risk premiums pre and post treaty for different levels of risk aversion.

From the pre and post treaty welfare distributions obtained above, we compute the risk premium (RP) and the Proportional Risk Premium (PRP) for different values of relative risk aversion. The table below compares the pre and post treaty values of the risk premium and the proportional risk premium, obtained both under normal as well as drought-like conditions for different values of relative risk aversion.

Table 5 about here.

From Table 5 it is evident that under conditions of scarcity post treaty RP values as well as PRP values are much lower compared to the pre-treaty period. This result is consistently observed for all levels of risk aversion parameters considered for the purpose of our analysis. If risk premium can be taken as an indicator for risk perception, then the implication is that the risk of substantial fluctuations in water availability lowers in the post treaty period under conditions of water scarcity. Thus we can conclude that irrespective of the level of risk averseness of the riparian, a well monitored treaty specification can have a favorable impact on the level of risk, especially under water scarce conditions.

7 Conclusion and Policy Implications

To summarize, from the simulation results we observe higher average basin welfare values and an entire rightward shift of the basin welfare distributions for different levels of risk aversion in the post treaty period. Moreover, a comparison of the RP and the PRP values demonstrates a reduction in risk in the post treaty period, under scarcity conditions as observed during the 1995 drought faced by the basin. To conclude, we can say that the AC treaty had a positive impact on Spain in terms of its agricultural basin welfare. We can further conclude that the 2nd CofP meeting was more successful in terms of generating positive treaty impacts as demonstrated by the DD estimates. Thus our analysis, by explicitly incorporating uncertainty which plays a dominant role in any economic decision making process, provides valuable insights into the welfare distribution of the riparians under status quo vis-a-vis under co-operation and the comparison of risk premiums under the status quo vis-a-vis under co-operation between the riparians. The results obtained from the analysis of the Spanish part of the basin suggests that for Spain, co-operation with Portugal has resulted in a higher Basin Welfare in general and lower risk premiums under conditions of water scarcity like that which prevailed during 1992-1995. According to our hypothesis, this leaves no incentive for Spain as a riparian to retract from the treaty. However, climate change involves uncertainties in an overwhelming number of dimensions and the question that remains unanswered is what would be the consequences of further fluctuations in water availability likely to be brought about by climate change. A future study would entail the incorporation of predicted climate change scenarios and a subsequent comparison of pre and post treaty benefits to the riparian, in order to ascertain if this treaty could be sustained in the face of extreme variability in water availability.

Future study will entail impact assessment of the AC treaty from the perspective of the other riparian nation, Portugal. It can be expected that the probability of disintegration of a treaty, given a specific level of disaster risk, would depend on differences in risk aversion, power asymmetries, asymmetries in the levels of development and the existence of international institutions. Also the extent to which a country needs to rely on shared rivers is driven to a great extent by how much freshwater a country can draw from other sources to meet its water demands. If water scarcity turns out to be an issue, there is likely to be a clash in interest between the nations and many studies predict that this would place the riparians into a conflictual zero-sum mindset (e.g. Cooley 1984; Klare 2001; Lonergan 2001). An upstream downstream relation between treaty signatories could turn out to be particularly problematic since it could allow the upstream state to impose negative externalities on the downstream state (Mitchell and Keilbach 2001; Stinnett and Tir 2009). It would be interesting to perform a comparative analysis of the equilibrium strategy with and without the presence of trade relations, since trade relationships can act as signals of countries' trustworthiness and create environments in which cooperation can flourish and costs of conflict are increased (Gartzke, Li, and Boehmer 2001).

To conclude, the deleterious effects of water scarcity on international security could be alleviated through well formulated agreements which define the rights and obligations of each nation, sets rules for sustainable joint use of a river basin along with the existence of proper institutions that focus on monitoring and law enforcement and has well-designed mechanisms to deal with disputes before they could arise. Several empirical studies bear the claim that states willingly agree to bear the cost of institutions when they feel the need for it. Tir and Ackerman (2009); showed that scarcity prompted countries to form treaties and also to include more institutional features to them. It is expected that the sobering estimates of the economic risks associated with disasters and the possibility of the breakdown of a treaty and its long-term consequences, would hopefully prompt planners to expedite the process of making provisions for such adverse circumstances, design ways to sustain co-operation in order to mitigate hazards and their potential to disrupt global peace.

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Figure 1: Identification of Treaty Impact using Difference-in-Differences Approach

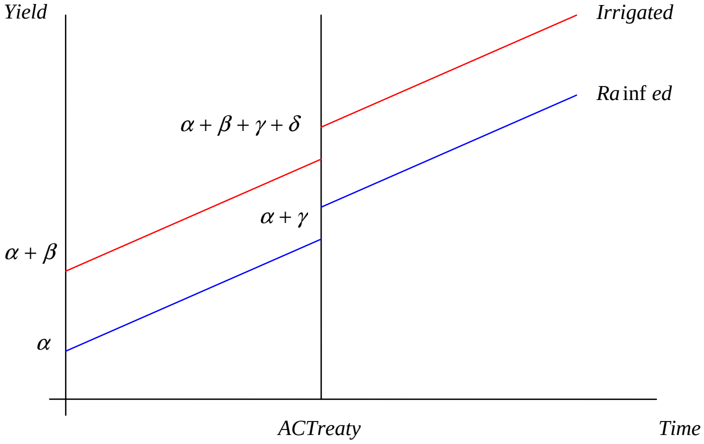


Figure 2: Distribution of Precipitation across the Spanish provinces within Tajo basin (year 2000)

Figure 3: Standard Deviation of Annual Precipitation

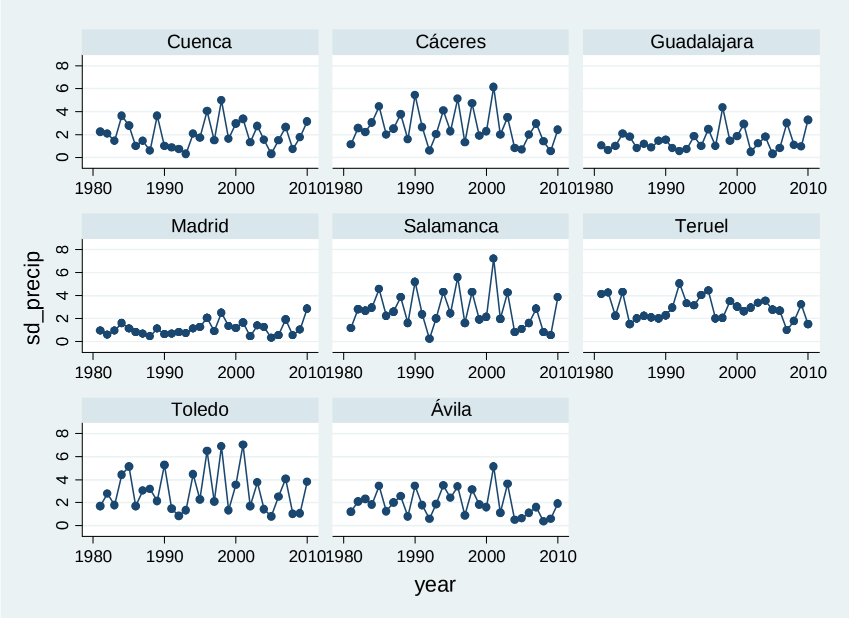


Figure 4: Major Crops Selected on the Basis of Cultivated Area

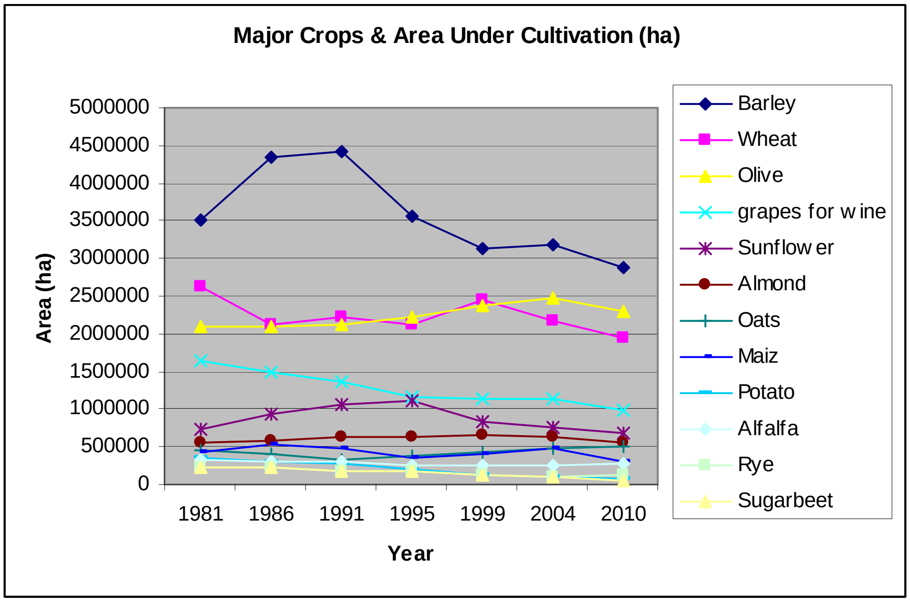


Figure 5: Box plots of crop yields before and after treaty broken down by type of land used

