Title
Runoff Variability and Transboundary Water Management: An Assessment of Risk to Regional Agreements From Likely Climatic Change

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Runoff Variability And Transboundary Water Management: An Assessment of Risk to
Regional Agreements From Likely Climatic Change

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

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in

Economics

by

Indrani Chatterjee

August 2014

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To my parents,

ABSTRACT OF THE DISSERTATION

Runoff Variability and Transboundary Water Management: An Assessment of Risk to
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by

Indrani Chatterjee

Doctor of Philosophy, Graduate Program in Economics
University of California, Riverside, August 2014
Professor Ariel Dinar,Co-Chairperson
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With localized increases in water stress, countries have become more reliant on sources
of freshwater which are often times shared with other riparian countries. Such
transboundary rivers are governed by treaties. 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. An additional source of complexity is that countries differ in their ability to
resist flow variabilities and thereby face different levels of risk from natural disasters and
hence are likely to have different propensities to co-operate with others. With Climate
Change the causes of non-compliance are exacerbated and this might hinder the ability of
river treaties to manage riparian conflicts. This raises concern whether arguments over
use of a limited resource might turn into international tensions and increase the likelihood

of conflicts. In view of the above, this dissertation attempts to estimate the risk faced by each riparian from natural disasters caused by extreme surface flows and explores whether this risk inflicts the risk of breaking down of a treaty as one or more parties retract from it. In order to do this a theoretical model is developed estimating the accepted level of risk premium associated with signing an international treaty and deriving the general conditions under which a riparian would choose to retract from an existing treaty. The model is then applied to the Tajo basin, to evaluate the effect of an existing river treaty (the Albufeira Convention) between Spain and Portugal on riparian welfare using satellite data on several water availability indices. Subsequently, it adopts a cooperative game theoretic exposition to find a fair and efficient way of allocating gains from cooperation and assess the stability of such an allocation scheme thereby evaluating the sustainability of the above treaty under extreme surface flows (drought conditions)

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CHAPTER 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 is 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 either estimated the nationwide risk from volatile surface flows. Nor have they derived the corresponding risk of the breakdown of a treaty. 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 dissertation attempts to accomplish.

This paper has five main research objectives. Firstly 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 periods in the Tajo Basin and explore the implications of suffering the same kind of drought under the negotiated treaty. Thus essentially comparing the pre treaty welfare distributions to the post treaty ones under conditions of water scarcity. This is done separately for Spain and Portugal, the two riparian countries in order to investigate if the implementation of the treaty had a positive impact on these riparians. Fourth, to compute risk premiums each country is willing to pay and the propensities of each riparian to comply with the treaty under varying degrees

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of risk aversion. Finally, to explore the gains from cooperation and the efficiency and stability of the existing treaty using a co-operative game theoretic framework.

To summarize, the most important contribution of this dissertation to the existing literature is to develop an analytical framework to assess the impact of an existing treaty and to conceptualize the likelihood of compliance to an international water treaty. Moreover, to empirically apply this framework to the Tajo basin to assess treaty impacts and compute the likelihood of compliance separately for each riparian under normal as well as under conditions of extreme scarcity.

The dissertation is organized as follows. Chapter 2 provides an overview of the related literature on several dimensions of the impact of climate change and also on the application of co-operative game theory in managing international water resources. Chapter 3 constructs the theoretical framework. Chapter 4 lays down the empirical strategy that would be adopted to apply the theoretical model to the Tajo Basin that would be examined for our analysis. This chapter also 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. Chapter 5 presents and discusses results obtained from the Spanish part of the Tajo basin. Chapter 6 presents similar results obtained by applying the model to the Portuguese part of the basin. Chapter 7 presents the results for the entire basin and explores the overall gains/ losses to the basin as a whole from the implementation of the treaty. It then tests the efficiency and stability of the treaty by adopting a Co-operative Game Theoretic Framework. Chapter 8 summarizes the paper and discusses the policy implications.

CHAPTER 2. LITERATURE REVIEW

2.1 Impact of climate change on the economy and the environment

Long term temperature records from historical documents reveal that every decade in the 20th century has been warmer than the preceding decades and that 10 out of the 11 warmest years on record have occurred since 2001 (Hansen et al. 2012, Jones et. al. 2012) Medvigy and Beaulieu (2011) conducted a study on solar radiation around the world and concluded that there was an increase in solar radiation variability that was correlated with variability in precipitation that may affect terrestrial ecosystem photosynthesis. 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. Ottman et. al. (2012) conducted field experiments by manipulating planting dates and using infrared heating to conclude that the wheat yield declined by 6% for per degree of increases in temperature. 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 linkages 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 provides 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

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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.

2.4 Cooperative Game Theory & International Water Resources

Cooperative Game Theory (CGT) has been widely applied in the analysis of water resources. It has been used to address various aspects of splitting joint incremental costs and benefits emerging from cooperation. CGT has been applied to the water sectors such as hydro power, water storage, multi objective water projects, municipal sewage treatment, disposal and reuse and international water cooperation. (Gately 1974; Loheman et. al 1979; Suzuki and Nakayama 1976; Dinar et al. 1986; Rogers 1993). For instance, Gately 1974 conducts a CGT analysis of investment planning in the Southern Electricity region in India. He estimates the cost of power supply to the region under different degrees of cooperation and arrives at some mutually accepted cost allocation alternatives. He also introduces in this paper, the concept of the players propensity to disrupt a coalition. Rogers (1997) shows that a cooperative solution provides higher welfare to the riparians compared to a non-cooperative solution in the case of the Ganges-Brahmaputra basin. He performs joint optimization and compares allocations based on several criterions like feasibility, Pareto admissibility and individual rationality. Jorgensen and Zaccour (2001) study the problem of river basin pollution faced by a downstream riparian using cooperative differential games. Fernandes (2002) also applies a differential CGT to the case of transboundary pollution in the US-Mexico border and compares solutions under cooperation and non-cooperation considering varying degrees of trade liberalization. The problem of asymmetric information has been dealt with in Maler (1990), who constructs a two country model of downstream pollution with asymmetric information represented by private information on abatement available only

to the upstream country and private information on damage costs available only to the downstream country. However, these works have been restricted to the assumption of a deterministic world. In Dinar et. al. (2003) we find a departure from the deterministic setting in water resource management, particularly to the case of a wastewater treatment plant. Their result suggests the incorporation of the stochastic aspects to the solution, which also depends on the players risk preferences and the nature of the water project cost function. An introduction to stochastic cooperative games can be found in Suijs (1998); Suijs et. al. (1999); Suijs and Borm (1999).

There have been several papers dealing with the allocation of water itself, instead of the allocation of costs and benefits. Braden, Eheart and Saleth (1991) employ a multilateral Nash Bargaining Model to the Crane Creek Watershed of Kentakee County, Illinois. They suggest that markets for water rights can be too rigid. Rather, rental or spot water markets can provide allocational flexibility needed to allow for changing conditions and thus improve efficiency. For multilateral bargaining models see Harsanyi (1986); Zeuthen (1930) and Nash (1950). Harrison and Tisdell (1992) considers a CGT model with transferrable utility to compare the effect of different allocation methods on the distribution of income after water trade among selected farm within the Border River region of Queensland, Australia. Sprumont (2000) proposes allocation schemes for riparians with quasilinear preferences over water and money. He also analyses efficiency, stability and fairness issues associated with such allocations of water and income. In Van den Brink, Van der Laan and Vasilev (2003) we observe a class of CGT known as line

graph games which are games with transferrable utility where the players are linearly ordered.

The literature applying game theory to International Water Basins reveals that non-cooperation is not necessarily the outcome for an open-access international water resource. Dufournaud and Harrington (1990, 1991) extend the cost allocation problem of Young et. al. (1982) and introduc the aspect of admissible coalitions. Becker and Easter (1997) work on the Great Lakes management and show that cooperation among a minimum number of agents creates incentives for the others and hence it is possible to have a stable coalition formation when a subset of players is willing to cooperate. Barrett (1994) in his review attempts to answer the question whether countries sharing water bodies necessarily share their benefits from cooperation. Guldmann and Kucukmehmetoglu (2002) use CGT concepts using a linear programming model to identify stable allocations of water to agricultural and urban uses in the Tigris-Euphrates River. Just and Netanyahu (1998) discuss the obstacles to the formation of grand coalitions in transboundary water basins brought forth by asymmetric information, asymmetric characteristics between riparians, upstream and downstream issues, conflicting national and international interests etc.

CHAPTER 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) shows 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

$$Y = q(A)......(1)$$

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;

$$g(A|x); \ \underline{A} \le A \le \overline{A} ....(2)$$

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

$$U(\Pi) = U[p \cdot q(A) - c \cdot x]; \text{ where } U' > 0 \ U'' \le 0 .....(3)$$

The expected national welfare is,

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

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,

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

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

$$U[p \cdot E[q(A)] - c \cdot x - RP] = \sum_{A=\underline{A}}^{\bar{A}} U[p \cdot q(A) - c \cdot x] \cdot g(A \mid x)......(6)$$

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

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

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-Pratt 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.

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

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, $\Pi_1 \geq \overline{\Pi_0}$

II.   Even if national welfare post-treaty is less than the national welfare pre-treaty $\Pi_1 \leq \overline{\Pi_0}$, the riparian will be willing to comply with the treaty provisions as long as, $\Pi_1 \geq p \cdot q\{E(A)\} - c \cdot x - \lambda(x)$, so that $U(\Pi_1) \geq E[U(\Pi_0)]$

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. The treaty thus can be thought of as providing insurance from extreme fluctuations in

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water availability, through co-operative efforts (like construction of dams) that could lead to mitigation during times of extreme scarcity. 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,

$$Risk \quad to \quad treaty = P[\Pi_1 < p \cdot q\{E(A)\} - c \cdot x - \lambda(x)]$$

CHAPTER 4. APPLICATION TO THE TAJO BASIN: THE EMPIRICAL STRATEGY

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)

4.2 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

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

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 4.1, in the second CofP meeting, the earlier negotiated flow regimes were changed and the minimum flows were set up on a weekly basis.

Basin	Control Station	Before the 2nd CofP Minimum Annual	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	

Table 4.1: Minimum Flow Requirements as Specified by the Albufeira Convention

4.3 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 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.

4.4 Data (Sources and Variables' 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].

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

[3] Figure 4.1 shows major crops in the basin selected on the basis of cultivated area.

Major Crops & Area Under Cultivation (ha)
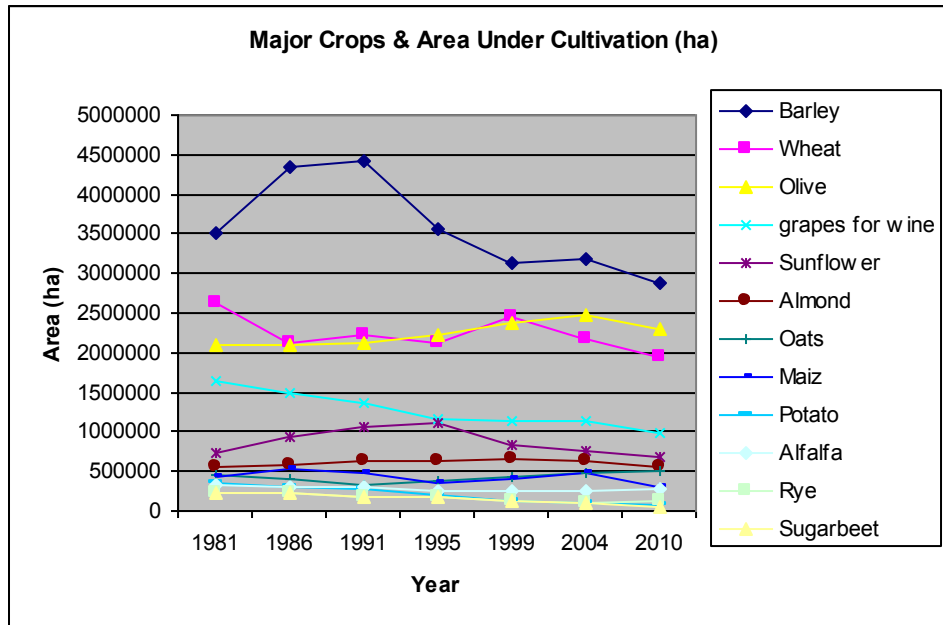
Figure 4.1: Major Crops Selected on the Basis of Cultivated Area

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

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

[5] Figure A.3 shows the crop prices all converted in terms of Euros/100kg.

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 unit less 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].

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[6] Table A.1 in appendix shows the correlation matrix for each of the hydrological variables.

These geo-coded hydrological variables were obtained at a monthly frequency. They had to be converted 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 geo-coded 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 was 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, 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 were created that took

a value of 1 for cultivation on irrigated land whereas it assumed a value of 0 for cultivation on rainfed land.

4.5 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. Figure 4.2 illustrates the steps taken in the Empirical Strategy section.
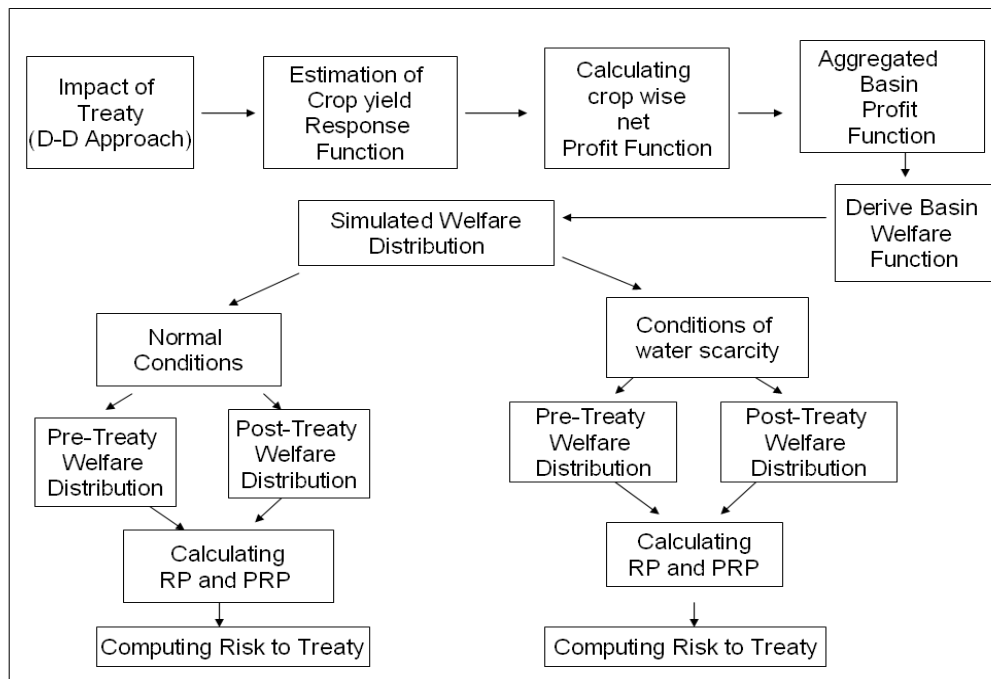
Figure 4.2: A Flowchart of the Empirical Strategy