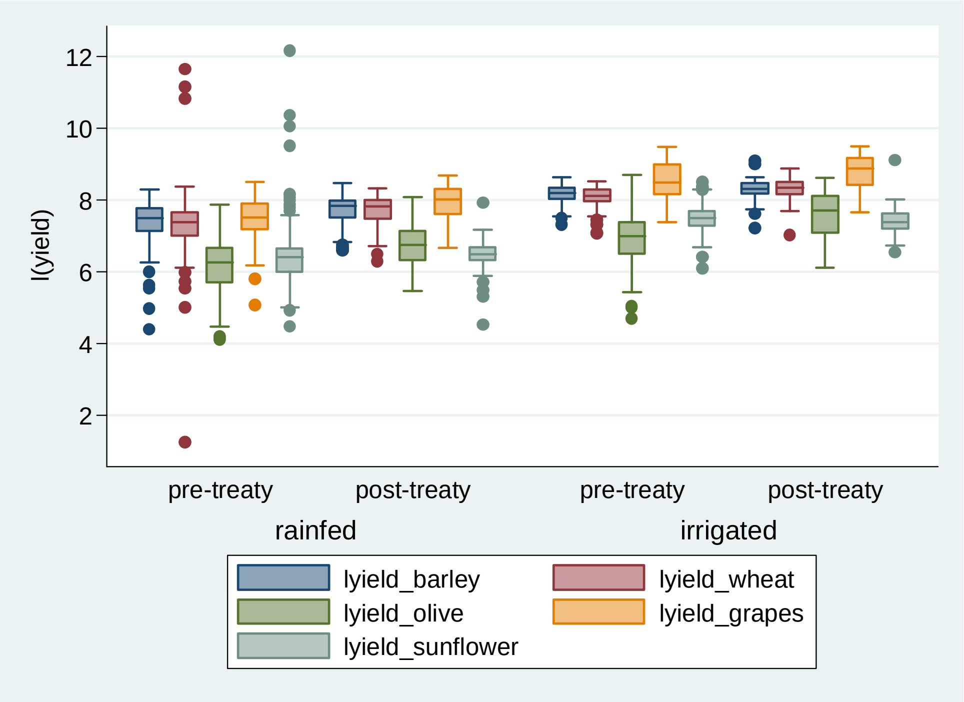
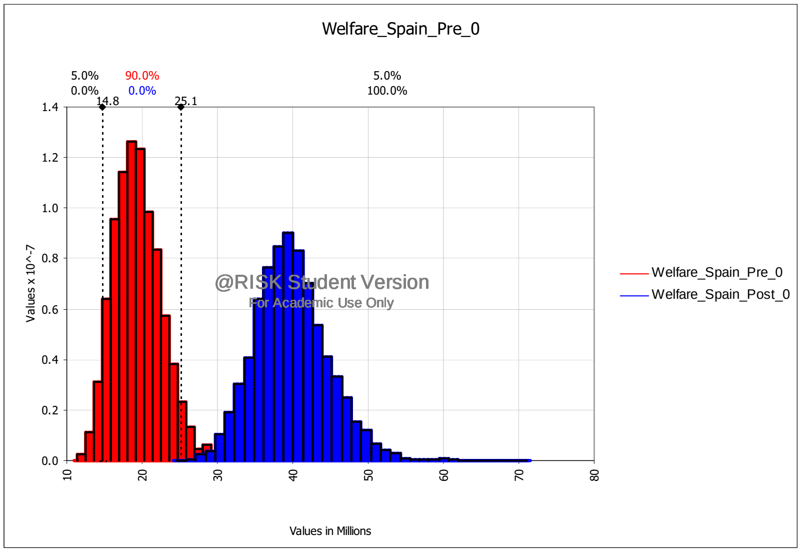
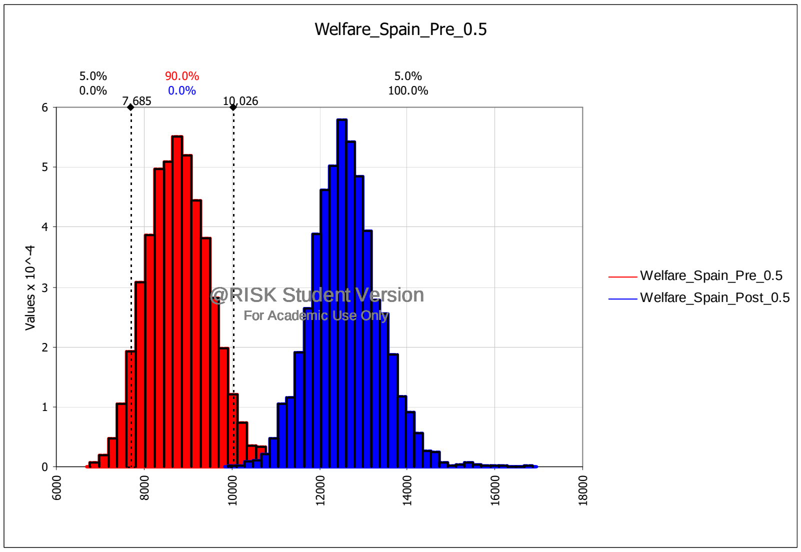


Figure 6: Comparison of Basin Welfare Distributions Pre & Post Treaty

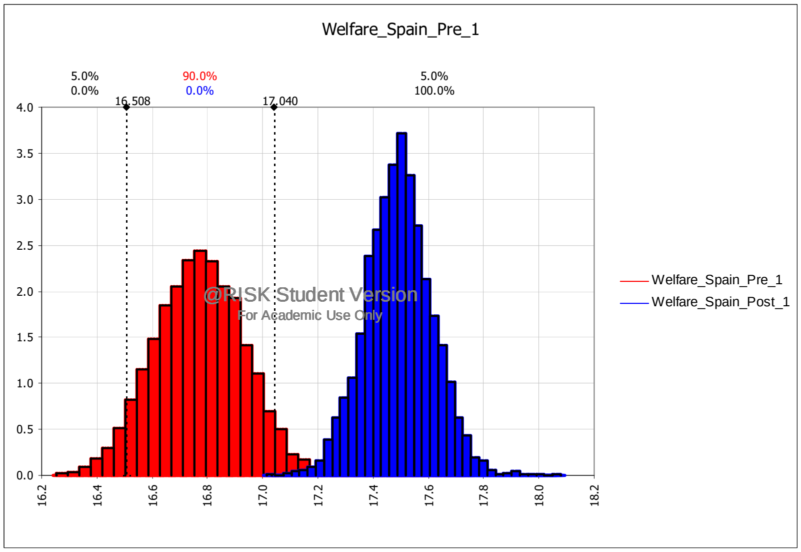
RRA=0



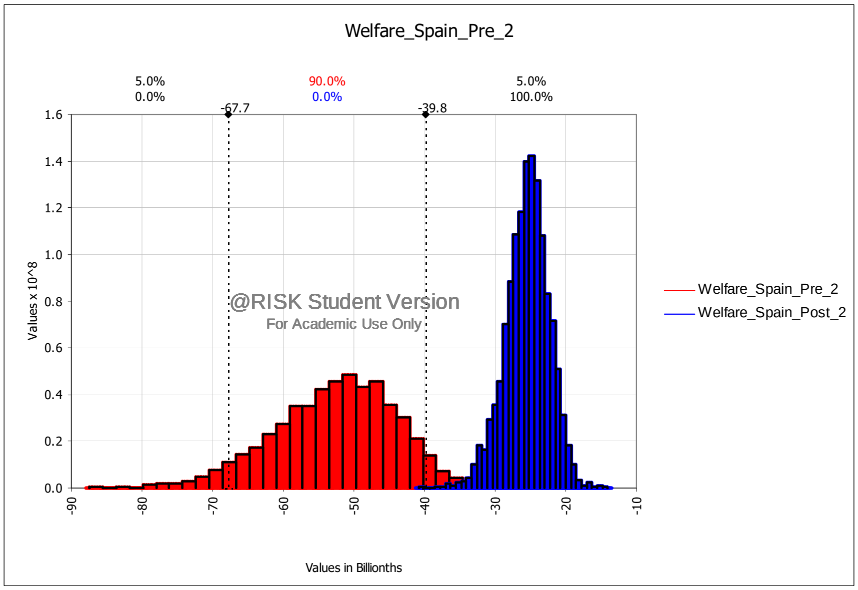
RRA=0.5



RRA=1



RRA=2


Welfare_Spain_Pre_2
5.0%
0.0%
90.0%
0.0%
5.0%
100.0%
-67.7
-39.8
1.6
1.4
1.2
1.0
0.8
0.6
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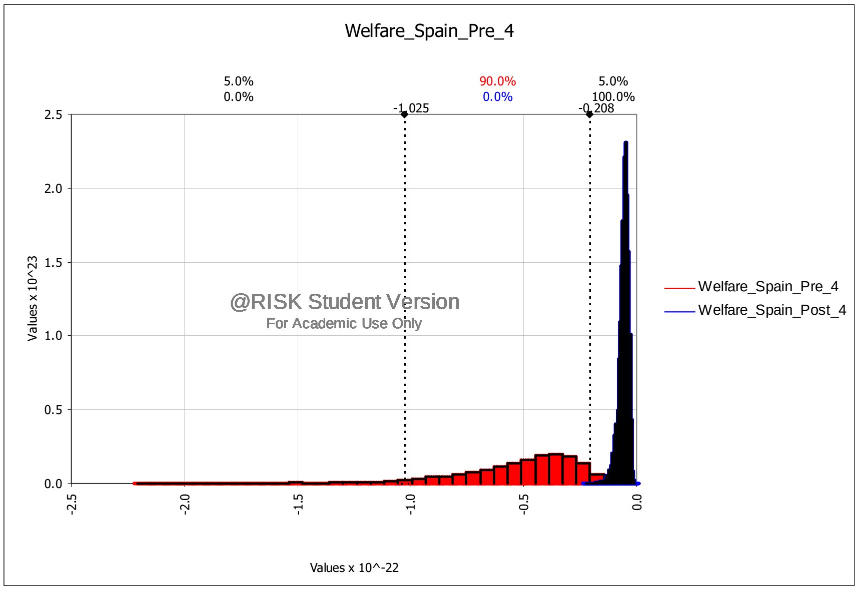
-30
-20
-10
Values in Billionths
Welfare_Spain_Pre_2
Welfare_Spain_Post_2

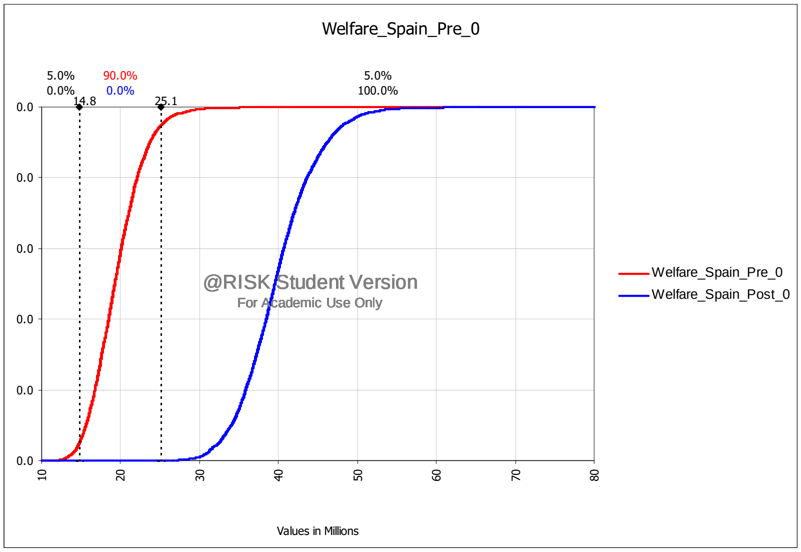
RRA=4


Welfare_Spain_Pre_4
5.0%
0.0%
90.0%
0.0%
5.0%
100.0%
-1.025
-0.208
2.5
2.0
1.5
1.0
0.5
0.0
Values x 10^23
@RISK Student Version
For Academic Use Only
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
Values x 10^-22
Welfare_Spain_Pre_4
Welfare_Spain_Post_4

d

Figure 7: Comparison of Cumulative Basin Welfare Distributions Pre & Post Treaty

RRA=0



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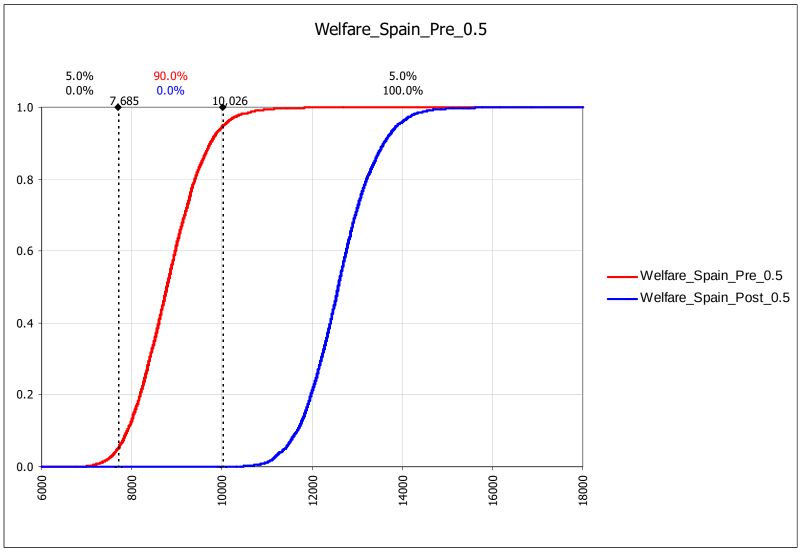