4.5.1 Identification of Treaty Effects and Estimation of the Pre and 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 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.
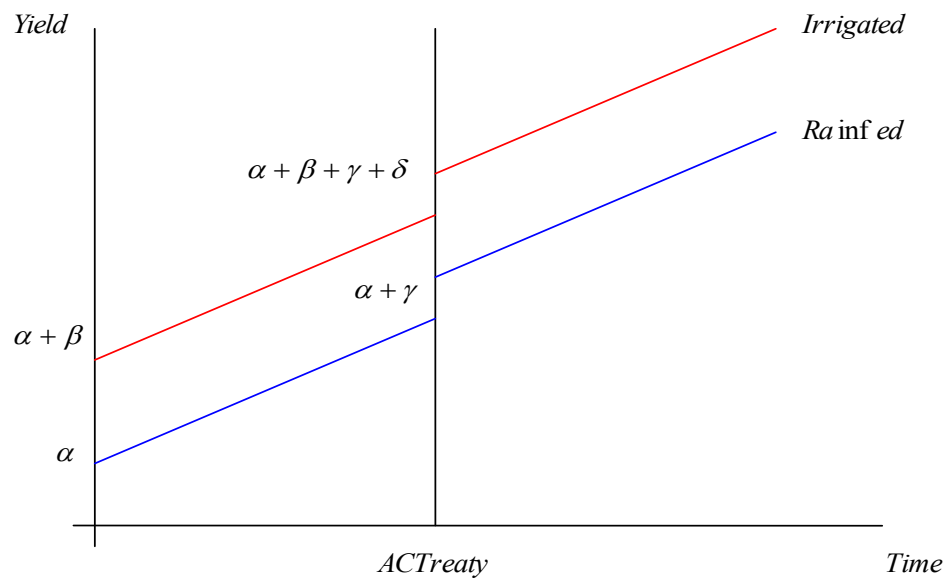
Figure 4.3: Identification of Treaty Impact using Difference-in-Differences Approach

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

$$Y_i = \alpha + \eta X_i + \beta \cdot Irrigated_i + \gamma \cdot PostTreaty + \delta(Irrigated * PostTreaty)_i + \varepsilon_i ...(9)$$

Where,

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

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

$PostTreaty$ = 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.

$$\delta_{DD} = \left(\overline{Y}_1^T - \overline{Y}_0^T\right) - \left(\overline{Y}_1^C - \overline{Y}_0^C\right) \dots\dots\dots\dots\dots(10)$$

Where, $\overline{Y}_i$ 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.

4.5.2 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

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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[7]. , for each crop i separately as shown below:

$$Q_i = AX^a \quad \text{................(11)}$$

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

$$Y_{it} = \alpha_0 + \alpha_1 \log(X_{it}) + \alpha_2 \cdot Irrigated_i + \alpha_3 (Irrigated_i \cdot Log(X_{it}) + \sum_{j=2}^{8} \beta_j \Pr ovince_j + \varepsilon_{it} ...(12)$$

Where,

$\Pr ovince_j$ = Dummy variable indicating the different provinces, 2,..., 8

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

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

α_0 = Constant term

α_1 = Coefficient on water availability index

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[7] Section 5.3 explains the use of the Cobb Douglas as the yield response function

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

ε_{it} = unobserved error term

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

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

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:

$$U(\Pi,\theta) = (\frac{1}{1-\theta}) \cdot \Pi^{1-\theta} \quad \text{................(14)}$$

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

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utility function exhibits Constant Relative Risk Aversion (CRRA) and Decreasing Absolute Risk Aversion (DARA) since $U'(\Pi) > 0$ $U''(\Pi) < 0$ [8]. 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:

$$R_a(\Pi) = -\frac{U''(\Pi)}{U'(\Pi)} = \frac{\theta}{\Pi} \quad ....(15)$$

and the coefficient of relative risk aversion is,

$$R_r(\Pi) = \Pi \cdot R_a(\Pi) = \theta \quad ....(16)$$

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

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

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 return for a sure thing.

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

---

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

We compare the welfare distributions, Risk Premiums and Proportional Risk Premiums 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

CHAPTER 5. RESULTS FOR THE SPANISH PART OF THE BASIN

The Empirical Methodology described in the previous chapter is applied to the Spanish part of the basin. This chapter shows the relevant results obtained thereby for our analysis.

5.1 Descriptive Statistics

Table 5.1 shows the pre and post treaty descriptive statistics for the important variables for instance for all of the hydrological variables and their lags and for the log of yields as well as for the log of area under cultivation for each of the 5 crops. 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 indicating water availability such as precipitation, SPI and the indices for soil wetness and soil moisture.

Table 5.1: Summary Statistics for the pre and post treaty period

Variable	Mean	Pre Treaty Std. Dev	Mean	Post Treaty Std. Dev
larea_barley	9.74	1.79	9.97	1.59
larea_wheat	9.04	1.78	9.02	1.5
larea_olive	8.02	2.93	8.22	2.55
larea_grape	7.73	3.05	7.76	2.81
larea_sunflower	8.17	1.94	7.53	1.88
lyield barley	7.76	0.61	7.99	0.46
lyield_wheat	7.7	0.79	7.99	0.47
lyield_olive	6.46	0.83	7.12	0.72
lyield_grape	7.87	0.76	8.27	0.64
lyield_sunflower	6.96	0.88	6.93	0.6
precip	49.17	11.72	52.04	12.36
spi	0.23	0.14	0.27	0.17
soil_moist	0.24	0.02	0.24	0.02
soil_wet	0.45	0.39	0.46	0.31
precip_1	48.4	11.06	51.47	12.09
spi_1	-0.09	0.25	0.08	0.28
precip_spatial lag1	46.83	8.76	49.86	9.61
spi_spatial lag1	-0.09	0.26	0.11	0.3
soil_moist_spatial lag1	0.25	0.02	0.26	0.16
soil_wet_spatial lag1	-0.16	0.6	0.15	0.54

The figure below shows the variability in water availability as measured by precipitation across the provinces[9].

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[9] 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

Figure 5.1: Distribution of Precipitation across the Spanish provinces within Tajo basin

(year 2000)

The above graph is obtained using kriging 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[10]. The figure below shows the yearly standard deviation of precipitation values for each of the 8 provinces during the post treaty period.

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[10] Figures for the other hydrological variables can be found in Appendix (Figures A.1 & A.2).
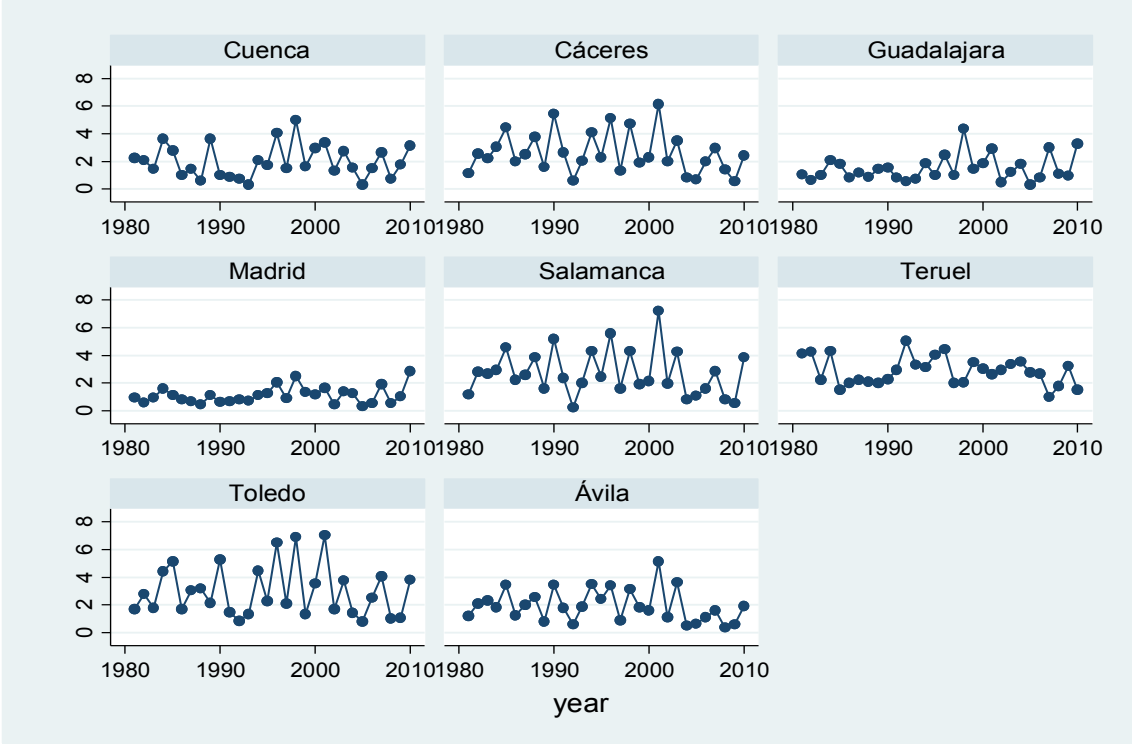
Figure 5.2: Standard Deviation of Annual Precipitation

From Figure 5.2, 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. Further, 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.
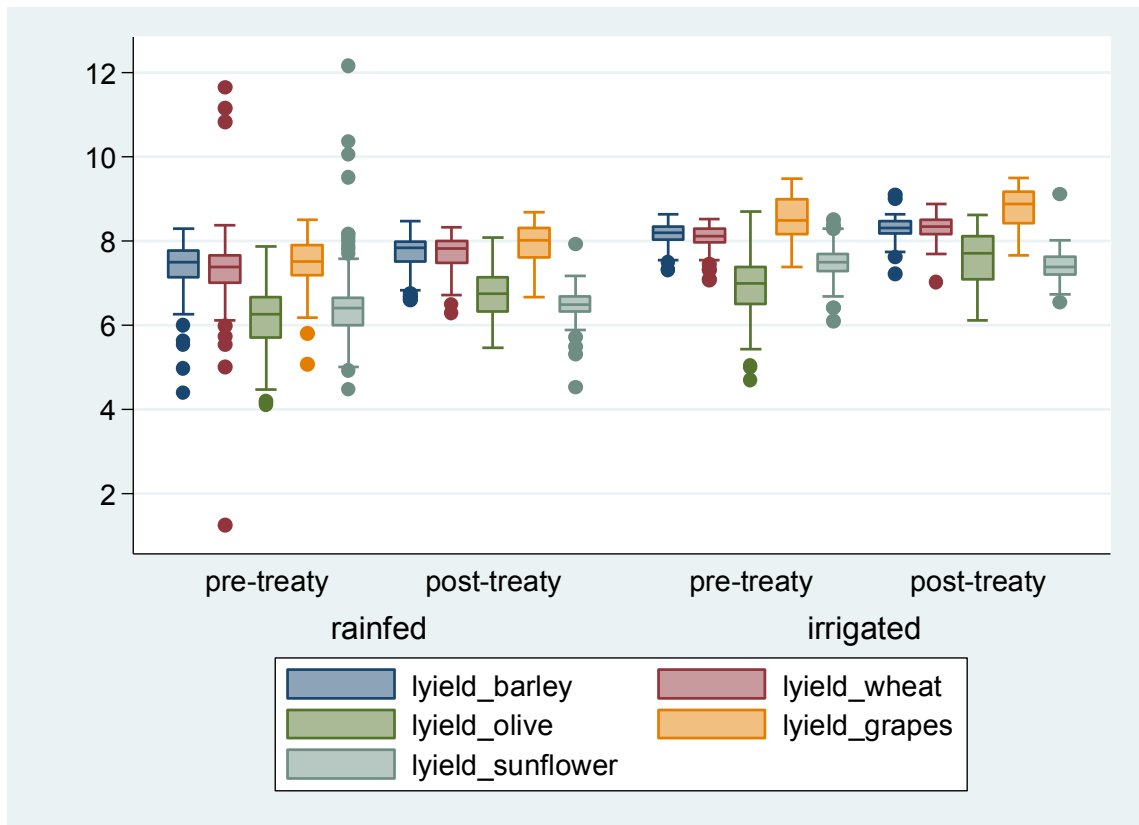
Figure 5.3: Box plots of crop yields before and after treaty broken down by type of land used

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.

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 t-test 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 statistically 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 for Sunflower, the average as well as the standard deviation of Gross Revenues in the post treaty scenario is significantly higher than those in the pre-treaty period[11].

5.2 Estimation of Treaty Impacts

Prior to obtaining the results for the estimation of treaty impacts through the difference-in differences (DD) 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.

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[11] Table A.2 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 A.3 shows ANOVA and t-test results for crop yields and gross revenue for cultivation on irrigated lands.

	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	0.07	-0.15	0.07	0	-0.1	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)	0.00 **	0	0.00 ***	0	0	0
	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	12.1	14.38	18.13
Prob > F	0	0	0	0	0	0

Table 5.2: Regression Estimates for Checking Parallel Trends Assumption

Table 5.2 shows regression estimates to check the parallel trends assumption 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[12]. 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 4.5.1. This analysis is performed twice, once to estimate the impact of the treaty implemented in the year 2000 and again

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[12] 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.

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.

Table 5.3: 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	0.00 **	0	0	0
	0.00	0.00	0.00	0.00	0.00	0.00
Precip_Time_Lag	0	0.02 ***	0	0.02 ***	0.01 **	0
	0.00	(0.01)	0.00	0.00	0.00	(0.01)
Precip_Spatial_Lag	0.04 ***	0	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	0.6	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	0	0	0	0	0

Table 5.3 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 5.3 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.

5.3 Estimation of Yield Response Functions

The next step is to obtain the Yield Response Function. Table 5.4 [13] shows the estimated coefficients obtained to derive this function. Yield responses were estimated for each of the water availability indices used. However the one shown here takes Precipitation as the hydrological variable as it gives the best fitted model compared to the others.

The table above shows the regression results from the best fitted model. It assumes a Cobb Douglas (CD) production function and is estimated by taking the log of this function. Thus the log of crop yield for each crop is regressed separately 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[14] and GLM methods of

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

[14] The GLS fit allows specification of the correlation structure of the residuals. GLS estimates using precipitation as the hydrological variable are shown in Table A.4

estimation for each hydrological variable[15]. 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 of the type of land dummy (by irrigation status) 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.

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. The Adjusted R square value is high compared to the

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[15] In a GLM model the distributional assumptions are expanded beyond the normal distribution to the general exponential family. Table A.5 shows regression results for CD production function using SPI as the hydrological variable.

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.

Table 5.4Cobb Douglas Production Function with Precipitation as the Hydrological Indicator

Variables	Barley Pre-Treaty	Barley Post Treaty	Wheat Pre-Treaty	Wheat Post Treaty	Olives Pre-Treaty	Olives 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 ***	1.4	-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	0	0	0	0	0

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 which used 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.

5.4 Simulation of Basin Welfare Distributions for AC Treaty (2000)

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; the gross revenue of the three main crops (Barley, Wheat and Olive) for each province was calculated separately[16]. 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.