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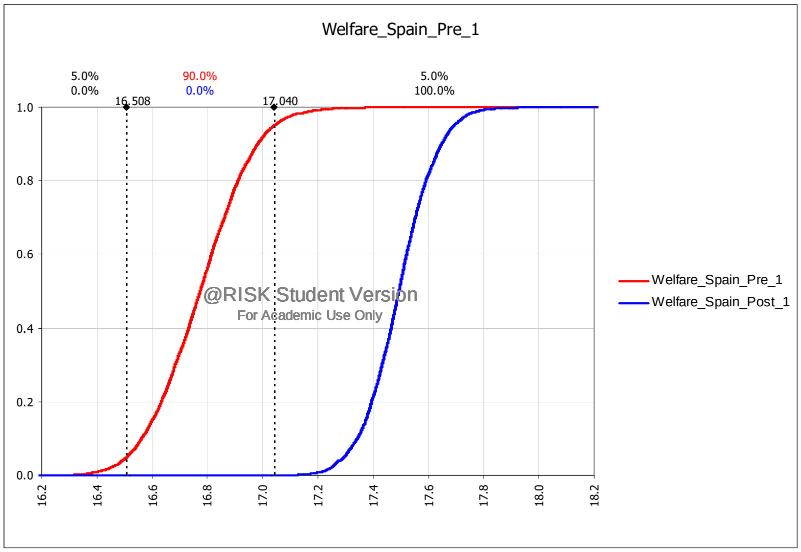
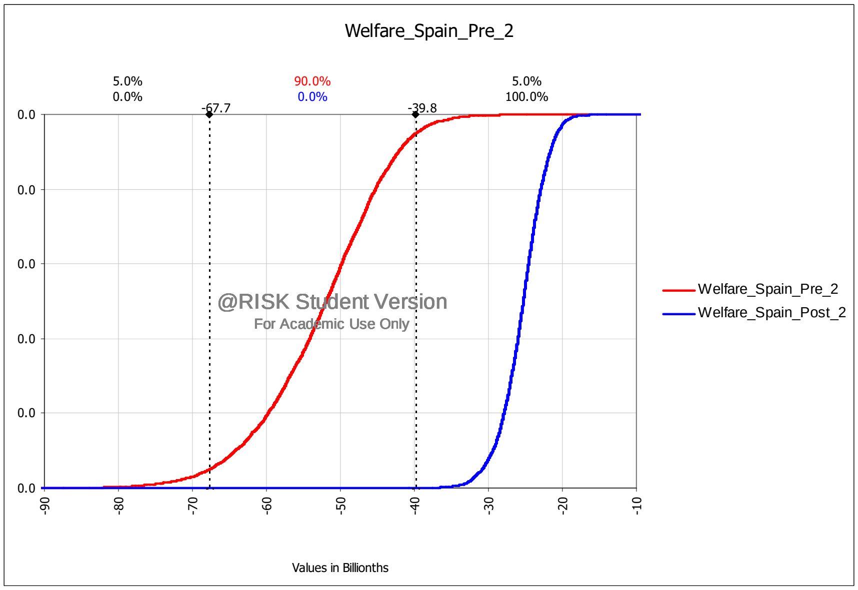


RRA=2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90.0%
0.0%
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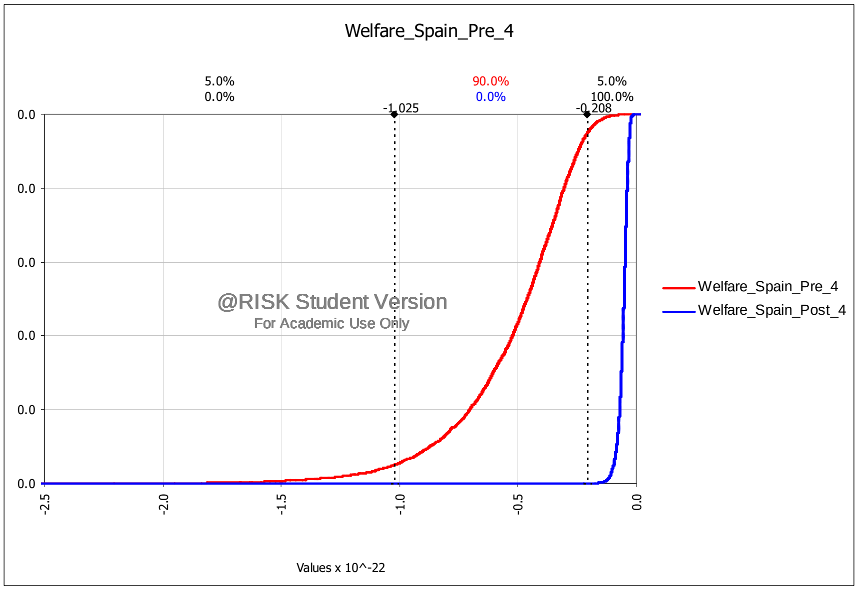
100.0%
-67.7
-39.8
0.0
0.0
0.0
0.0
0.0
0.0
-90
-80
-70
-60
-50
-40
-30
-20
-10
@RISK Student Version
For Academic Use Only
Welfare_Spain_Pre_2
Welfare_Spain_Post_2
Values in Billionths

RRA=4


Welfare_Spain_Pre_4
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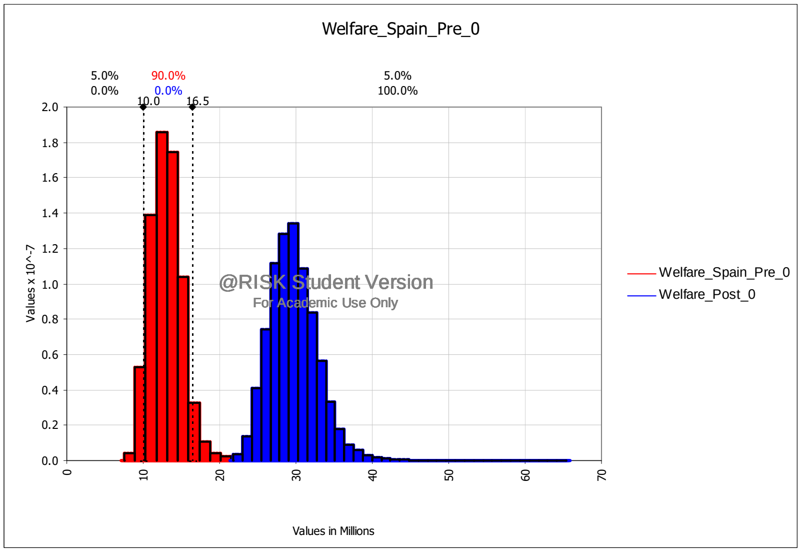
0.0%
90.0%
0.0%
5.0%
100.0%
-1.025
-0.208
0.0
0.0
0.0
0.0
0.0
0.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
@RISK Student Version
For Academic Use Only
Welfare_Spain_Pre_4
Welfare_Spain_Post_4
Values x 10^-22

Figure 8: Comparison of Simulated Welfare Distributions under drought conditions

RRA=0



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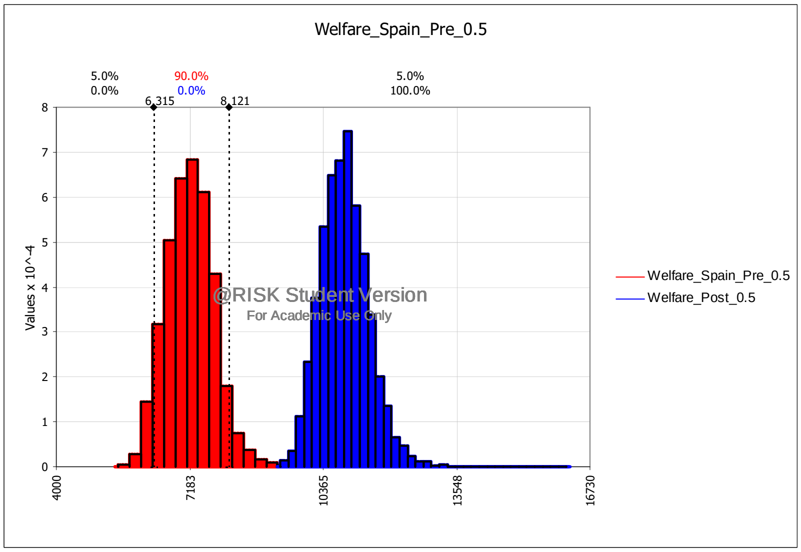

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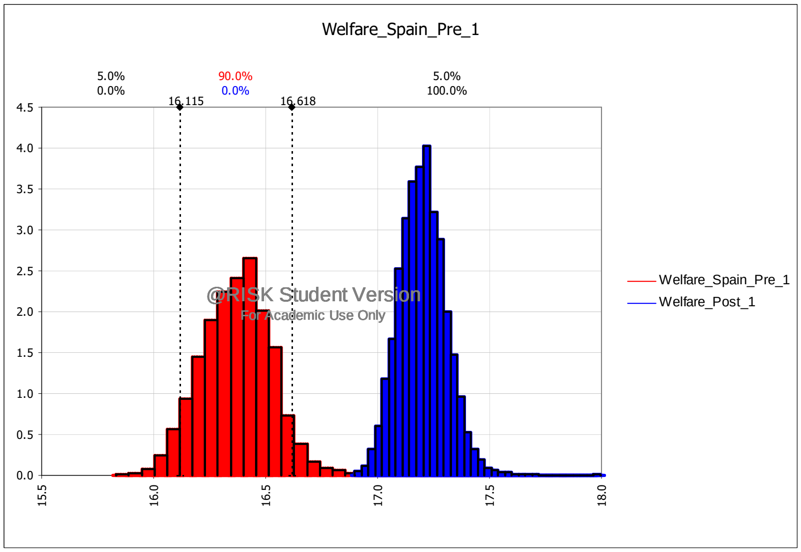