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[16] Figure A.4 in appendix shows the pre and post cumulative distributions of Gross Revenues for a specific crop (Barley) in Caceres

5.4.1   Comparison of Basin Welfare Pre and Post Treaty under Normal conditions

The graphs below show the simulation results comparing the probability densities and cumulative distributions of Basin Welfare Distributions obtained before and after the
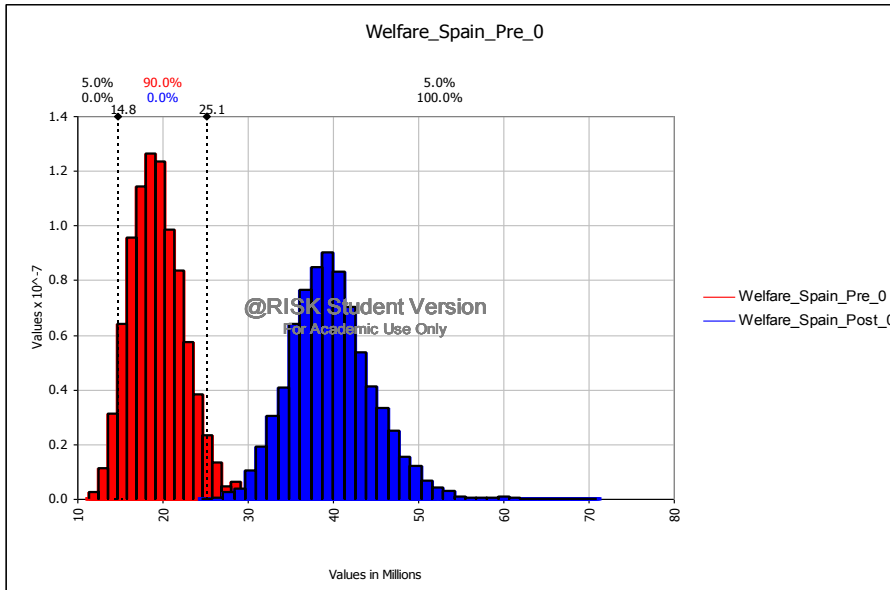
Figure 5.4: Comparison of Basin Welfare Distributions Pre & Post Treaty (RRA = 0)
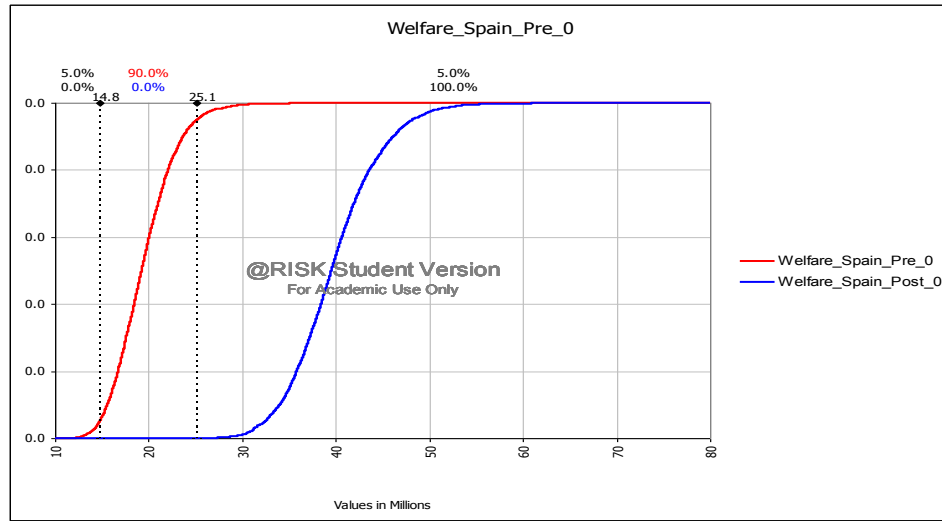
Figure 5.5: Comparison of Cumulative Basin Welfare Distributions Pre & Post Treaty

(RRA = 0)

implementation of the treaty in the year 2000[17]. The blue and red curves represent the

welfare distribution functions for the pre and post treaty scenarios respectively
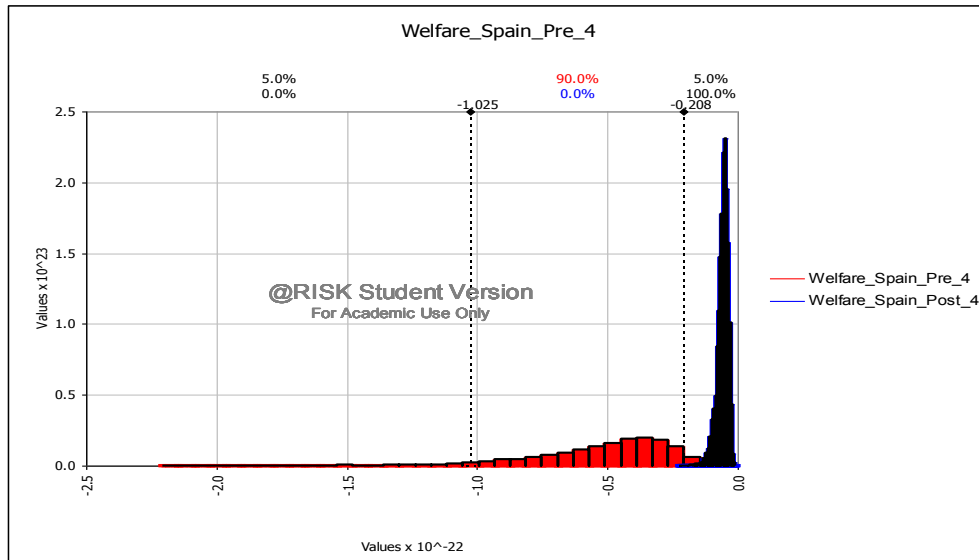
Figure 5.6: Comparison of Basin Welfare Distributions Pre & Post Treaty (RRA = 4)

[17] Simulations were conducted and graphs were generated using the Decisions Tools Suite 6.
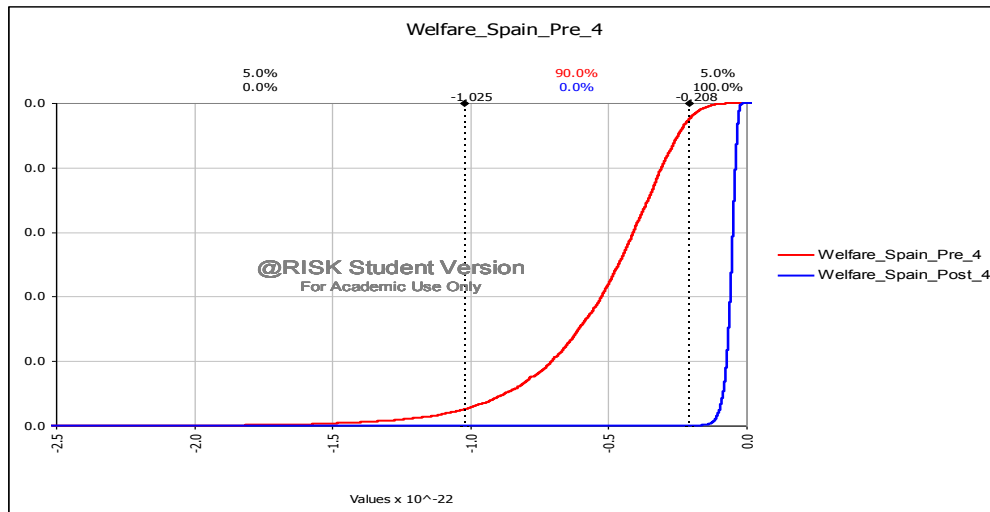
Figure 5.7: Comparison of Cumulative Basin Welfare Distributions Pre & Post Treaty

(RRA = 4)

From the above figures 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. For all the other risk aversion coefficients, there is a similar rightward shift of the welfare distribution in the post treaty situation.

5.4.2 Simulated Basin Welfare Pre & Post Treaty (2000) for Drought-like Conditions Prevailing in 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 periods are set based on those observed during the year 1995 which faced the most severe conditions

(i) RRA=0
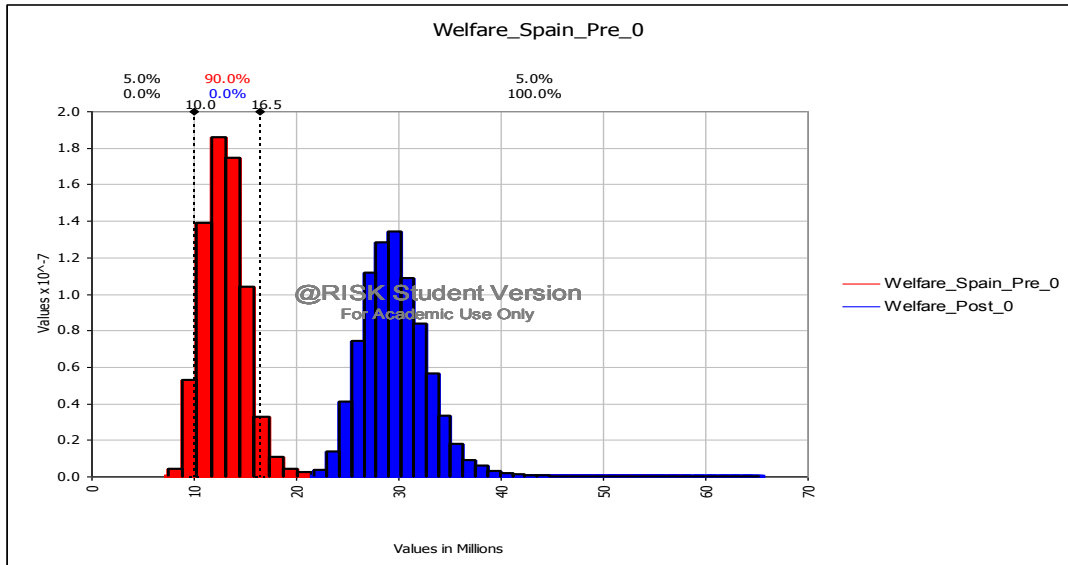
Figure 5.8: Comparison of Simulated Welfare Distributions under drought conditions
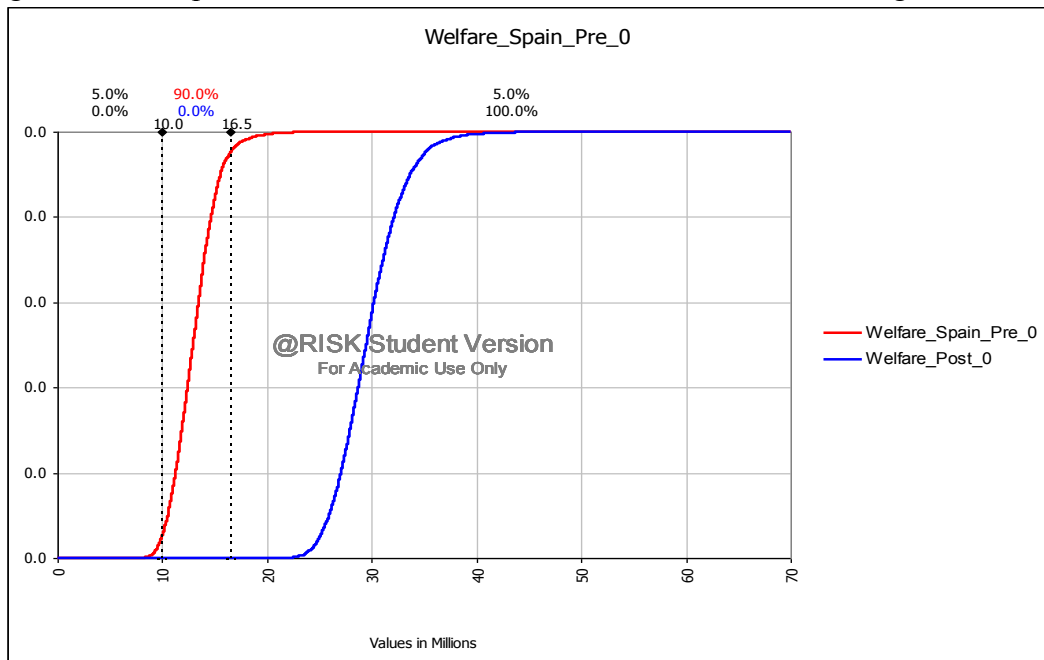
Figure 5.9: Comparison of Simulated Cumulative Welfare Distributions under drought
conditions

(ii) (RRA = 4)
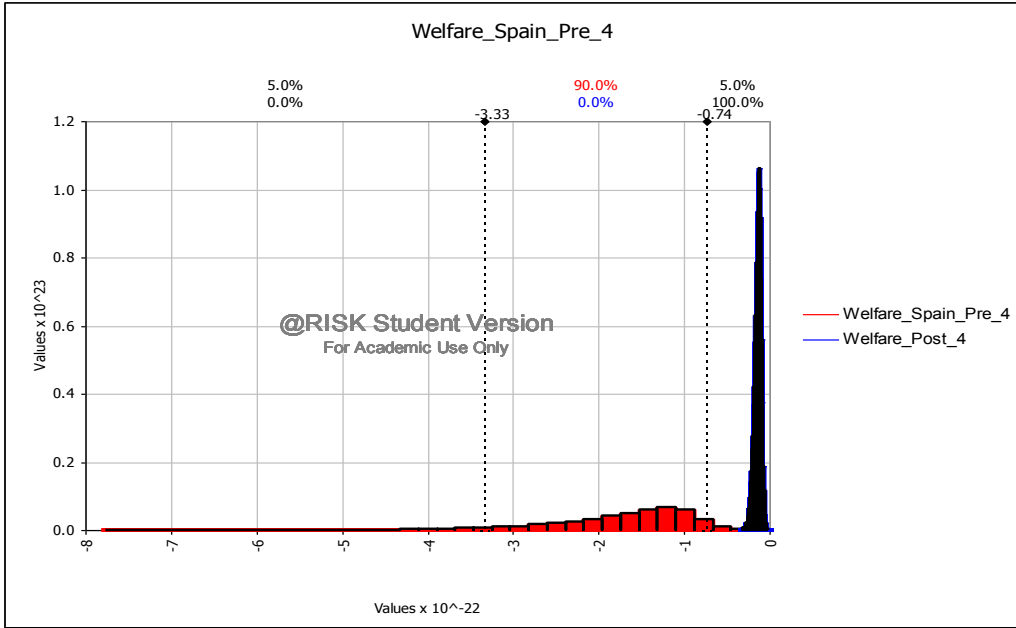
Figure 5.10: Comparison of Simulated Welfare Distributions under drought conditions
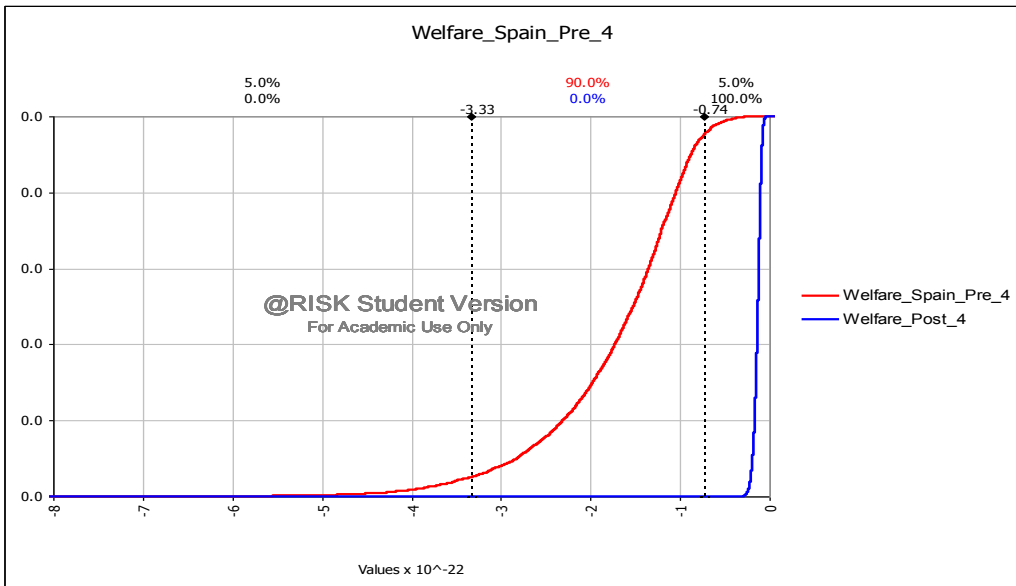
Figure 5.11: Comparison of Simulated Cumulative Welfare Distributions under drought
conditions

A rightward shift of the Basin Welfare Distribution observed from above figures indicate 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. 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.

5.4.3 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 5.5: Comparison of Risk Premiums

Risk Premium	Normal Pre-treaty	Condition Post Treaty	Drought-like Pre-treaty	Condition Post Treaty
RP_0	0	0	0	0
RP_0.5	140304.21	142912.74	90937.2	84468.23
RP_1	280608.42	285825.47	181874.4	168936.47
RP_2	561216.83	571650.94	363748.8	337872.94
RP_4	1122433.67	1143301.88	727497.59	675745.88
PRP_0	0	0	0	0
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
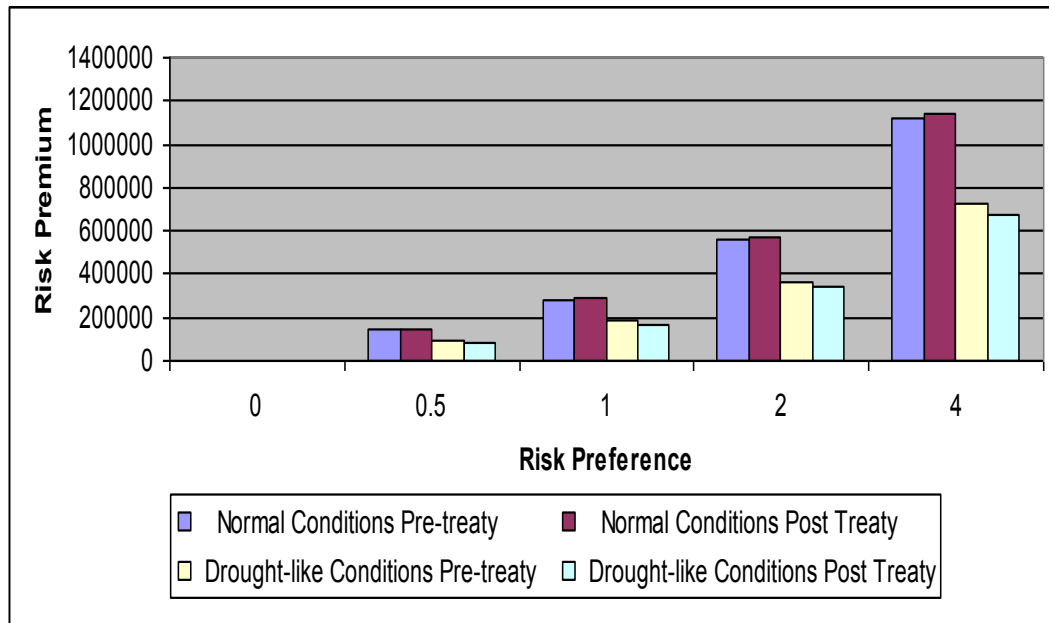
Figure 5.12: Comparison of Risk Premiums under Normal and Drought Conditions
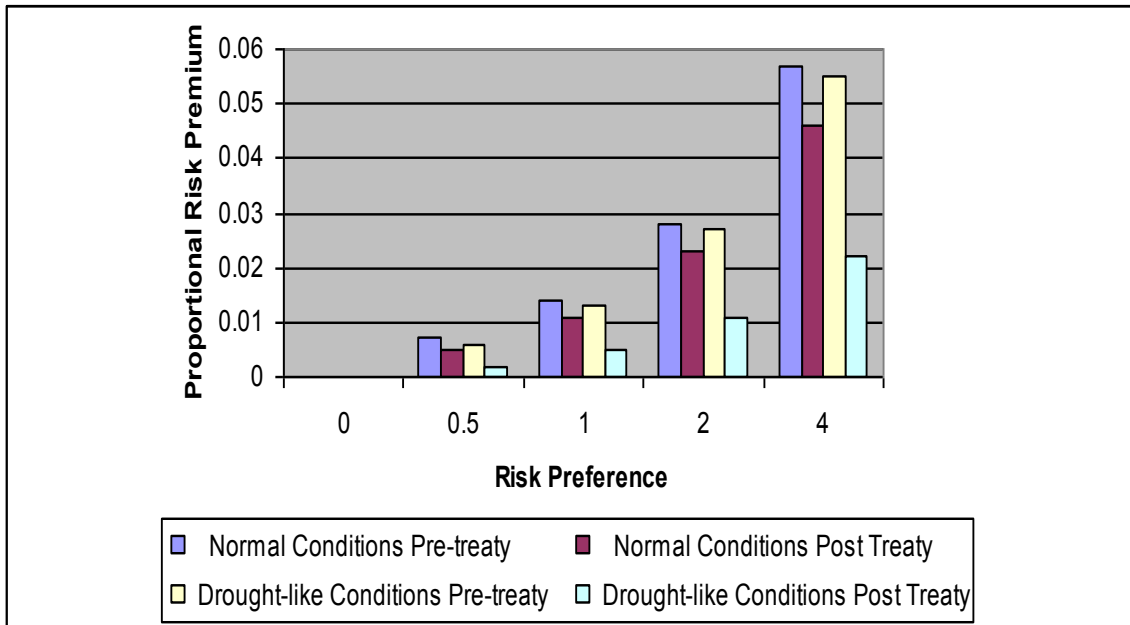
Figure 5.13: Comparison of Proportional Risk Premiums under Normal and Drought Conditions

From Table 5.5 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 as also observed clearly from Figures 5.8 and 5.9. 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.

5.5 Results for the Modified AC Treaty (2008)

The variable of interest here is the interaction between Irrigated Land Dummy and Post Treaty Time Dummy. This interaction term is significant for both Barley and Wheat, for the modified AC treaty, implying that the yields for both Barley and Wheat are positively affected by the 2nd treaty which entails frequent monitoring of flow regimes. This result substantiates the validity of our research design. We next proceed to derive the yield response functions for cultivations on Irrigated Land and compare these yield response functions across the pre and post treaty cases.

5.5.1 Regression Results

Table 5.6: Showing the Regression Estimating the Yield Response Functions

Variable	Barley		Wheat		Olive	
	Pre-treaty	Post-Treaty	Pre-treaty	Post-Treaty	Pre-treaty	Post-Treaty
Log(Precip)	2.299**	.236	2.298***	.393	-.491	.827*
	(.725)	(.364)	(.618)	(.341)	(1.078)	(.417)
Irrigated Dummy	.676	1.432	3.208	2.658	-5.913	1.036
	(3.351)	(2.156)	(2.856)	(1.877)	(6.083)	(2.483)
Irrigated_Log(Precip)	-.059	-.204	-.669	-.508	1.701	.001
	(.836)	(.538)	(.713)	(.467)	(1.523)	(.620)
Province 2	-0.818**	-.391*	-.683**	-.500***	.636	.554**
	(.331)	(.223)	(.283)	(.177)	(.427)	(.216)
Province 3	-.143	-.015	-.137	-.124	-.466	-.449**
	(.212)	(.175)	(.180)	(.165)	(.348)	(.211)
Province 4	-.314	-.203	-.075	-.026	.239	.572***
	(.221)	(.174)	(.188)	(.165)	(.334)	(.199)
Province 5	-.915***	-.192	-.714***	-.141	.227	.452*
	(.277)	(.177)	(.237)	(.167)	(.487)	(.254)
Province 6	-0.44**	-.246	-.364*	-.247	.084	.477**
	(.211)	(.174)	(.180)	(.165)	(.316)	(.199)
Province 7	-.489**	-.145	-.713***	-.320*	.536	.984***
	(.230)	(.175)	(.196)	(.166)	(.350)	(.201)
Province 8	-.930***	-.386**	-.879***	-.266	1.143***	1.127***
	(.244)	(.175)	(.208)	(.165)	(.376)	(.200)
Constant	-.876	6.918***	-.936	6.344***	8.553*	2.946*
	(2.850)	(1.456)	(2.430)	(1.367)	(4.241)	(1.668)
N	30	45	30	47	28	43
Adjusted R Square	0.5	0.53	0.66	0.57	0.66	0.82
F-Stat	3.88	5.9	6.66	7.12	6.19	20.42
Prob>F	0.005	0	0.002	0	0.001	0

The table above (Table 5.6) shows the results obtained while estimating a Cobb-Douglas

Yield response function. The yields for both Barley and Wheat are significantly affected

by precipitation before the modified treaty. However the post treaty coefficient of

precipitation for these two crops is non-significant, implying that the fluctuations in precipitation do not have a significant impact on the yields for these crops.

5.5.2   Simulation Results

From the above regression, we obtain the coefficients of yield response functions to generate the Gross Revenues for each of the three crops separately across the 8 provinces. The results below show the Gross Revenues aggregated across the 8 provinces for each of the 3 crops and also the Agricultural Gross Revenues, obtained by aggregating them over the 3 crops.

5.5.2.1 Comparison of Crop Specific Gross Revenues Pre and Post Treaty
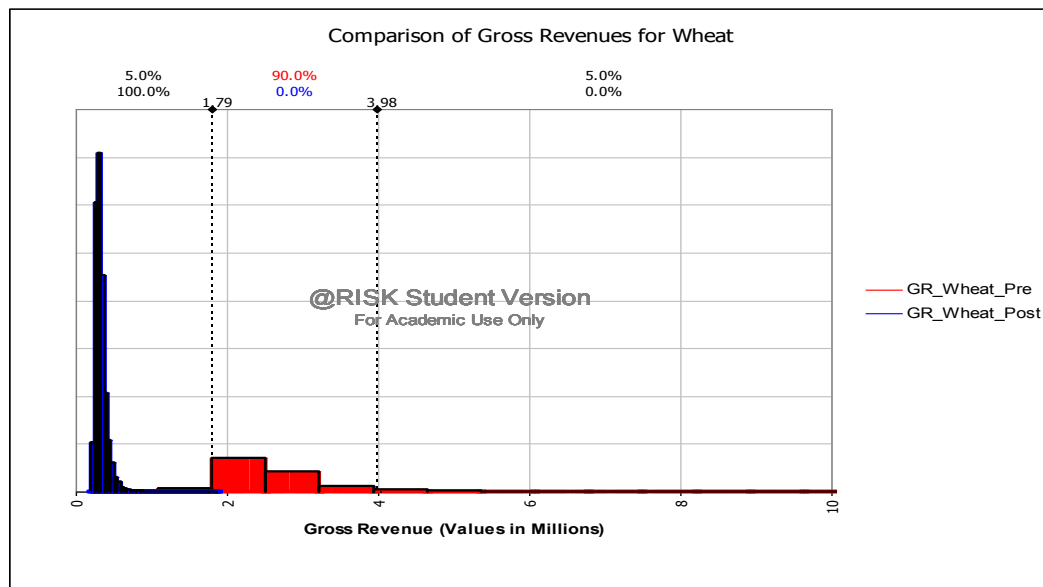
Figure 5.14: Comparison of Simulated Gross Revenue Distributions for Wheat

The Distribution of Gross Revenues from Wheat has shifted to the right in the post treaty period, indicating higher average revenues post treaty.
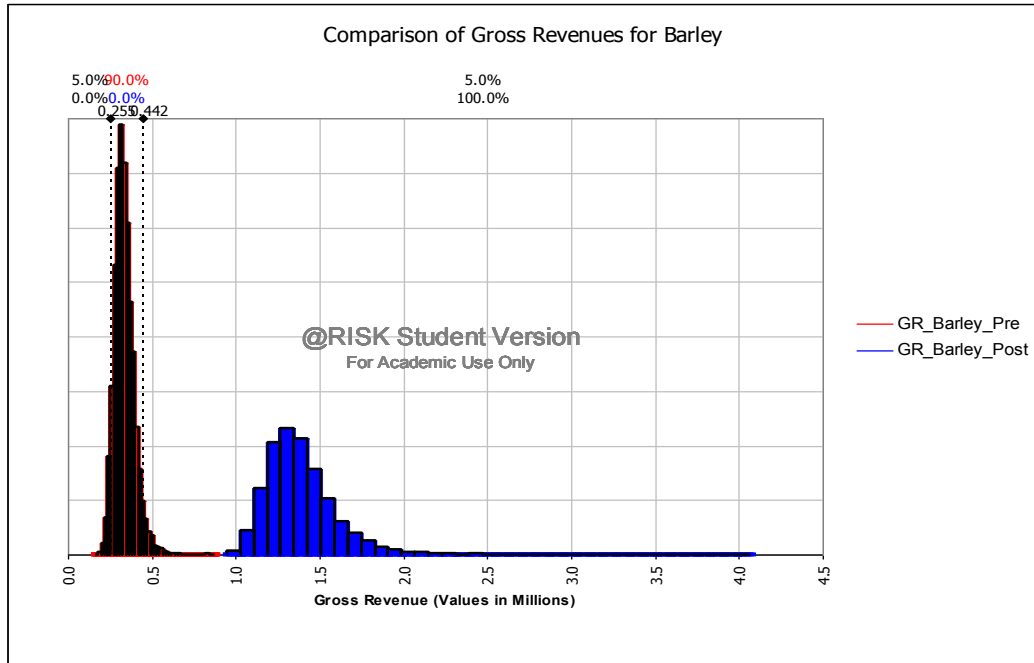
Figure 5.15: Comparison of Simulated Gross Revenue Distributions for Barley

A comparison of the simulated results on Gross Revenues from Barley production, reveal that the post-treaty Gross Revenues have a slightly higher average .