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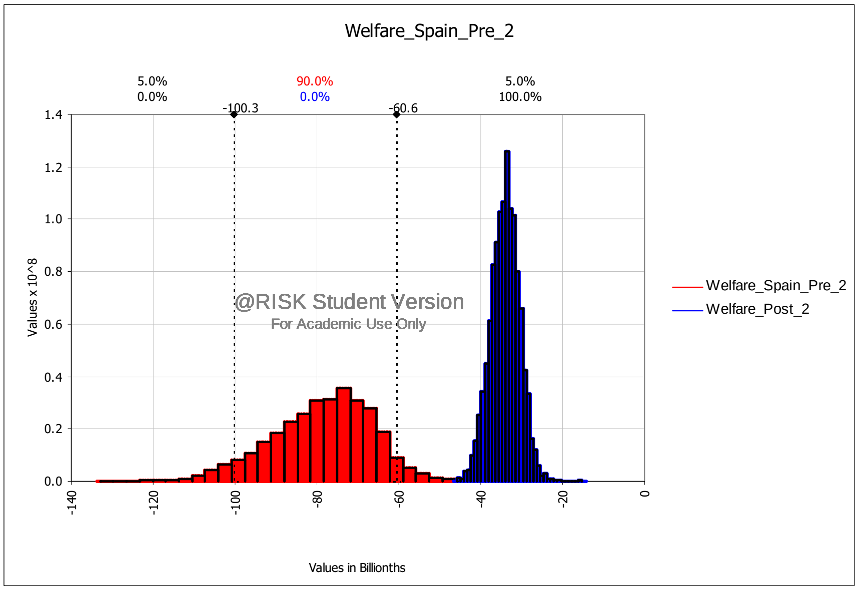
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0.0%
90.0%
0.0%
5.0%
100.0%
-100.3
-60.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Values x 10^8
@RISK Student Version
For Academic Use Only
-140
-120
-100
-80
-60
-40
-20
0
Values in Billionths
Welfare_Spain_Pre_2
Welfare_Post_2

d

RRA=4

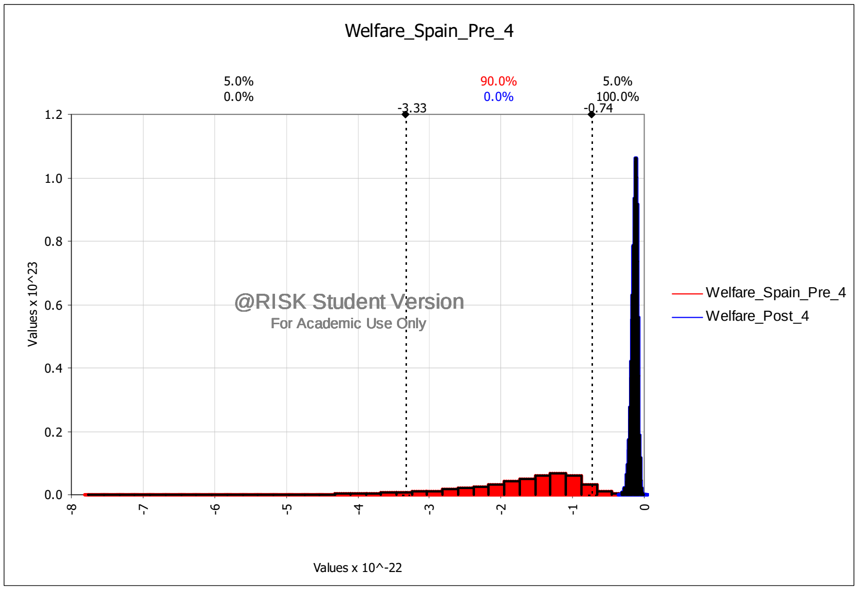
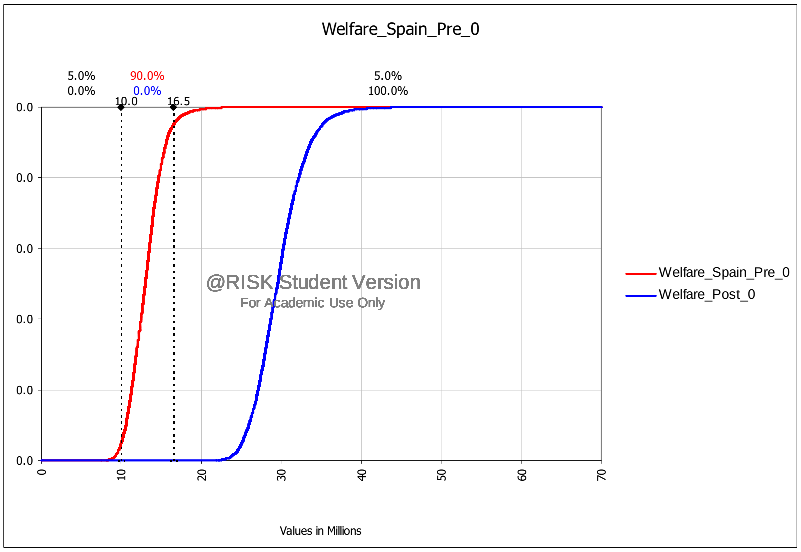
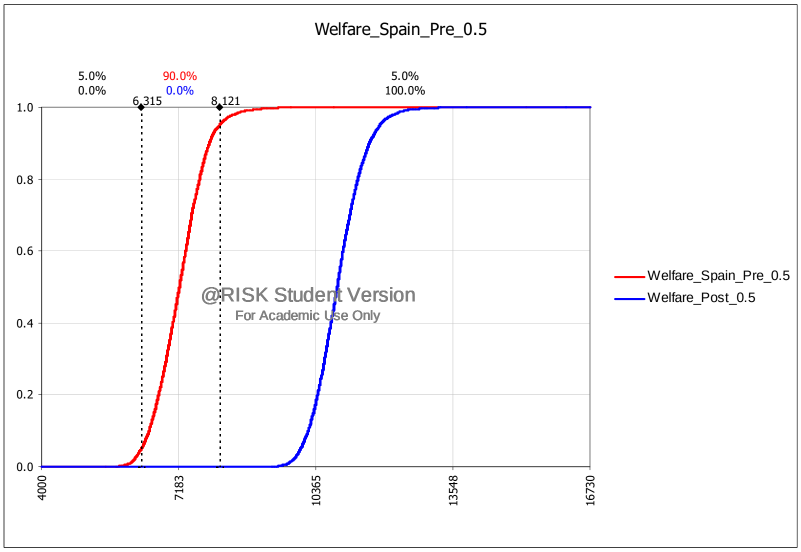

Welfare_Spain_Pre_4
5.0%
0.0%
90.0%
0.0%
5.0%
100.0%
-3.33
-0.74
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Values x 10^23
@RISK Student Version
For Academic Use Only
-8
-7
-6
-5
-4
-3
-2
-1
0
Values x 10^-22
Welfare_Spain_Pre_4
Welfare_Post_4

Figure 9: Comparison of Simulated Cumulative Welfare Distributions under drought conditions

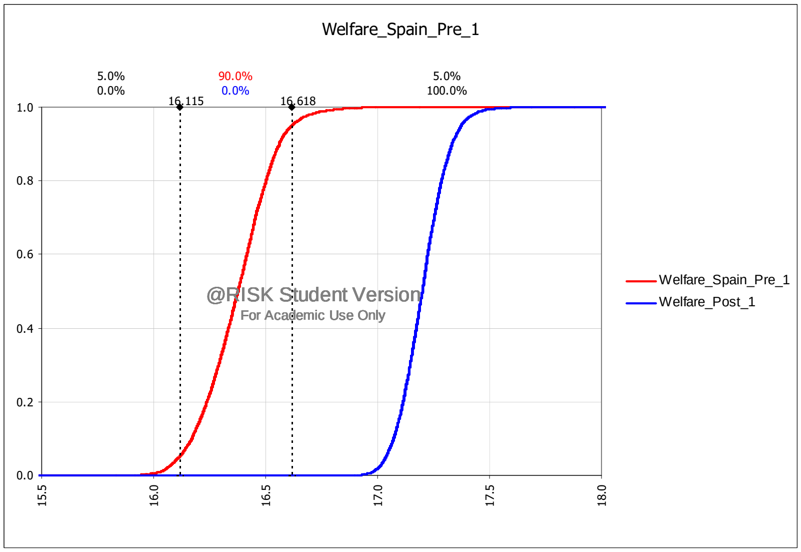
RRA=0



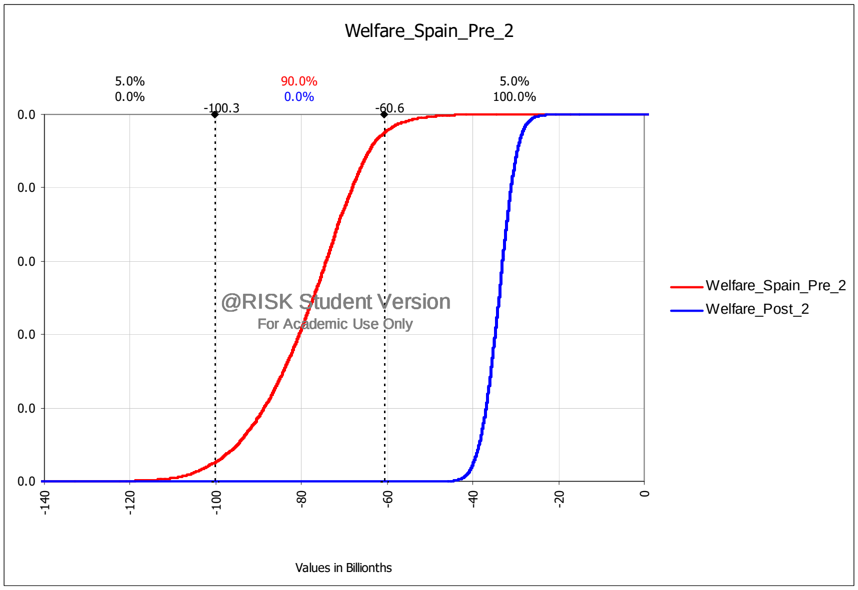
RRA=0.5



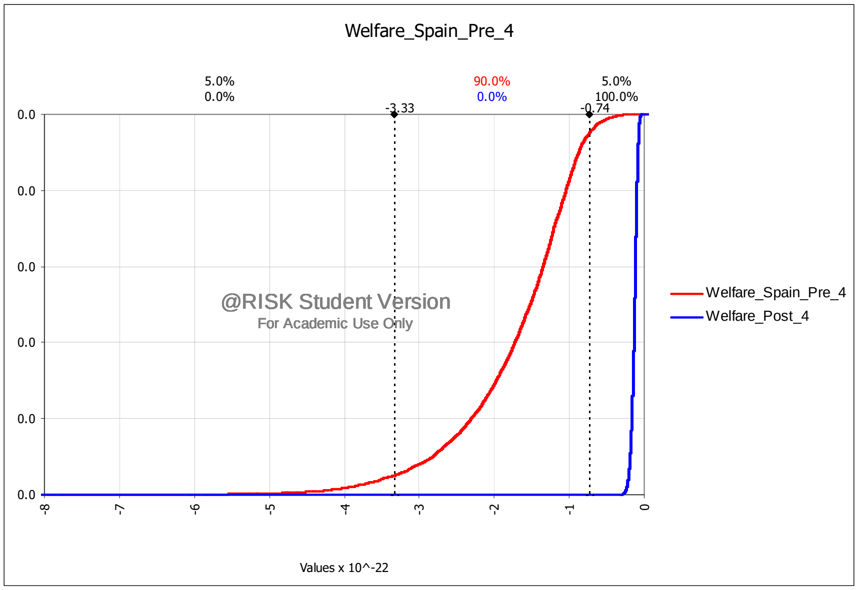
RRA=1



RRA=2


Welfare_Spain_Pre_2
5.0%
0.0%
90.0%
0.0%
5.0%
100.0%
-100.3
-60.6
0.0
0.0
0.0
0.0
0.0
0.0
-140
-120
-100
-80
-60
-40
-20
0
@RISK Student Version
For Academic Use Only
Welfare_Spain_Pre_2
Welfare_Post_2
Values in Billionths