5.5.2.2 Comparison of Pre & Post Agricultural Gross Revenues

The agricultural Gross Revenues aggregated over all 3 crops show a lower mean value but they appear to be more stable in the pre treaty period.
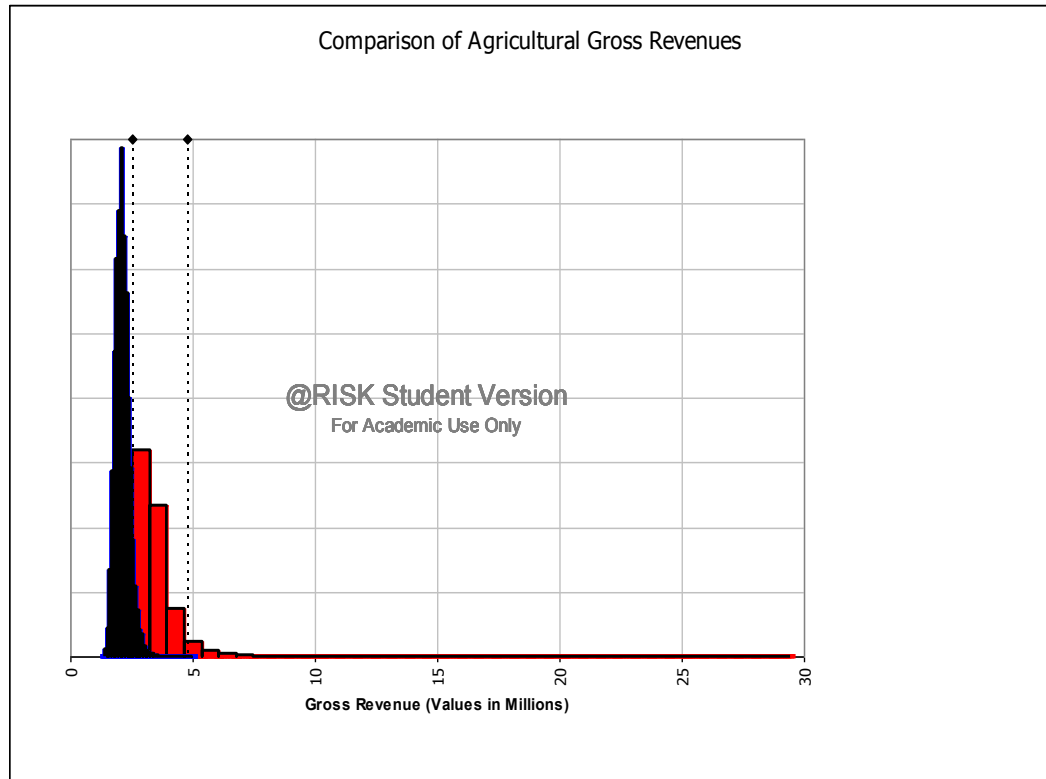
Figure 5.16: Comparison of Simulated Agricultural Gross Revenue Distribution

5.5.2.3 Comparison of Pre and Post Agricultural Welfare Functions

As explained in the empirical strategy section, the welfare function used here is:

$$U(\Pi,\theta) = (\frac{1}{1-\theta}) \cdot \Pi$$

Where,

Π = Aggregated profits for the entire basin

θ = Coefficient of Relative Risk Aversion

We now obtain the simulated Welfare Distributions for different values of θ to detect how the degree of risk aversion of a riparian might alter the welfare functions compared in the pre and post treaty periods.

Simulations are performed for each of the following levels of the constant Relative Risk

Aversion parameter. Here, $\theta = 0$ stands for risk neutrality, while $\theta = 4$

implies indicates extreme risk aversion.
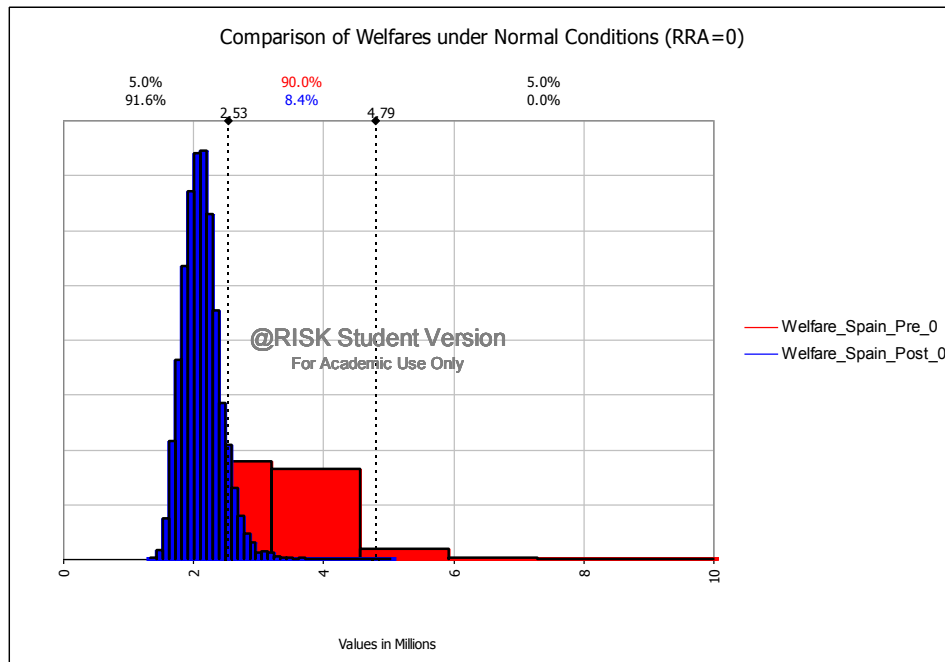
(i)   Results for RRA=0

Figure 5.17: Comparison of Simulated Agricultural Welfare Distributions

(ii) Results for RRA=1
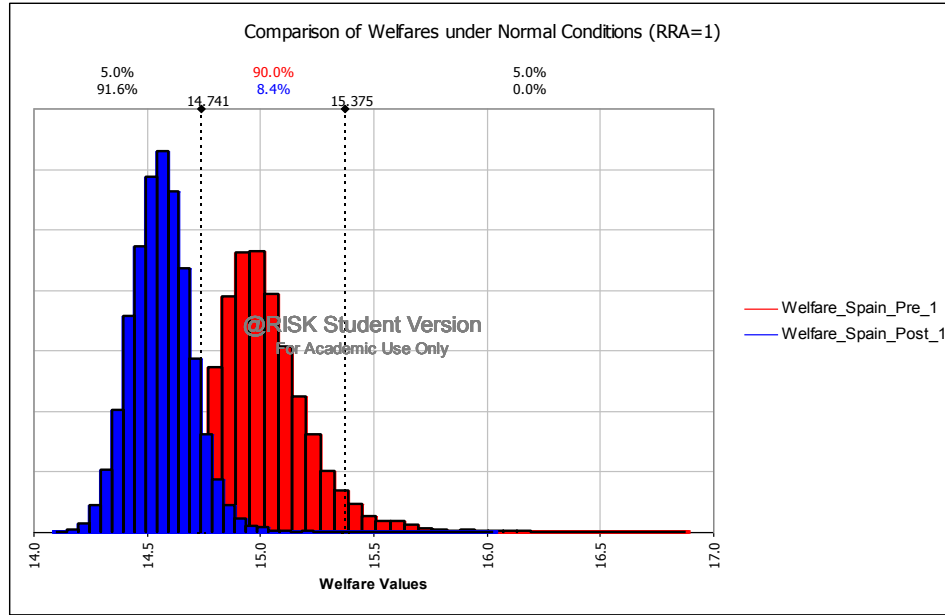
Figure 5.18: Comparison of Simulated Agricultural Welfare Distributions

The simulated welfare distributions obtained for different levels of risk aversion disclose that irrespective of the degree of risk aversion, the post treaty welfare values, though have a lower mean value, they are more stable than the pre-treaty ones.

5.5.2.4 Comparison of Risk Premiums (RP) Pre and Post Treaty

The coefficient of Absolute and Relative Risk Aversion for the above utility function respectively is,

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

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

We use these to compute the Risk Premium (RP) as well as the Proportional Risk Premium (PRP). Following Freund (1956) the approximate *RP* and *PRP* is computed as explained in section 4 using the following equations

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$$RP = 0.5 \cdot R_a \cdot V(\Pi) \qquad PRP = \frac{RP}{E(\Pi)}$$

From each of the Welfare Functions obtained we derive the Risk Premium and the Proportional Risk Premiums under varying levels of the risk aversion parameter.
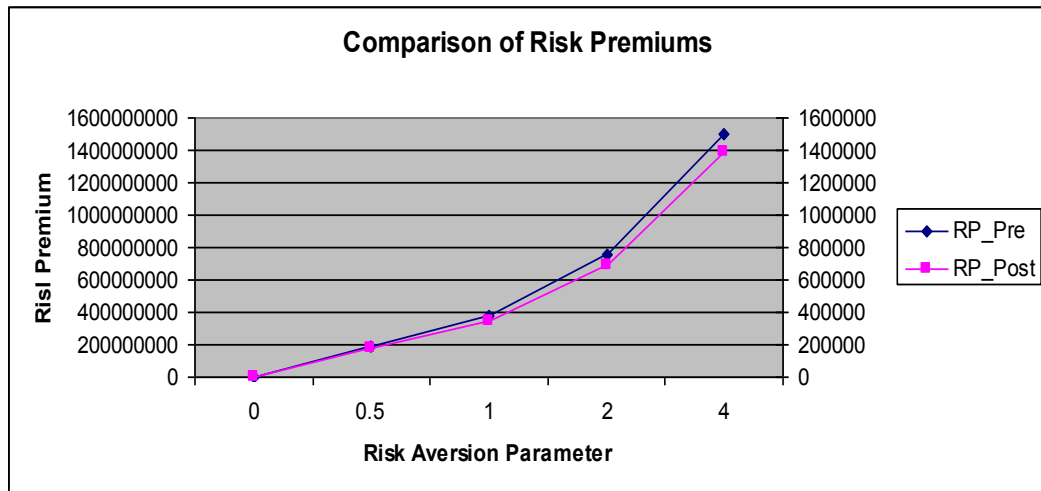
Figure 5.19: Comparison of Risk Premiums

A comparison of Risk Premiums pre and post treaty reveal slightly lower values of Risk Premium across all risk aversion parameters.

5.5.2.5 Comparison of Proportional Risk Premiums (PRP) Pre and Post Treaty

Comparisons of Proportional Risk Premiums (or Risk Premiums as a proportion of mean revenues) disclose a similar trend as the Risk Premiums. We observe that the PRP is slightly lower in the post treaty period, irrespective of the degree of risk aversion. The figure below shows Pre and Post treaty Proportional Risk Premiums for the different levels of Relative Risk Aversion Parameters considered here.
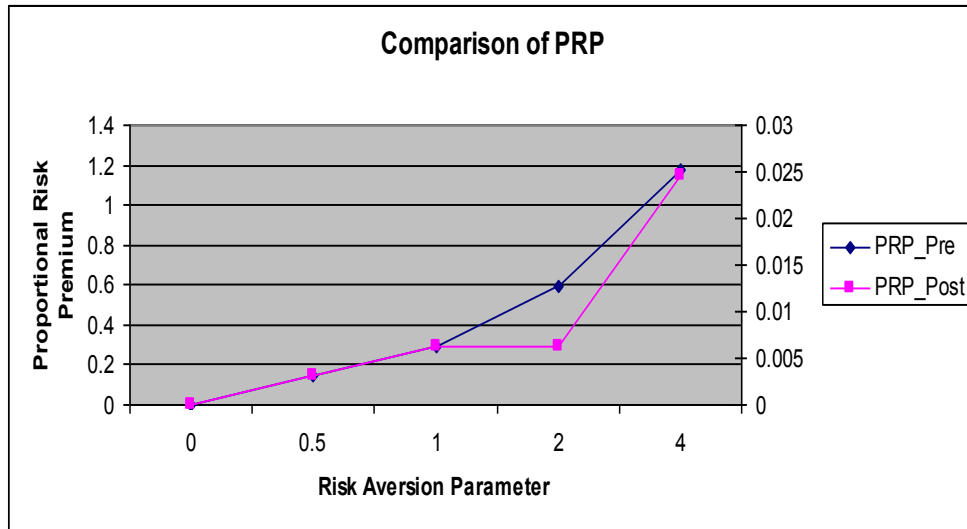
Figure 5.20: Comparison of Proportional Risk Premiums

To conclude, it can be expected that the upstream riparian might be willing to forego some amount of wealth, in order to stabilize productive activities.

5.5.2.6 Comparison of Counterfactual Pre and Post Agricultural Welfare Functions Under Drought Conditions

The above comparisons between pre and post treaty scenarios were performed under normal conditions of water availability. Now, similar welfare comparisons are performed between pre and post treaty under conditions of water scarcity. In particular, this is done by taking precipitation values that prevailed during the drought that took place in between the years 1992-1995. The graphs below show how post treaty welfares compare against pre-treaty ones under conditions of scarcity for different levels of risk aversion parameter.

(i)   Results for RRA=0
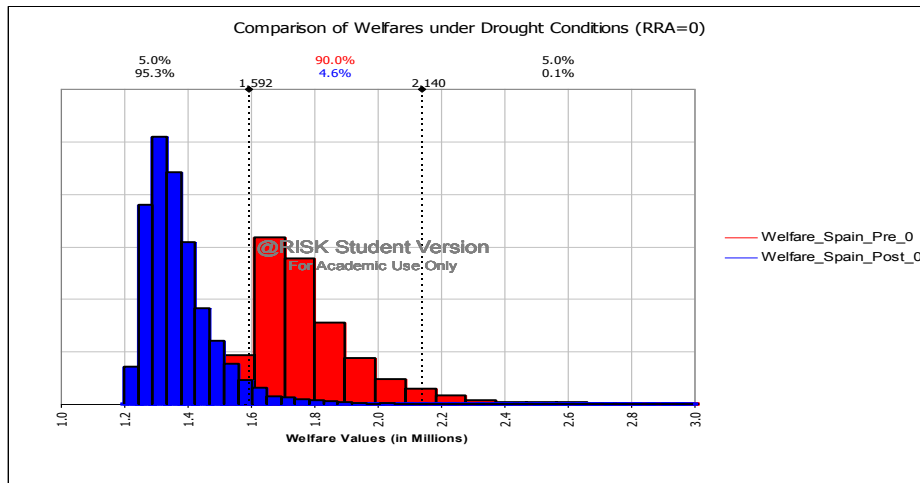
Figure 5.21: Comparison of Agricultural Welfare Distributions (Drought Conditions)

(ii)   Results for RRA=1
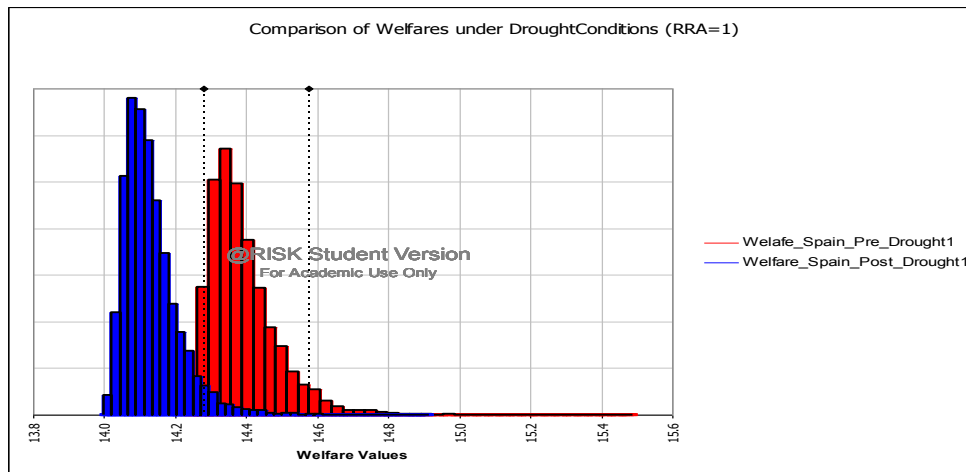
Figure 5.22: Comparison of Simulated Agricultural Welfare Distributions (Drought Conditions)

It is consistently observed over different levels of risk aversion, that the post treaty welfare values are lower compared to the pre-treaty welfare values. However, post treaty welfare is relatively more stable than pre-treaty welfare levels.

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5.5.2.7 Comparison of Counterfactual Risk Premiums (RP) Pre and Post Treaty Under Drought Conditions

The risk premium values are computed as shown in section VI, but this time under conditions of water scarcity.
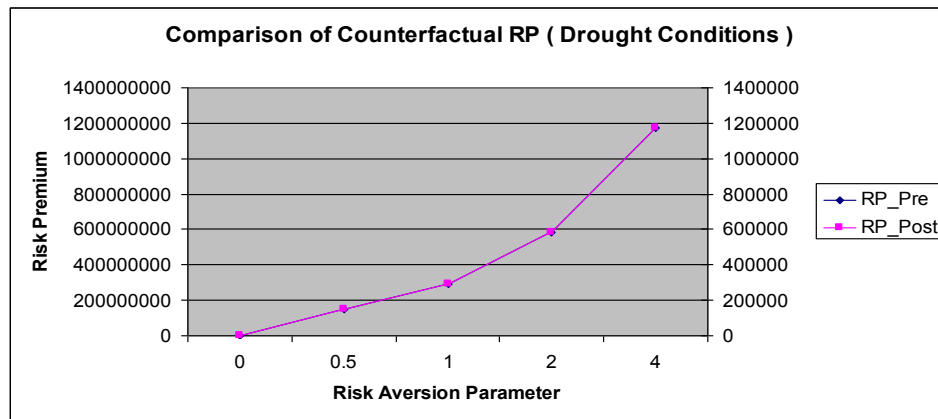
Figure 5.23**:** Comparison of Risk Premiums (Drought Conditions)

It can be observed from the graph that the post treaty Risk Premium values are quite close to the pre-treaty risk premiums. Contrary to what was observed under normal conditions, Risk premium does not decline for an upstream country under conditions of water scarcity

5.5.2.8 Comparison of Counterfactual Proportional Risk Premiums (PRP) Pre and Post Treaty under Drought Conditions

The Proportional Risk Premium is computed as shown in section VII. However, these represent the PRP under drought conditions.
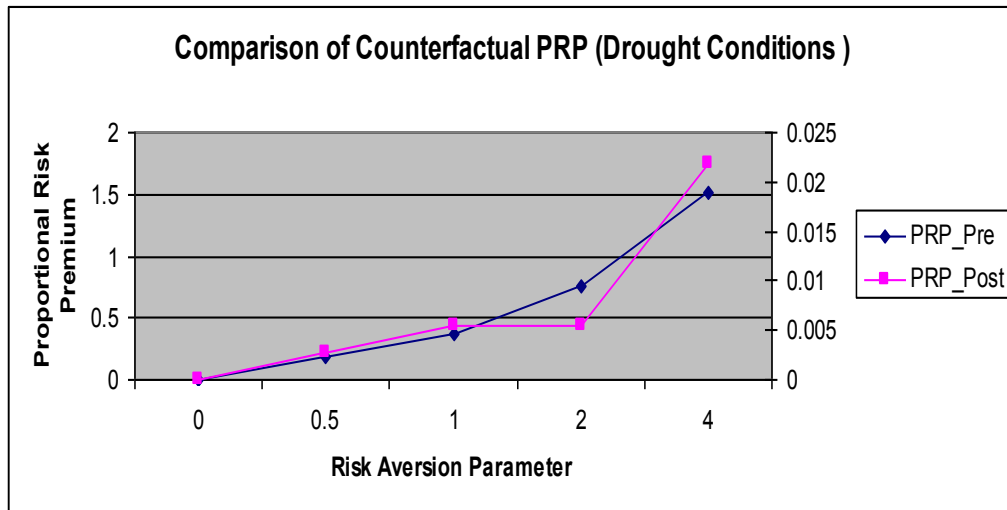
Figure 5.24: Comparison of Proportional Risk Premiums (Drought Conditions)

5.5.2.9 Computation of Total Risk Premium, Threshold Income Values and Probability of Non-compliance

The next step entails calculating the Total Risk Premium and obtaining the threshold value of revenue that a riparian would be willing to lose in order to insure against fluctuations in water availability and also the likelihood of compliance or non-compliance to treaty under water scarcity. The Total Risk Premium (TRP) or $\lambda(x)$ can be computed as follows:

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

Where the first term $p\{q[E(A)] - E[q(A)]\}$ represents Production Premium or the premium arising out of stabilization of productive activities at the mean level. The Total Risk Premium represents the amount of wealth that a riparian is willing to forego in order to insure against the fluctuations in water availability. The threshold level of income, represents the minimum level of income that a riparian will be willing to accept in order to comply with the treaty specifications. It is obtained by subtracting the total risk premium from the pre-treaty income. The Probability of breakdown or non compliance to treaty is calculated as the probability of obtaining a post treaty income level that is lower than the threshold level of income.

Table 5.7: Table showing TRP, Threshold Income & Likelihood of Compliance (Normal Conditions)

Risk Aversion	TRP	Threshold Income	Prob (Income<Threshold Value)
0	-226703.23	1269226703.23	0.00
0.5	187789073.07	1081210926.93	0.00
1	375804849.36	893195150.64	0.00
2	751836401.95	517163598.05	0.00
4	1503899507.13	-234899507.13	0.00

Table 5.8: Table showing TRP, Threshold Income & Likelihood of (Drought Conditions)

Risk Aversion	TRP	Threshold Income	Prob (Income<Threshold Value)
0	2344961.51	774644205.70	0.00
0.5	148882092.70	628107074.40	0.00
1	295419223.90	481569943.20	0.00
2	588493486.30	188495680.80	0.00
4	1174344962.00	397355794.40	0.00

From the above two tables we observe that TRP is mostly positive, especially under scarce conditions, for all levels of risk aversion. This shows that Spain is willing to give up positive levels of wealth to stabilize its income, especially when faced with water scarcity. Further, it is evident that the probability of non-compliance is lower under conditions of scarcity

CHAPTER 6. RESULTS FOR THE PORTUGAL SIDE OF THE TAJO BASIN

Portugal receives higher levels of rainfall compared to Spain and this is true especially for the northern parts of Portugal. A description of the spatial distribution of rainfall is given by Figure below. Figure 6.1 below shows a map of Portugal with 18 districts as the administrative unit. This was done using precipitation values that were extracted at the district level using ArcGIS 10. The GIS software through its Geostatistical tools allow us to map the spatial distribution of precipitation for the year 2005 using kriging techniques. A darker shade of brown indicates dry regions experiencing sparse rainfall, whereas a lighter shade indicates dense precipitation values. It can thus be observed that the southern parts of Portugal receive much less precipitation than the northern parts. Data on agricultural yields obtained from the Yearly Agricultural Statistics Report published by the INE (Instituto Nacional de Estatística) are at the NUTS (Nomenclature of Territorial Units for Statistics) 2 regional level. Hence we aggregate the district precipitation values at this level

Figure 6.1: Spatial Distribution of Precipitation

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6.1 Regression Results for the Modified AC Treaty

The yield response functions for the four crops Corn, Grapes and Olive are estimated using a Cobb Douglas Production function using precipitation here as the hydrological indicator.

Figure 6.2: Regression Estimating the Yield Response Functions for Corn, Grape & Olive

	CORN	GRAPE	OLIVE
Log (Temperature)	0.22	1.68*	1.15**
	(0.14)	(0.89)	(0.49)
Log (Precipitation)	0.24***	0.92**	0.03
	(0.05)	(0.35)	(0.19)
Region 2	-0.48***	-0.25	-0.40**
	(0.04)	(0.26)	(0.14)
Region 3	0.09**	0.28	0.30**
	(0.04)	(0.24)	(0.13)
Treaty	0.21***	0.44**	0.07
	(0.03)	(0.20)	(0.11)
Constant	0.55	-8.54	-3.71**
	(0.48)	(3.05)	(1.68)
N	24	24	24
Adjusted R Square	0.94	0.63	0.64
F-Stat	79	6	9.1
Prob>F	0	0	0

The other covariates include 2 region dummies NUTS region 2 dummy and NUTS region 3 dummy for the 3 regions namely Centro, Lisboa and Alentejo. We see that precipitation is significant for Corn and Grape post treaty

6.2 Simulation Results

The yield response function is estimated from the coefficients obtained in the previous section. This yield response function is used along with the pre and post distributions of precipitation, to simulate and compare welfare distributions for the Portuguese part of the Tajo Basin.

6.2.1 Comparison of Pre & Post Agricultural Welfare Functions (Normal Conditions)

The figures below show the simulation results under normal conditions of water availability. It draws values from the actual distribution of precipitation pre and post treaty. These results are shown for risk neutrality and for extreme risk aversion.
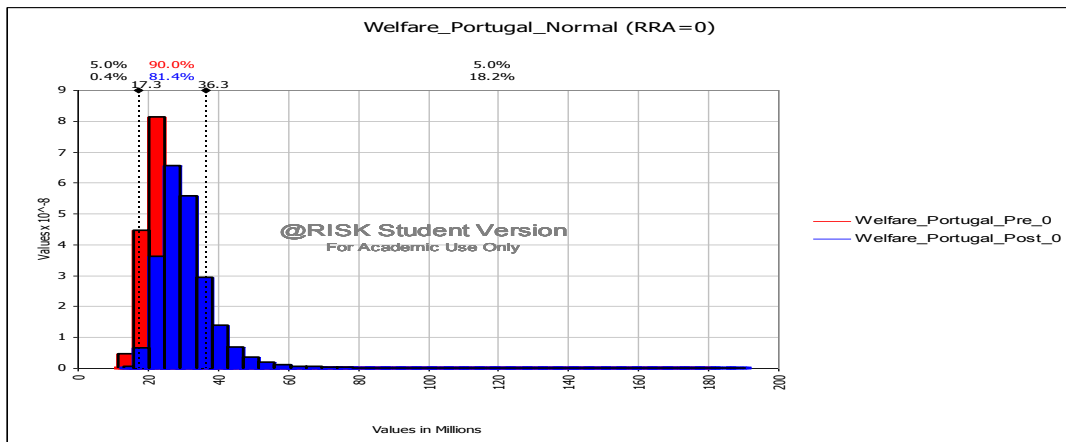
(i)   Results for RRA=0

Figure 6.3: Comparison of Simulated Agricultural Welfare Distributions (RRA=0)

(ii)   Results for RRA=1
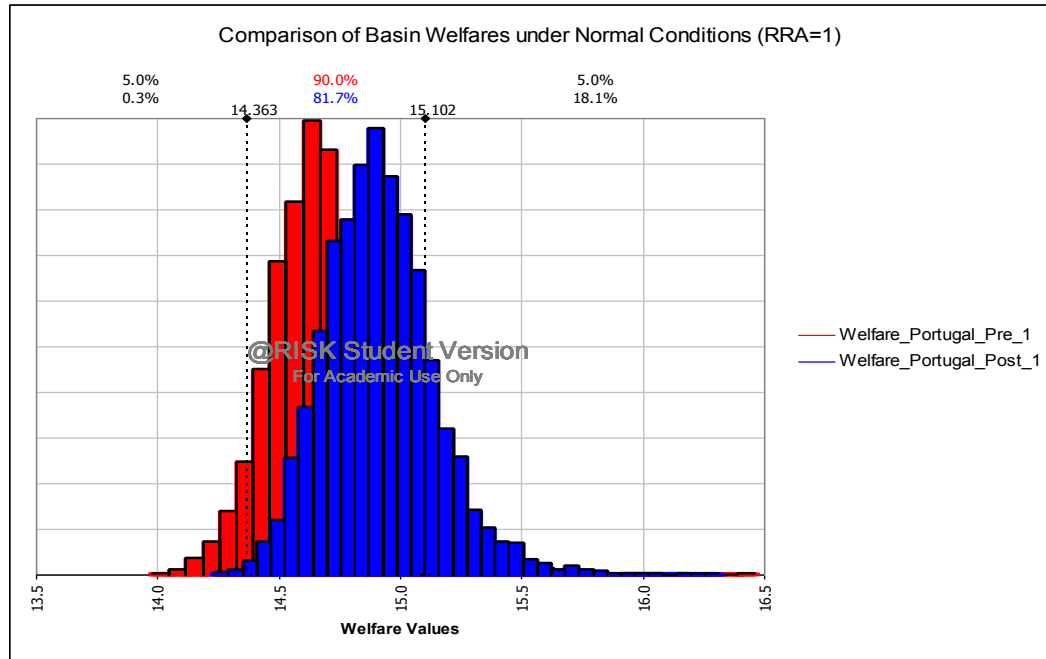
Figure 6.4: Comparison of Simulated Agricultural Welfare Distributions (RRA=4)

From the above simulation results it is clearly evident that Portugal is better off in the post treaty scenario for all levels of risk aversion. For higher levels of risk aversion the welfare values are also more stable compared to the pre-treaty case. Another pattern observed here is that the welfare values post treaty gets closer to the welfare values pre-treaty. This is because under risk neutrality, welfare increases at a constant rate for higher as gross revenue increases; whereas for high levels of risk aversion the welfare function becomes convex implying that welfare under such conditions would increases at a decreasing rate as gross revenue rises.