RRA=4


Welfare_Spain_Pre_4
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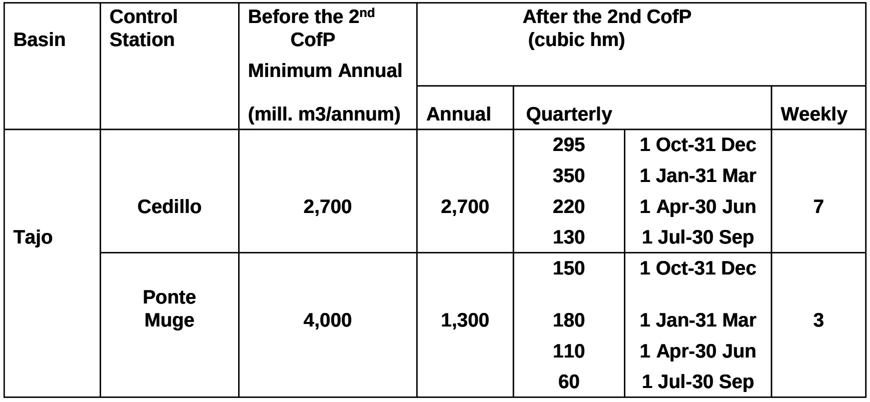
90.0%
0.0%
5.0%
100.0%
-3.33
-0.74
0.0
0.0
0.0
0.0
0.0
0.0
-8
-7
-6
-5
-4
-3
-2
-1
0
@RISK Student Version
For Academic Use Only
Welfare_Spain_Pre_4
Welfare_Post_4
Values x 10^-22

Table 1: Minimum Flow Requirements as Specified by the Albufeira Convention



Basin	Control Station	Before the 2nd CofP Minimum Annual (mill. m3/annum)	After the 2nd CofP (cubic hm)			
			Annual	Quarterly		Weekly
Tajo	Cedillo	2,700	2,700	295	1 Oct-31 Dec	7
				350	1 Jan-31 Mar	
				220	1 Apr-30 Jun	
				130	1 Jul-30 Sep	
	Ponte Muge	4,000	1,300	150	1 Oct-31 Dec	3
				180	1 Jan-31 Mar	
				110	1 Apr-30 Jun	
				60	1 Jul-30 Sep	

Source: Garrido & Llamas (2010)

Table 2: Regression Estimates for Checking Parallel Trends Assumption

	Barley		Wheat		Olive	
	Ist CofP	2nd CofP	Ist CofP	2nd CofP	Ist CofP	2nd CofP
Pre-Treaty Time Dummy	0.22 **	0.19 *	0.26 **	0.07	-0.35 **	0.08
	(0.11)	(0.11)	(0.11)	(0.10)	(0.14)	(0.13)
Land & Pre-Treaty Time_Interaction	0.07	-0.15	0.07	0.00	-0.10	0.01
	(0.15)	(0.15)	(0.15)	(0.15)	(0.23)	(0.20)
Precip_Square	-0.19 ***	-0.22 ***	-0.20 ***	-0.20 ***	-0.15 ***	-0.21 ***
	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)	(0.03)
Log(area under cultivation)	0.00 **	0.00	0.00 ***	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	9.63 ***	10.07 ***	9.44 ***	9.68 ***	8.43 ***	8.67 ***
	(0.32)	(0.41)	(0.27)	(0.35)	(0.25)	(0.30)
N	109	75	109	77	90	70
R-Sq Within	0.45	0.44	0.48	0.43	0.42	0.56
F statistic	19.64	12.19	22.19	12.10	14.38	18.13
Prob > F	0.00	0.00	0.00	0.00	0.00	0.00

Table 3: Table Showing the Difference-in-Difference Estimates for the Treaty Impacts

	Barley		Wheat		Olive	
	Ist CofP	2nd CofP	Ist CofP	2nd CofP	Ist CofP	2nd CofP
Land Dummy	0.60 ***	0.42 ***	0.59 ***	0.45 ***	0.79 ***	0.89 ***
	(0.10)	(0.11)	(0.12)	(0.08)	(0.19)	(0.17)
Post-Treaty Time Dummy	-0.37 ***	-0.49 ***	-0.37 **	-0.42 ***	0.14	-0.09
	(0.10)	(0.04)	(0.13)	(0.06)	(0.14)	(0.14)
Land &Post Treaty Time_Interaction	-0.02	0.25 **	0.03	0.21 **	-0.04	0.07
	(0.06)	(0.09)	(0.06)	(0.08)	(0.19)	(0.09)
Precip_Square	0.00 **	0.00	0.00 **	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Precip_Time_Lag	0.00	0.02 ***	0.00	0.02 ***	0.01 **	0.00
	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.01)
Precip_Spatial_Lag	0.04 ***	0.00	0.04 ***	-0.01	0.01	-0.02
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.03)
Constant	6.40 ***	6.73 ***	6.41 ***	7.03 ***	5.93 ***	7.66 ***
	(0.15)	(0.75)	(0.21)	(0.73)	(0.24)	(1.11)
N	95	65	95	67	76	61
R-Sq Within	0.60	0.74	0.63	0.72	0.53	0.62
F statistic	851.09	31.39	292.81	28.22	683.97	359.23
Prob > F	0.00	0.00	0.00	0.00	0.00	0.00

Table 4: Cobb Douglas Production Function with Precipitation as the Hydrological Indicator

	Barley	Barley	Wheat	Wheat	Olives	Olives
Variables	Pre-Treaty	Post Treaty	Pre-Treaty	Post Treaty	Pre-Treaty	Post Treaty
Log(Precip)	1.45 ***	0.66 ***	0.77 ***	0.82 ***	0.57 **	0.26
	(0.15)	(0.15)	(0.27)	(0.14)	(0.25)	(0.19)
Land Dummy	3.78 ***	2.42 ***	0.82	2.95 ***	1.40	-0.86
	(0.76)	(0.84)	(1.37)	(0.78)	(1.50)	(1.21)
Land & Log(Precip)	-0.77 ***	-0.47 **	-0.01	-0.60 ***	-0.15	0.44
	(0.20)	(0.21)	(0.35)	(0.20)	(0.39)	(0.31)
Province						
2	-0.89 ***	-0.28 ***	-0.55 ***	-0.23 **	-0.02	0.48 ***
	(0.09)	(0.11)	(0.17)	(0.10)	(0.17)	(0.14)
3	-0.19 **	-0.15 *	0.09	-0.05	-0.66 ***	-0.33 **
	(0.09)	(0.10)	(0.16)	(0.09)	(0.16)	(0.14)
4	-0.17 **	-0.14 *	0.06	0.02	-0.21	0.20 *
	(0.09)	(0.10)	(0.16)	(0.09)	(0.18)	(0.12)
5	-0.48 ***	-0.29 ***	-0.41 **	-0.18 **	-0.65 ***	0.15
	(0.09)	(0.10)	(0.17)	(0.09)	(0.17)	(0.14)
6	-0.21 **	-0.38 ***	0.01	-0.31 ***	-0.16	0.17
	(0.09)	(0.10)	(0.16)	(0.09)	(0.15)	(0.12)
7	-0.33 ***	-0.28 ***	-0.11	-0.42 ***	0.55 ***	0.71 ***
	(0.09)	(0.10)	(0.16)	(0.09)	(0.17)	(0.12)
8	-0.44 ***	-0.37 ***	-0.18	-0.25 ***	0.63 ***	1.01 ***
	(0.09)	(0.10)	(0.16)	(0.09)	(0.17)	(0.13)
Constant	2.09 ***	5.37 ***	4.45 ***	4.67 ***	4.04 ***	5.43 ***
	(0.57)	(0.59)	(1.02)	(0.56)	(0.95)	(0.76)
N	288	184	288	186	227	161
Adjusted R Square	0.63	0.47	0.29	0.56	0.45	0.67
F statistic	49.55	17.48	12.44	24.72	19.55	33.07
Prob > F	0.00	0.00	0.00	0.00	0.00	0.00

Table 5: Comparison of Risk Premiums

	Normal	Condition	Drought-like	Condition
Risk Premium	Pre-treaty	Post Treaty	Pre-treaty	Post Treaty
RP_0	0.00	0.00	0.00	0.00
RP_0.5	140304.21	142912.74	90937.20	84468.23
RP_1	280608.42	285825.47	181874.40	168936.47
RP_2	561216.83	571650.94	363748.80	337872.94
RP_4	1122433.67	1143301.88	727497.59	675745.88
PRP_0	0.00	0.00	0.00	0.00
PRP_0.5	0.007	0.005	0.006	0.002
PRP_1	0.014	0.011	0.013	0.005
PRP_2	0.028	0.023	0.027	0.011
PRP_4	0.057	0.046	0.055	0.022

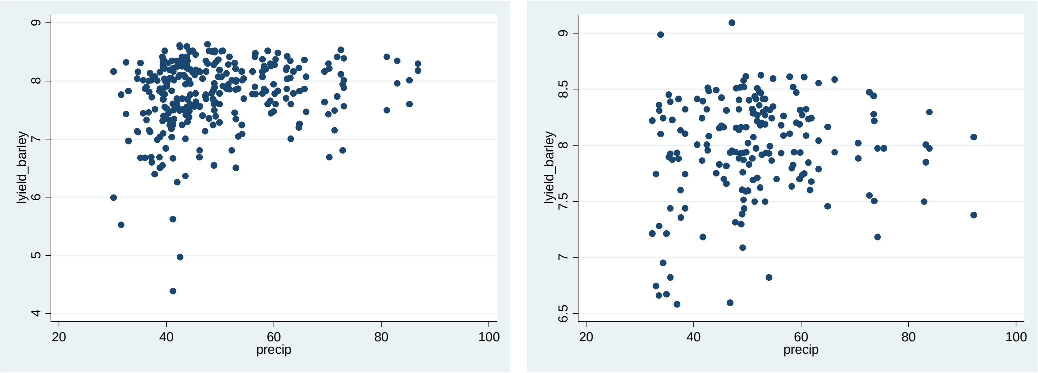
Appendix

Figure 10: Spatial Distribution of Soil Wetness Values

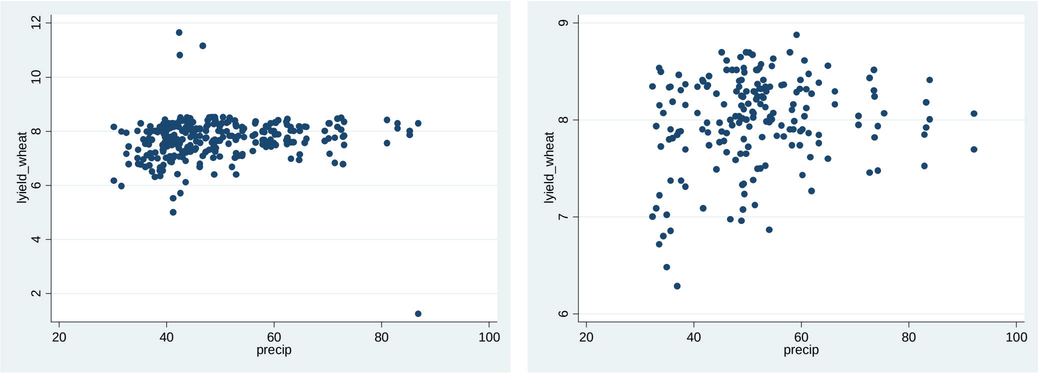
Figure 11: Distribution of Drought Index Values

Figure 12: Yield as a function of precipitation pre (left panel) and post (right panel) treaty