6.2.2   Comparison of Risk Premiums (RP) Pre and Post Treaty
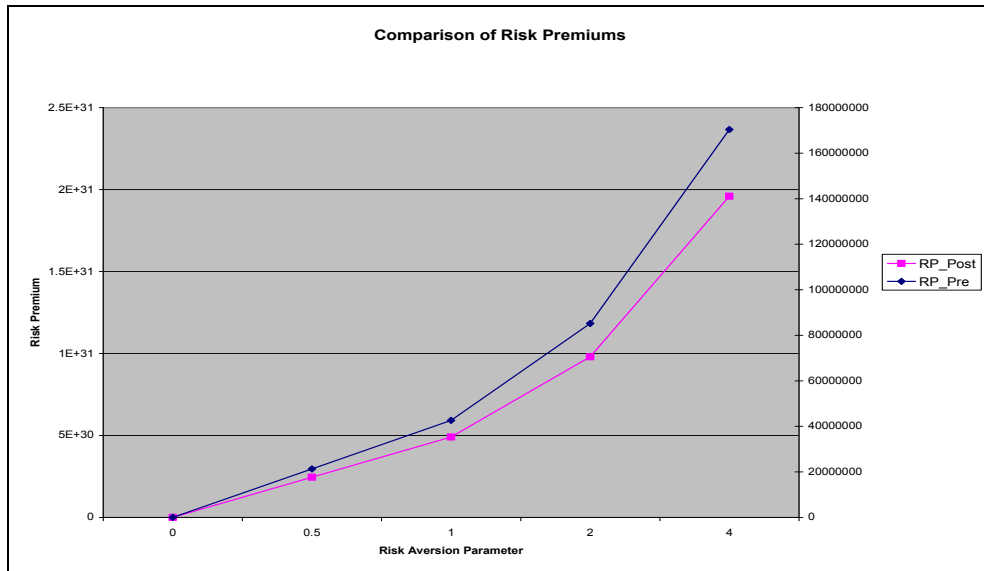
Figure 6.5: Comparison of Proportional Risk Premiums

6.2.3   Comparison of Proportional Risk Premiums (PRP) Pre & Post Treaty
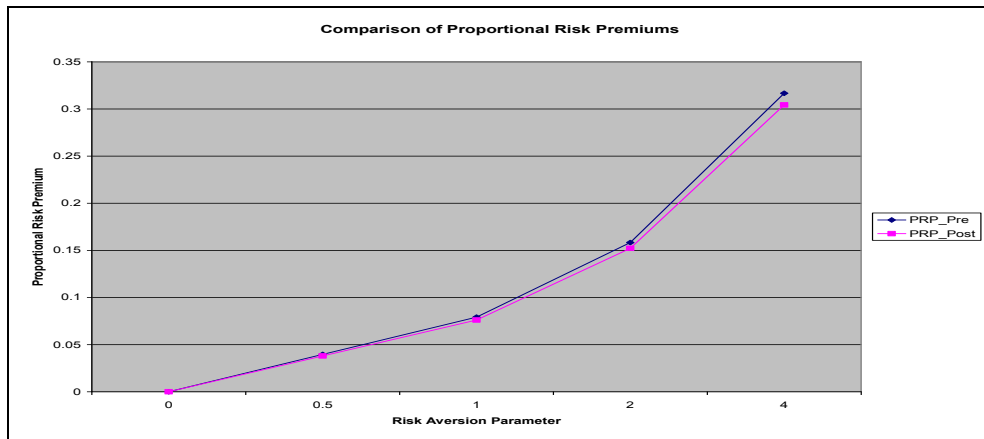
Figure 6.6**:** Comparison of Proportional Risk Premiums (Drought Conditions)

The figures above exhibit a similar pattern. In both cases higher levels of risk aversion are associated with higher levels of premium both in an absolute sense as well as a proportion of the mean revenue. This is expected since, the Risk Premium here indicates

the willingness of a riparian country to give up some of their revenue, in order to insure against future unseen adverse events. The more averse a riparian is to risk the higher the premium it is willing to forego. Thus it can be thought of as the risk perception of the riparian. It can also be concluded that the risk perception has lowered in the post treaty period, as we consistently observe lower levels of both absolute as well as proportional premium for all levels of risk aversion.

6.2.4 Computation of Total Risk Premium, Threshold Income Values and Probability of Non-compliance

From the table below it is apparent that the Total Risk Premium (TRP) is higher for higher levels of risk aversion. The threshold income is the minimum amount of income or gross revenue that the riparian is willing to accept in order to comply with the treaty specification. It is computed by subtracting the total risk premium from the pre treaty revenue as explained in the theoretical framework section

As expected this acceptable level of minimum income falls as risk aversion rises and as riparians are prepare to forego more in the form of premium and settle for a lower level of income. Thus we see that under risk neutrality, the TRP is the lowest and consequently the threshold income is the highest.

Table 6.1: Table showing TRP, Threshold Income & Likelihood of Compliance (Drought Conditions)

Risk Aversion	TRP	Threshold Income	Prob (Income<Threshold Value)
0	0.004369322	537940570.1	0.004450333
0.5	21290832.12	516649737.9	0.004450333
1	42581664.24	495358905.8	0.004450333
2	85163328.47	452777241.6	0.004450333
4	170326656.9	367613913.1	0.004450333

As expected this acceptable level of minimum income falls as risk aversion rises and as riparians are prepare to forego more in the form of premium and settle for a lower level of income. Thus we see that under risk neutrality, the TRP is the lowest and consequently the threshold income is the highest.

6.2.5 Comparison of Pre & Post Agricultural Welfare Functions (under Drought Conditions)

The figures below show the cumulative distribution of the simulated welfares pre and post treaty under drought conditions that existed during the year 1995.

(i) RRA = 0
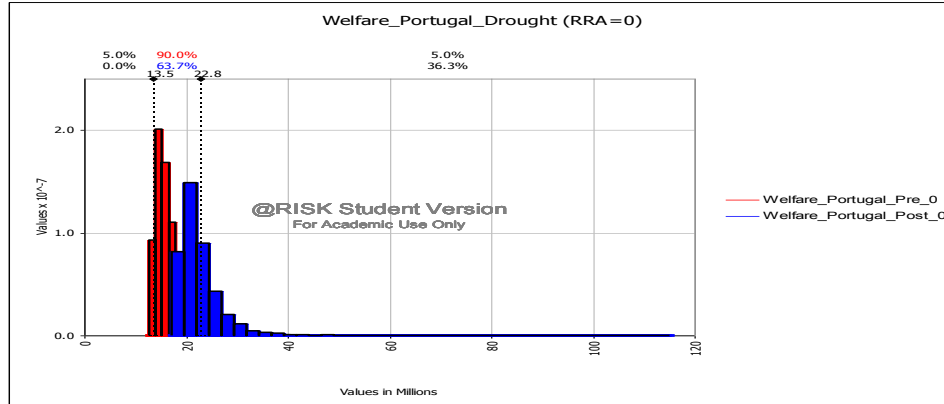
Figure 6.7: Comparison of Simulated Agricultural Welfare Distributions (Drought Conditions)

(iii)   RRA= 1
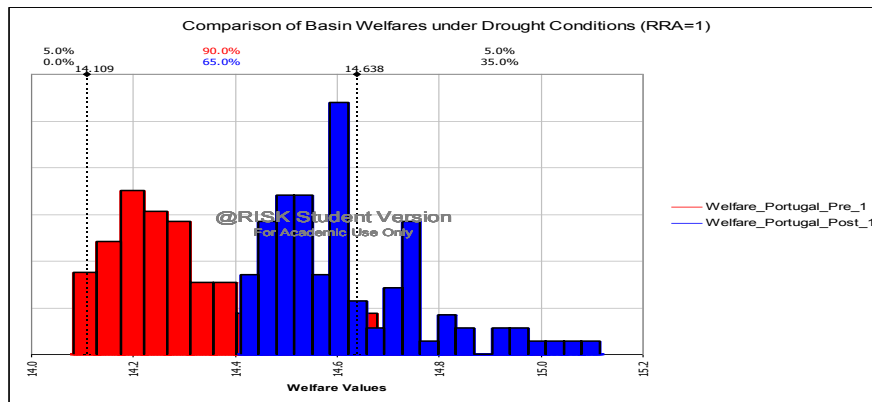
Figure 6.8: Comparison of Simulated Agricultural Welfare Distributions (Drought Conditions)

The simulation results for Portugal indicate that this riparian is better off in the post treaty scenario compared to the pre-treaty one. Moreover, under conditions of scarcity, Portugal's counterfactual welfare has substantially improved compared to the pre-treaty scenario. Thus as expected the downstream country undoubtedly fares better under the treaty and more so in times of drought.

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CHAPTER 7. TESTING THE STABILITY AND EFFICIENCY OF THE ALBUFEIRA CONVENTION

Results from the Spanish part of the Tajo basin suggest that under risk neutrality Spain is worse off after the implementation of the treaty, even under drought like conditions. However we observe the opposite results for Portugal. Now the question that naturally arises is how does the basin as a whole fare under pre and post treaty and drought scenarios. Hence, prior to testing the stability and the efficiency of the treaty specifications, welfare comparisons of the overall basin is made before and after the treaty, to find if the riparians would jointly encounter gains or losses from cooperation. For this we consider the periods before and after the modified AC treaty (2008), since we had robust results for this period. So we restrict our analysis for the periods from 2004 to 2011.

This chapter starts by presenting and comparing the overall basin welfare distributions pre and post treaty under both scenarios of water availability. It then proceeds to employ a cooperative game theoretic framework for examining if the AC treaty is indeed acceptable and stable even under conditions of scarcity and under the presence of various risk aversion levels

7.1 Simulation Results

The overall basin welfares pre and post treaty are simulated under normal as well as under drought like conditions as shown below

7.1.1 Computation of Overall Basin Welfares or the Joint Welfare under Cooperation (Normal Conditions)

(i)   Results for RRA=0

(ii)   Results for RRA=0.5

Basin Welfare under Normal Conditions (RRA=0.5)
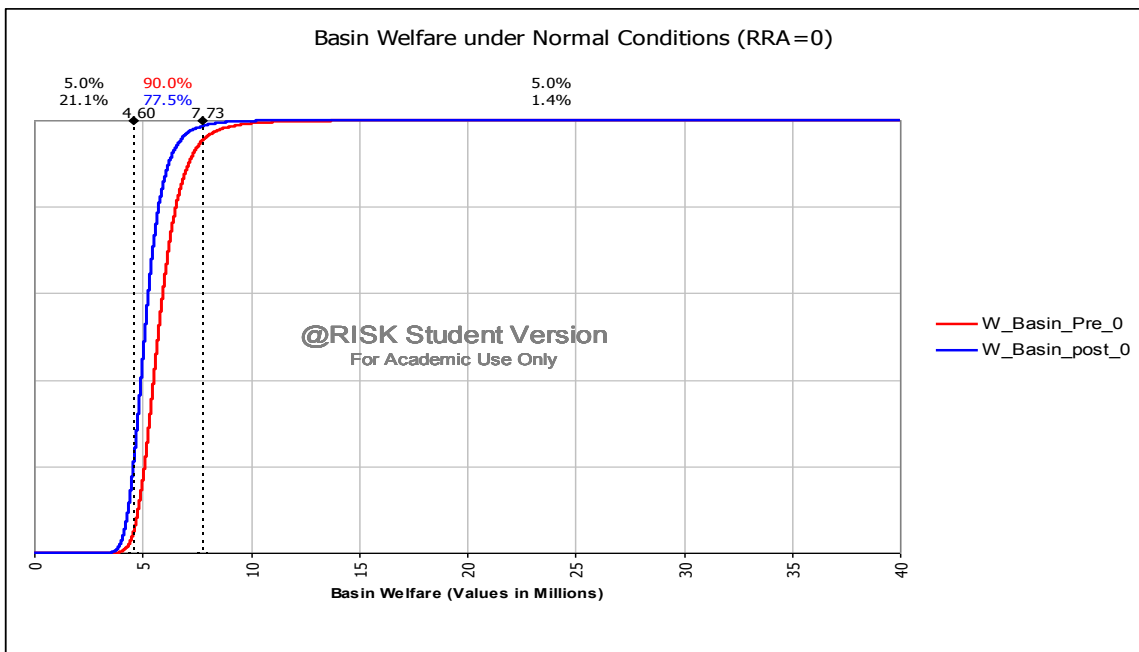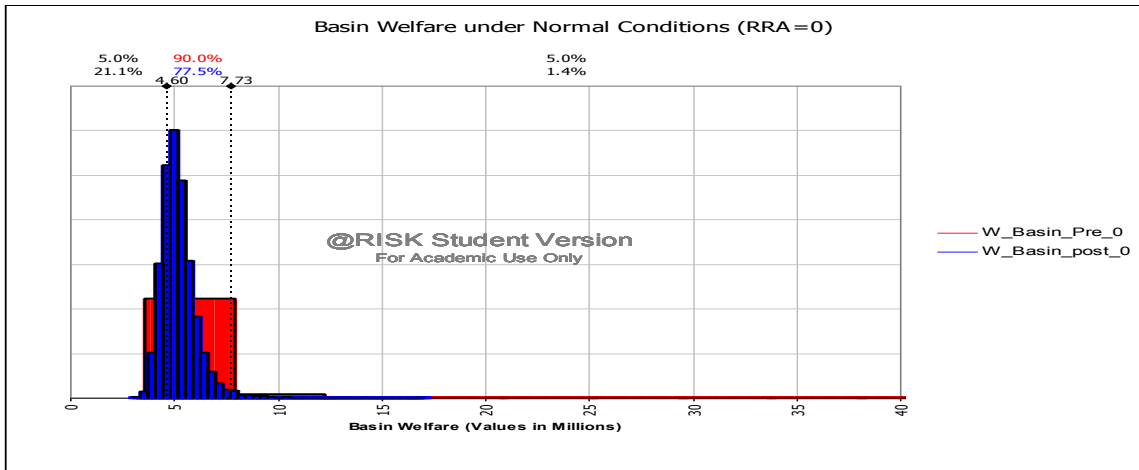
Basin Welfare under Normal Conditions (RRA=0.5)