Barley



Wheat



Olives

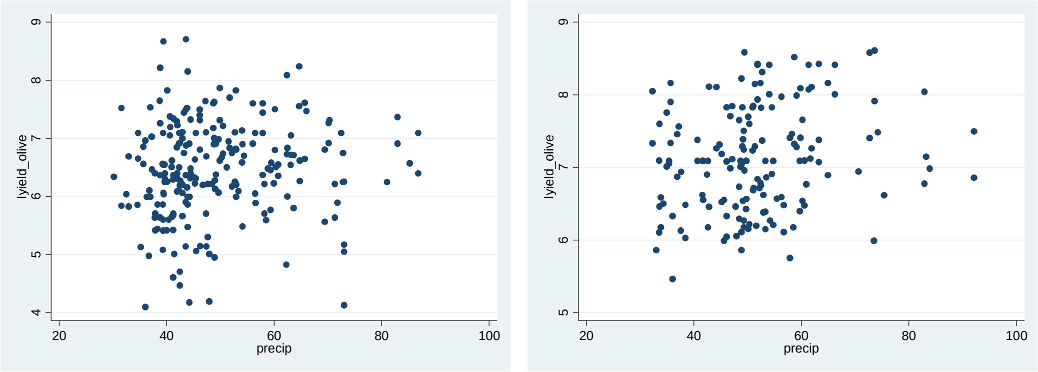
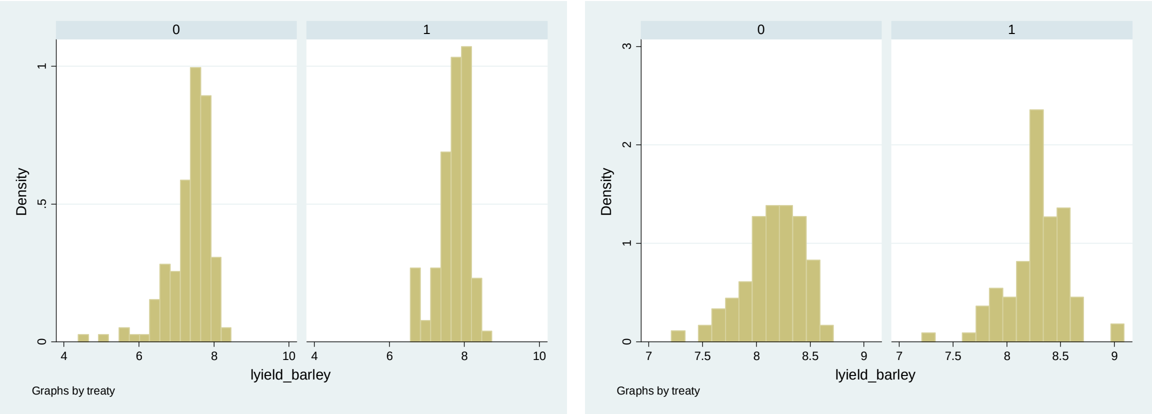
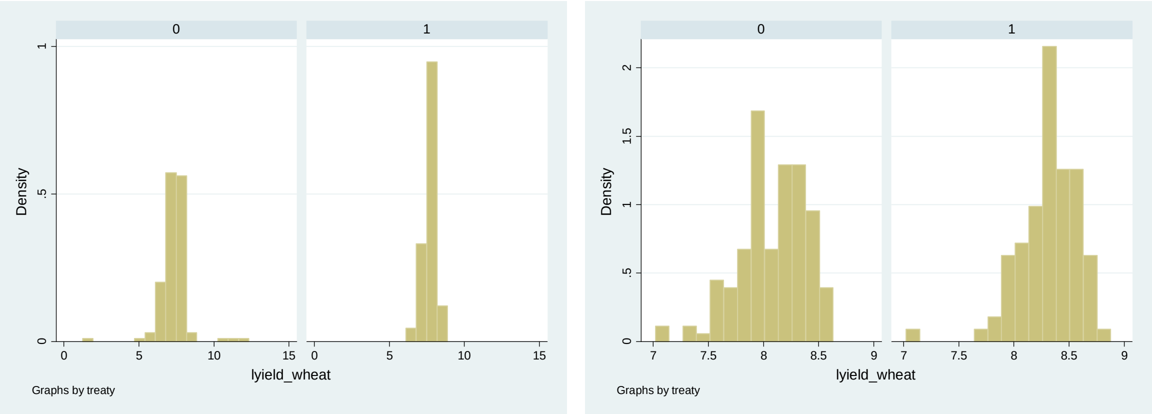


Figure 13: Histogram of crop yields before and after the treaty



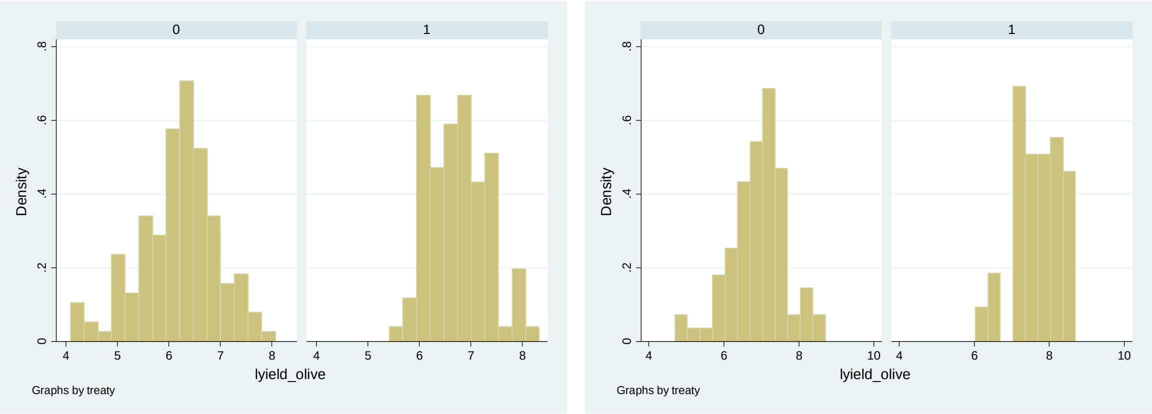
Barley (On Rainfed Land)

Barley (On Irrigated Land)



Wheat (On Rainfed Land)

Wheat (On Irrigated Land)



Olive (On Rainfed Land)

Olive (On Irrigated Land)

Figure 14: Graph showing price trends of the five crops

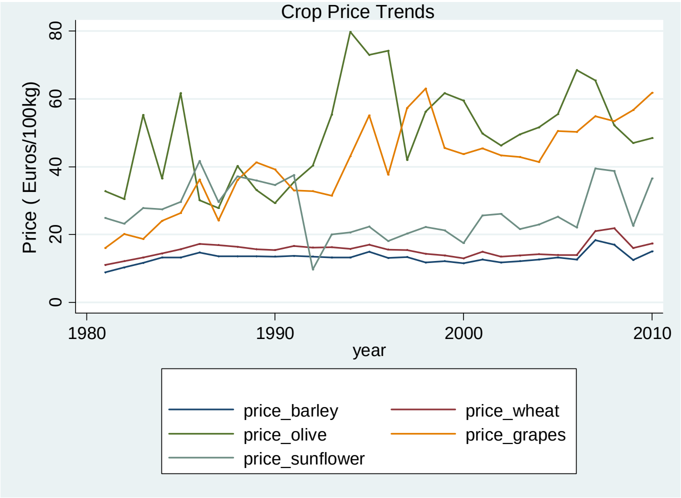
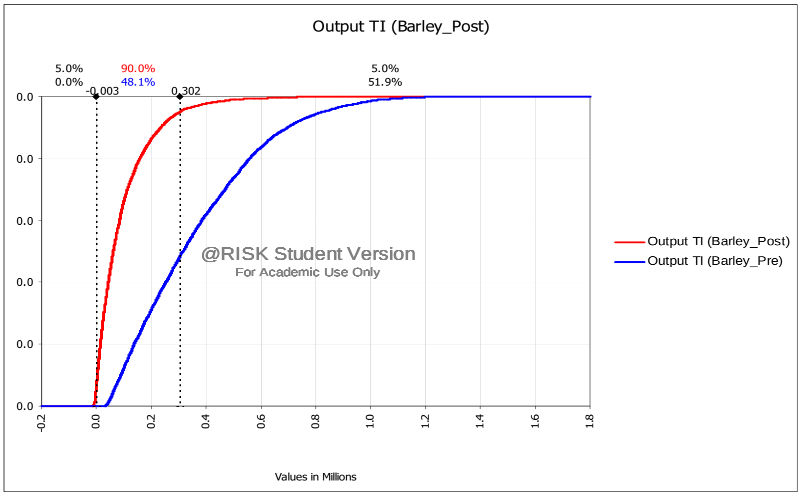
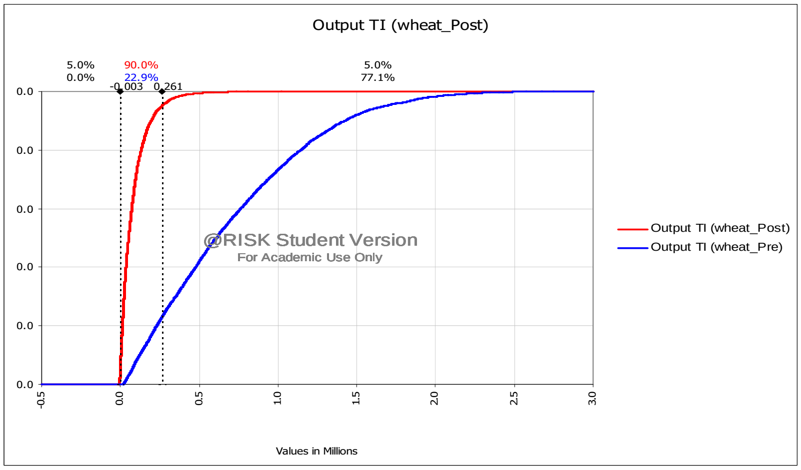


Figure 15: Simulation of Cropwise Gross Revenue for Caceres

(a) Barley



(b) Wheat



(c) Olive

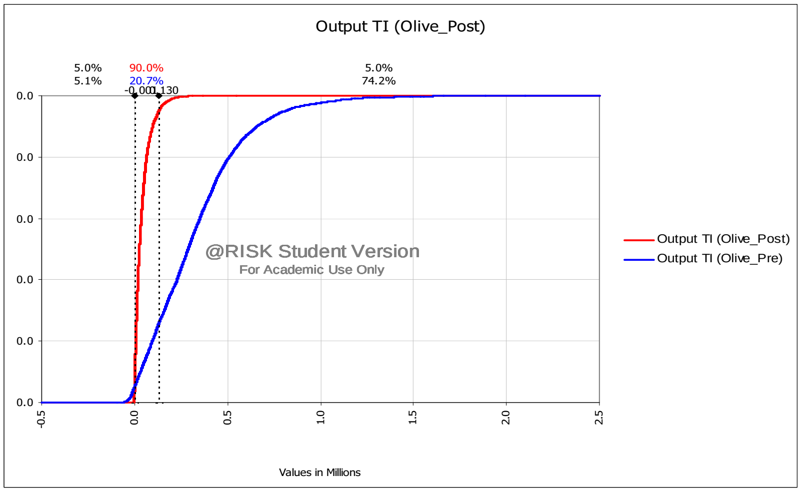
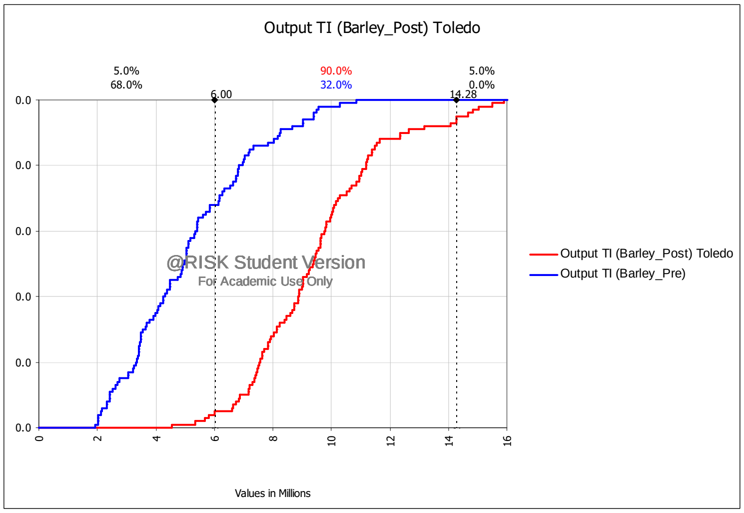
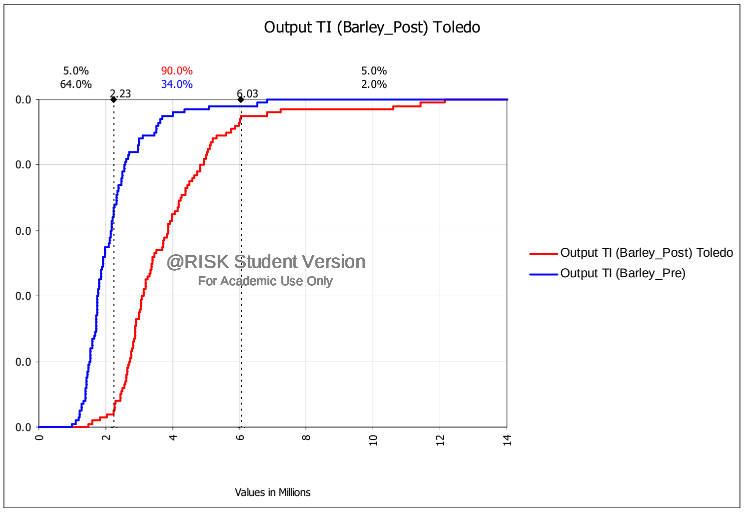


Figure 16: Simulation of Cropwise Gross Revenue for Toledo

(a) Barley



(b) Wheat



(c) Olive

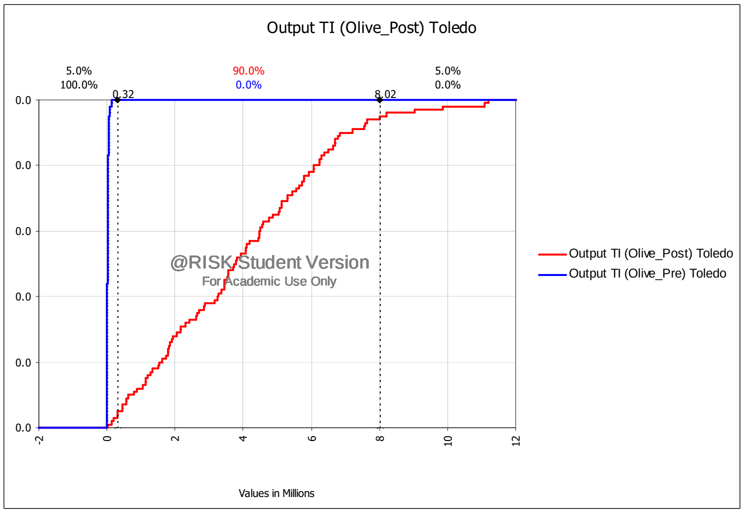
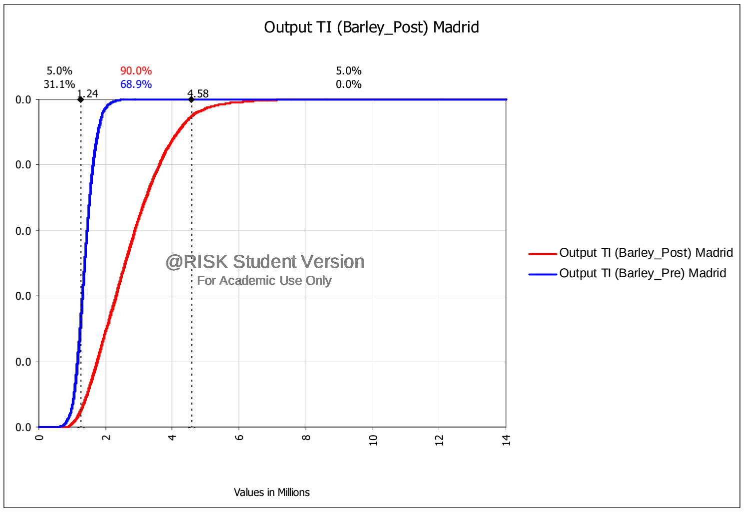
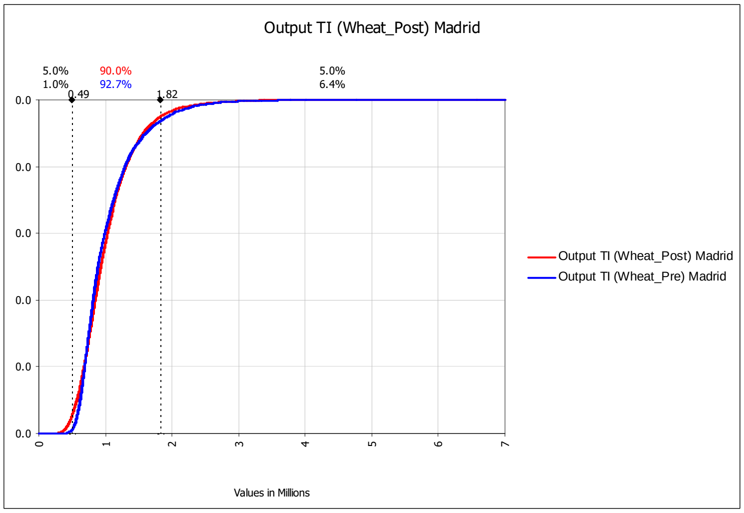


Figure 17: Simulation of Cropwise Gross Revenue for Madrid

(a) Barley



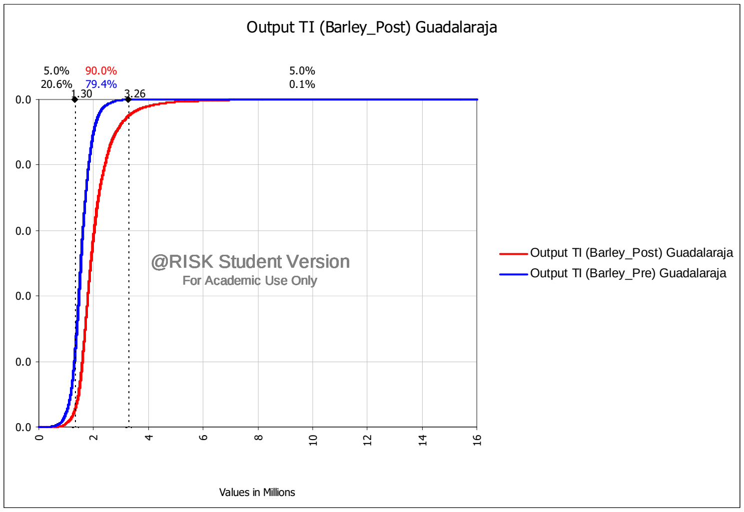
(b) Wheat



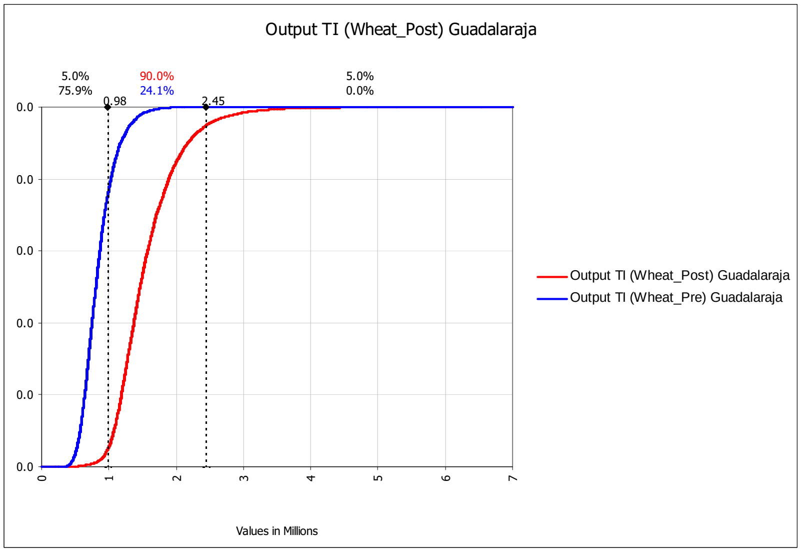
(c) Olive

Figure 18: Simulation of Cropwise Gross Revenue for Guadalaraja

(a) Barley



(b) Wheat



(c) Olive

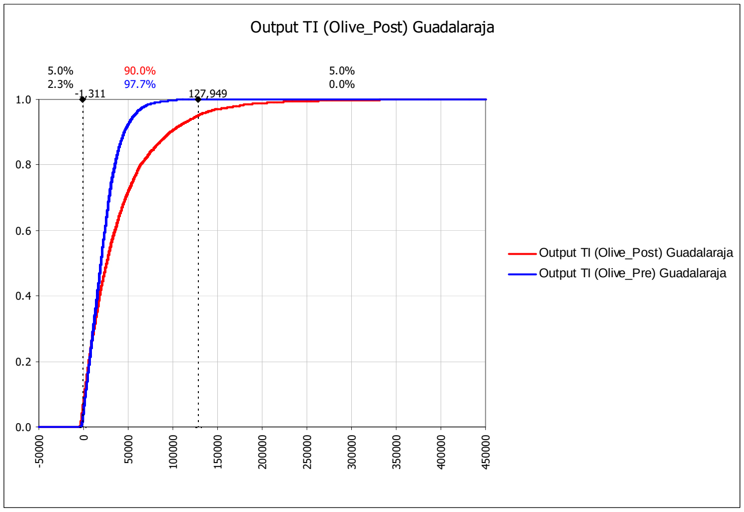
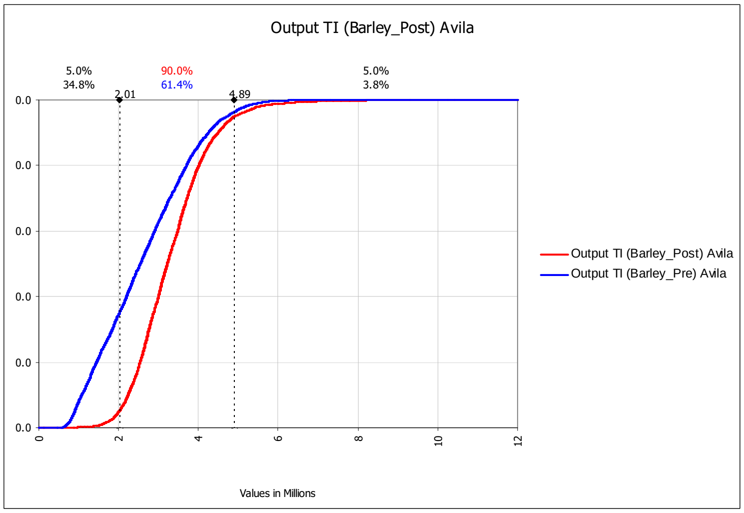
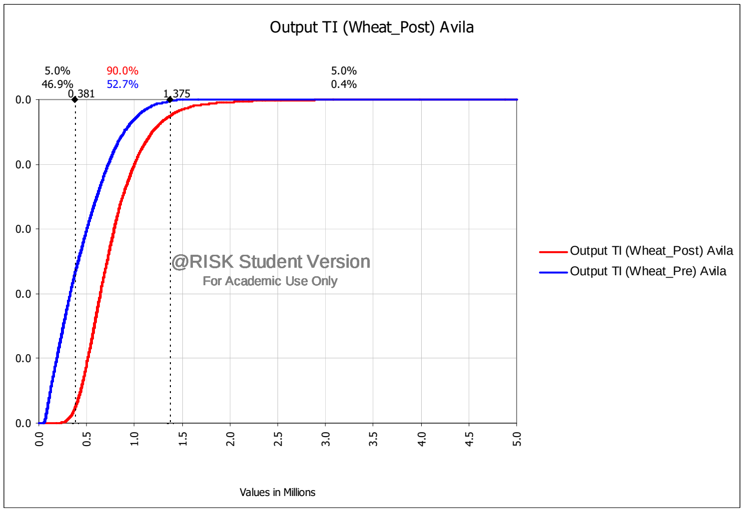


Figure 19: Simulation of Cropwise Gross Revenue for Avila

(a) Barley



(b) Wheat



(c) Olive

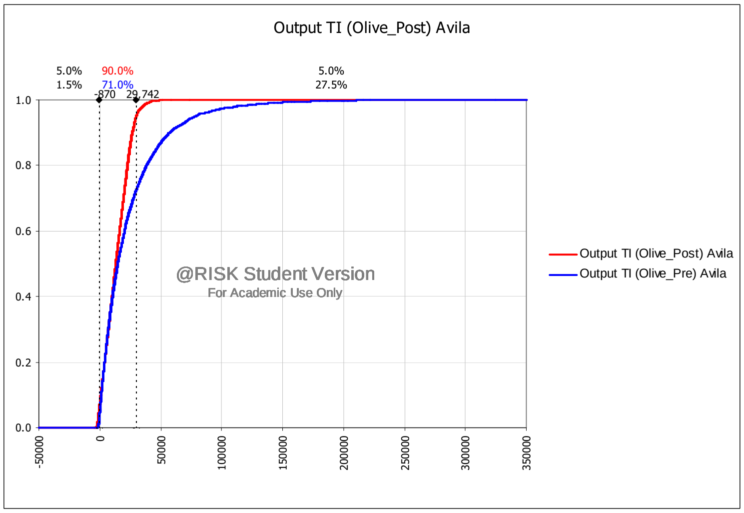


Table 6: Summary Statistics for the pre and post treaty period

Variable	Pre Treaty				Post Treaty			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
larea_barley	9.74	1.79	4.79	12.62	9.97	1.59	5.01	12.57
larea_wheat	9.04	1.78	3.91	11.95	9.02	1.5	4.75	11.44
larea_olive	8.02	2.93	1.1	11.5	8.22	2.55	0.69	11.64
larea_grape	7.73	3.05	0.7	12.21	7.76	2.81	0.69	11.89
larea_sunflower	8.17	1.94	2.4	12.47	7.53	1.88	3.53	11.98
lyield barley	7.76	0.61	4.38	8.63	7.99	0.46	6.58	9.09
lyield_wheat	7.7	0.79	1.25	11.64	7.99	0.47	6.29	8.88
lyield_olive	6.46	0.83	4.09	8.7	7.12	0.72	5.46	8.61
lyield_grape	7.87	0.76	5.06	9.47	8.27	0.64	6.66	9.49
lyield_sunflower	6.96	0.88	4.47	12.16	6.93	0.6	4.51	9.1
precip	49.17	11.72	30.18	86.87	52.04	12.36	32.29	92.16
spi	0.23	0.14	0	0.67	0.27	0.17	0	0.65
soil_moist	0.24	0.02	0.21	0.28	0.24	0.02	0.22	0.3
soil_wet	0.45	0.39	0.01	1.76	0.46	0.31	0	1.35
precip_1	48.4	11.06	30.18	86.87	51.47	12.09	32.29	92.16
spi_1	-0.09	0.25	-0.67	0.44	0.08	0.28	-0.57	0.62
precip_spatial lag1	46.83	8.76	31.61	72.49	49.86	9.61	32.29	74.27
spi_spatial lag1	-0.09	0.26	-0.67	0.39	0.11	0.3	-0.57	0.65
soil_moist_spatial lag1	0.25	0.02	0.21	0.28	0.26	0.16	0.23	0.3
soil_wet_spatial lag1	-0.16	0.6	-1.76	1.55	0.15	0.54	-0.74	1.35

Table 7: Anova & t-test Results for Differences in Mean & s.d. of Rainfed & Irrigated Land Usage

Crop		Rainfed	Land	Usage	Irrigated	Land	Usage
	Statistic	Pre Treaty	Post Treaty	Difference	Pre Treaty	Post Trety	Difference
Barley							
	Std. Dev	0.95	1.29	0.34	0.82	0.78	-0.04
	Mean	11.29	11.09	-0.2	8.19	8.75	0.56
Wheat							
	Std. Dev	0.77	0.72	-0.05	0.79	0.79	0
	Mean	10.64	10.28	-0.36	7.44	7.69	0.25
Olive							
	Std. Dev	1.05	1.21	0.16	1.86	2.13	0.27
	Mean	9.98	9.82	-0.16	4.64	5.83	1.19
Grapes							
	Std. Dev	1.48	1.51	0.03	2.27	3.15	0.88
	Mean	9.54	9.07	-0.47	4.38	5.74	1.36
Sunflower							
	Std. Dev	1.61	2.12	0.51	1.52	1.18	-0.34
	Mean	9.32	8.31	-1.01	7	6.74	-0.26

Table 8: Anova & t-test Results for Yield and Gross Revenue on Irrigated Land

		Yield			Gross Revenue		
Crop	Statistic	Pre Treaty	Post Treaty	Difference	Pre Treaty	Post Treaty	Difference
Barley							
	Std. Dev	0.27	0.28	0.01	1777143	3849840	2072697 ***
	Mean	8.15	8.28	0.13 ***	2253873	4188670	1934797 ***
Wheat							
	Std. Dev	0.30	0.27	-0.03	893754	1376717	482963 ***
	Mean	8.08	8.31	0.23 ***	1132052	1855789	723737 ***
Olive							
	Std. Dev	0.75	0.61	-0.14 *	340010	1983404	1643393 ***
	Mean	6.92	7.64	0.72 ***	131587	973254	841666 ***
Grapes							
	Std. Dev	0.54	0.44	-0.10 *	9997012	46679615	36682602 ***
	Mean	8.56	8.79	0.23 ***	2061590	21475369	19413778 ***
Sunflower							
	Std. Dev	0.38	0.36	-0.02	2358426	1255794	-1102632 ***
	Mean	7.47	7.40	-0.08 *	1700276	1236932	-463344 **

Table 9: Correlation Matrix for Hydrological Variables

	precip	spi	soil_moist	soil_wet
precip	1			
spi	0.1895	1		
soil_moist	0.6782	0.2051	1	
soil_wet	0.0011	0.2313	0.0595	1

Table 10: Cobb Douglas Production Function with SPI as the Hydrological Indicator

	Barley	Barley	Wheat	Wheat	Olives	Olives
Variables	Pre-Treaty	Post Treaty	Pre-Treaty	Post Treaty	Pre-Treaty	Post Treaty
Log (SPI)	-0.02	0.00	-0.05	0.02	0.06	-0.02
	(0.03)	(0.03)	(0.05)	(0.03)	(0.05)	(0.04)
Land Dummy	0.79 ***	0.56 ***	0.88 ***	0.56 ***	0.87 ***	0.96 ***
	(0.10)	(0.09)	(0.16)	(0.09)	(0.16)	(0.13)
Land & Log (SPI)	0.00	0.00	0.06	-0.03	0.04	0.07
	(0.05)	(0.05)	(0.07)	(0.05)	(0.08)	(0.06)
Province						
2	-0.62 ***	-0.17	-0.36 **	-0.11	0.15	0.58 ***
	(0.10)	(0.11)	(0.16)	(0.11)	(0.16)	(0.14)
3	-0.14	-0.14	0.12	-0.04	-0.62 ***	-0.30 **
	(0.10)	(0.10)	(0.16)	(0.10)	(0.16)	(0.15)
4	-0.08	-0.11	0.12	0.05	-0.13	0.23 *
	(0.10)	(0.10)	(0.16)	(0.10)	(0.18)	(0.13)
5	-0.14	-0.18 *	-0.17	-0.06	-0.48 ***	0.24 *
	(0.10)	(0.10)	(0.16)	(0.10)	(0.15)	(0.14)
6	-0.13	-0.36 ***	0.07	-0.28 ***	-0.12	0.19 *
	(0.10)	(0.10)	(0.16)	(0.10)	(0.15)	(0.13)
7	-0.22 **	-0.24 **	-0.04	-0.37 ***	0.62 ***	0.75 ***
	(0.10)	(0.10)	(0.16)	(0.10)	(0.16)	(0.13)
8	-0.23 **	-0.31 ***	-0.03	-0.18 *	0.77 ***	1.08 ***
	(0.10)	(0.10)	(0.16)	(0.10)	(0.17)	(0.13)
Constant	7.53 ***	7.91 ***	7.25 ***	7.85 ***	6.28 ***	6.38 ***
	(0.10)	(0.09)	(0.15)	(0.09)	(0.14)	(0.11)
N	288	184	288	186	227	161
Adjusted R Square	0.49	0.42	0.25	0.48	0.45	0.65
F statistic	28.02	13.98	10.56	18.05	19.21	30.64
Prob > F	0.00	0.00	0.00	0.00	0.00	0.00

Table 11: Random Effects GLS with Precipitation as the Hydrological Indicator

	Barley	Barley	Wheat	Wheat	Olives	Olives
Variables	Pre-Treaty	Post Treaty	Pre-Treaty	Post Treaty	Pre-Treaty	Post Treaty
Precip	0.72 ***	0.06 ***	0.10 **	0.07 ***	0.03	0.06 **
	(0.02)	(0.01)	(0.05)	(0.01)	(0.05)	(0.03)
Precip Timelag	-0.001	0.00	0.00	0.00	0.01 *	0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
Precip Spatial Lag	-0.003	0.01	0.02 *	0.00	0.00	-0.03 *
	(0.005)	(0.01)	(0.01)	(0.01)	(0.03)	(0.02)
Precip Square	0 ***	0.00 ***	0.00 **	0.00 ***	0.00	0.00 *
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Land Dummy	1.49 ***	0.96 ***	0.50	1.10 ***	0.87 **	0.49 **
	(0.19)	(0.19)	(0.60)	(0.21)	(0.38)	(0.24)
Land & Precip	-0.014 ***	-0.01 ***	0.01	-0.01 ***	0.00	0.01 *
	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)
Constant	5.04***	5.73 ***	4.27 ***	5.51 ***	5.33 ***	5.43 ***
	(0.46)	(0.30)	(1.13)	(0.24)	(0.71)	(0.37)
R-Sq Within	0.59	0.52	0.26	0.59	0.27	0.50
N	238	160	238	162	180	137
Wald Chi2	721.07	1778.75	1796.95	394.75	77.33	1445.60
Prob	0.00	0.00	0.00	0.00	0.00	0.00