(iii)   Results for RRA=1

Comparison of Basin Welfares under Normal Conditions (RRA=1)
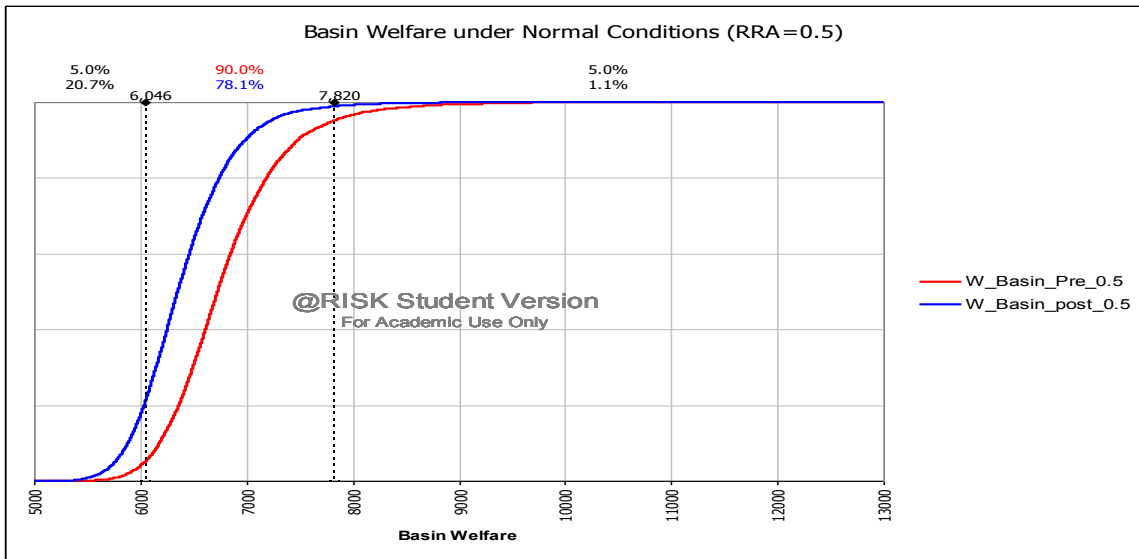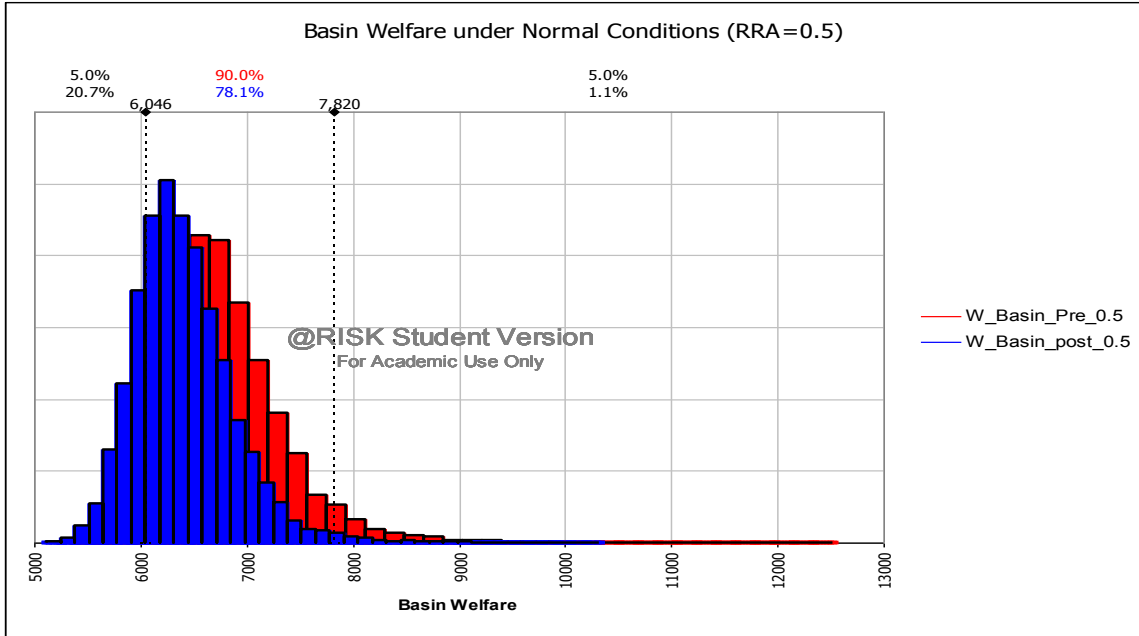
Comparison of Basin Welfares under Normal Conditions (RRA=1)
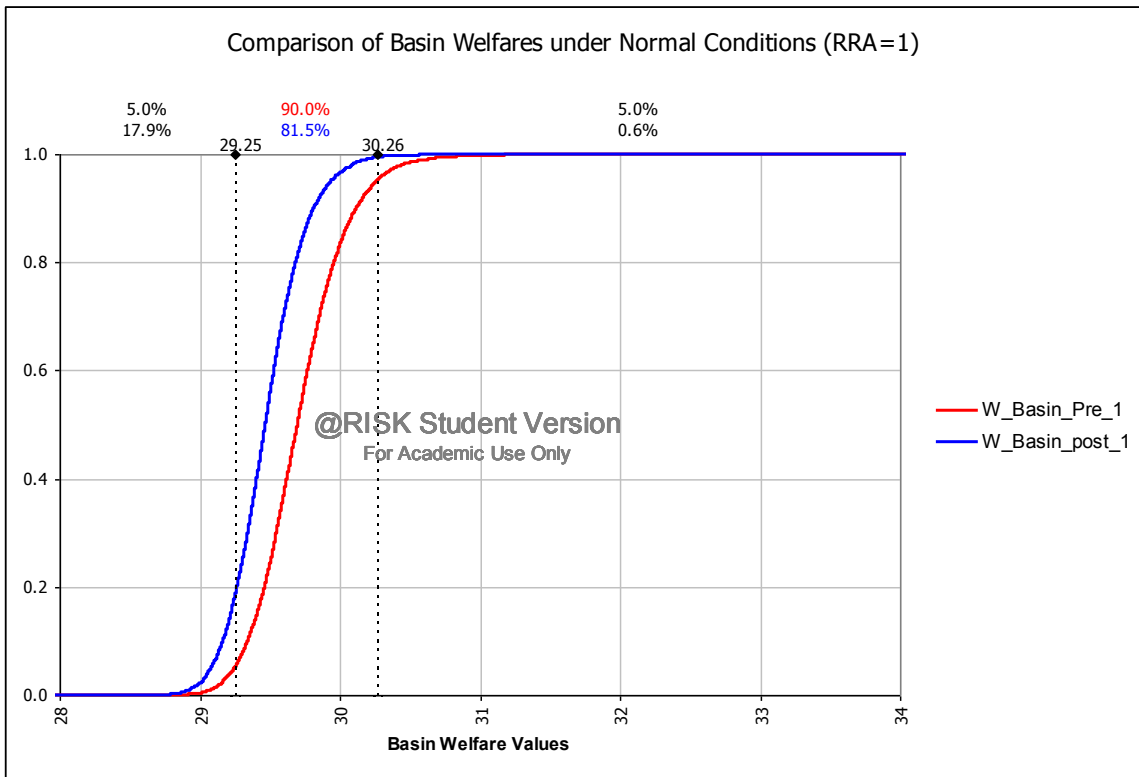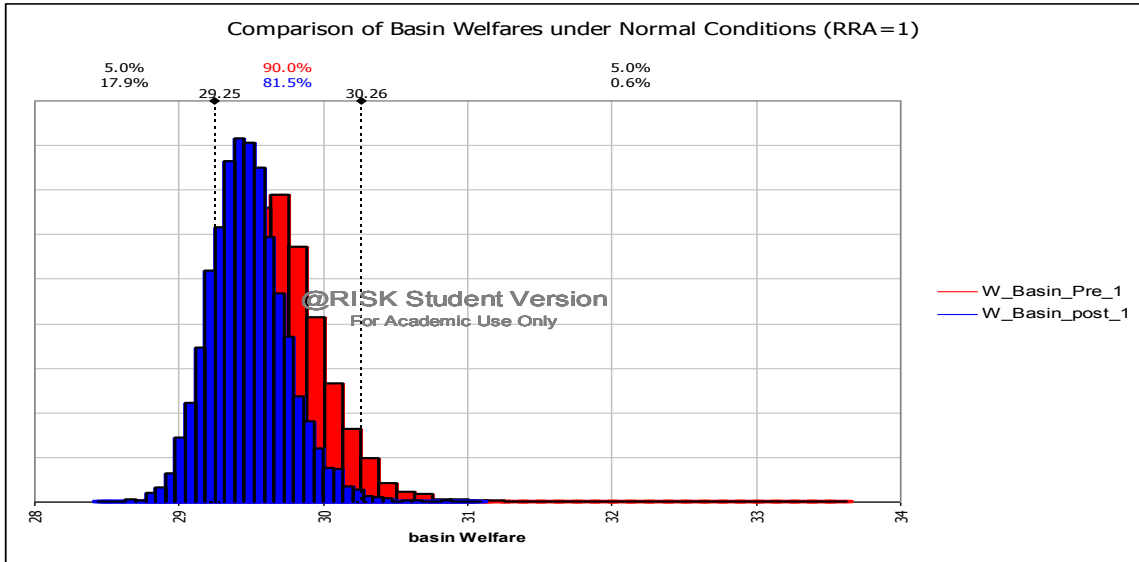
From the above simulation results it can be seen that the pre treaty basin welfares under normal conditions are lower for the different levels of risk aversion shown here.

7.1.2 Computation of Overall Basin Welfares or the Joint Welfare under Cooperation (Drought Conditions)

(i) RRA= 0

Basin Welfare under Drought Conditions (RRA=0)

Basin Welfare under Drought Conditions (RRA=0)

(ii)   RRA= 0.5

Basin Welfare under Drought Conditions (RRA=0.5)

Basin Welfare under Drought Conditions (RRA=0.5)

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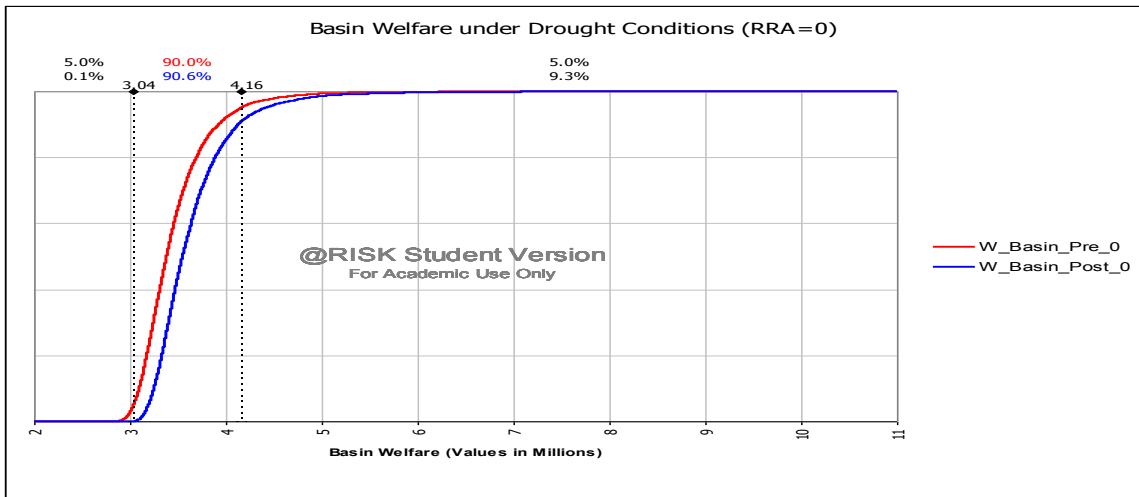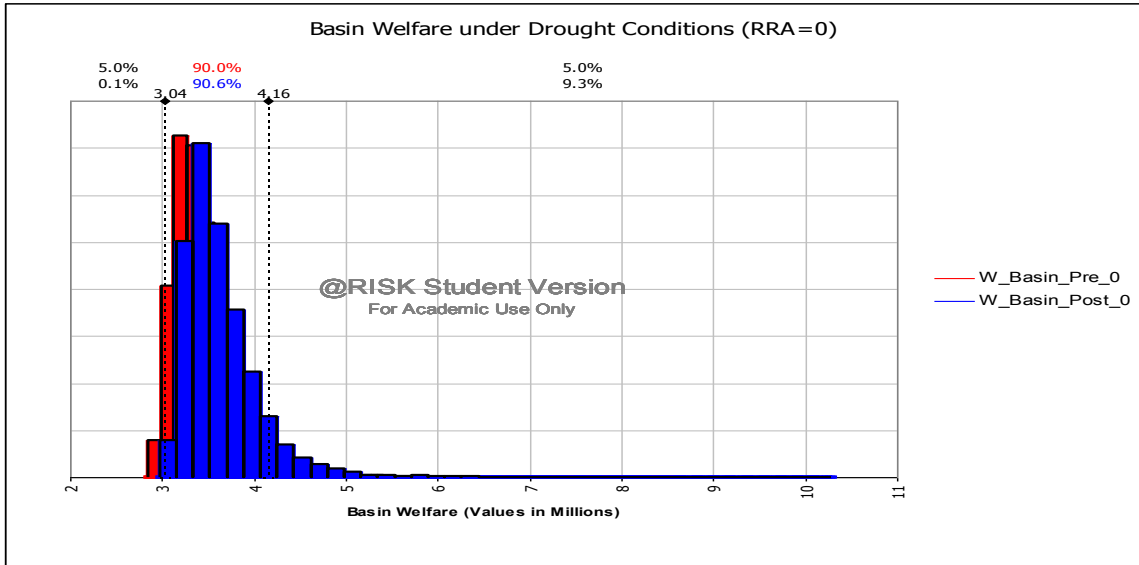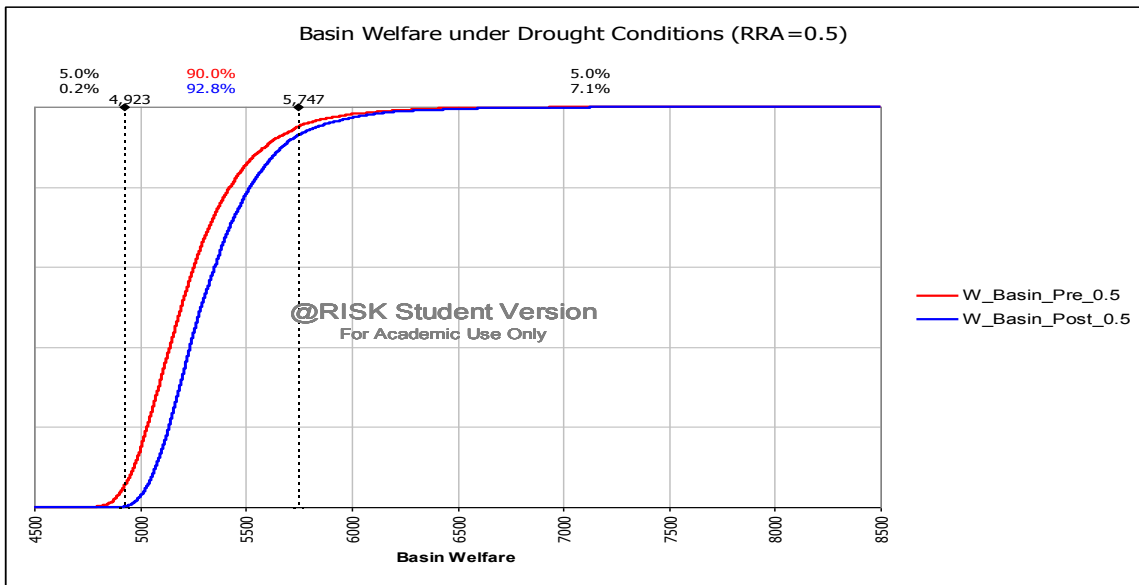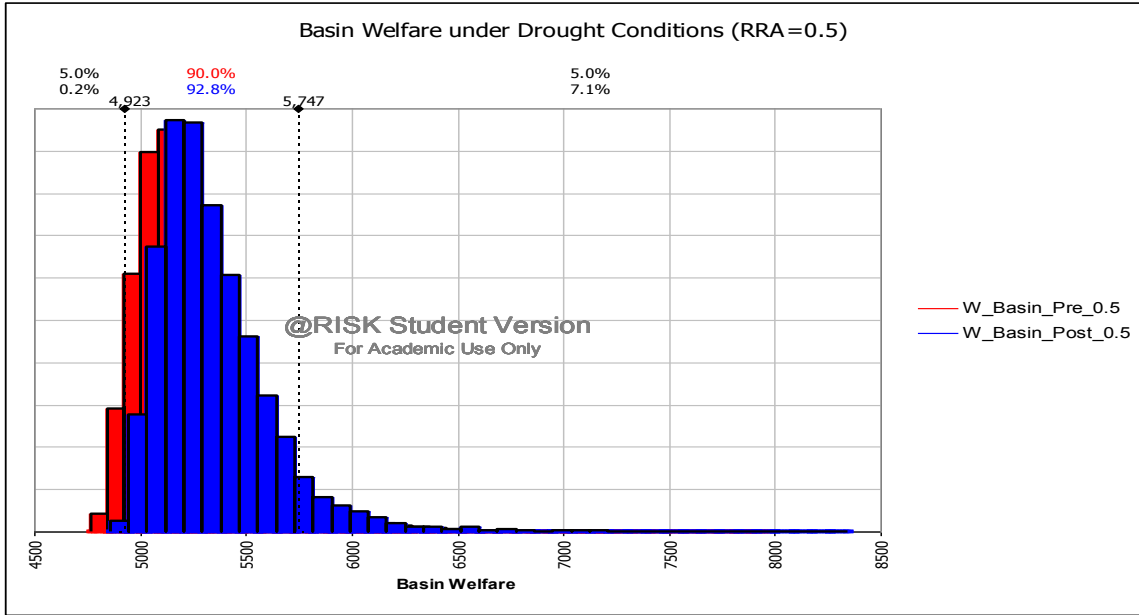
(iii)   RRA = 1
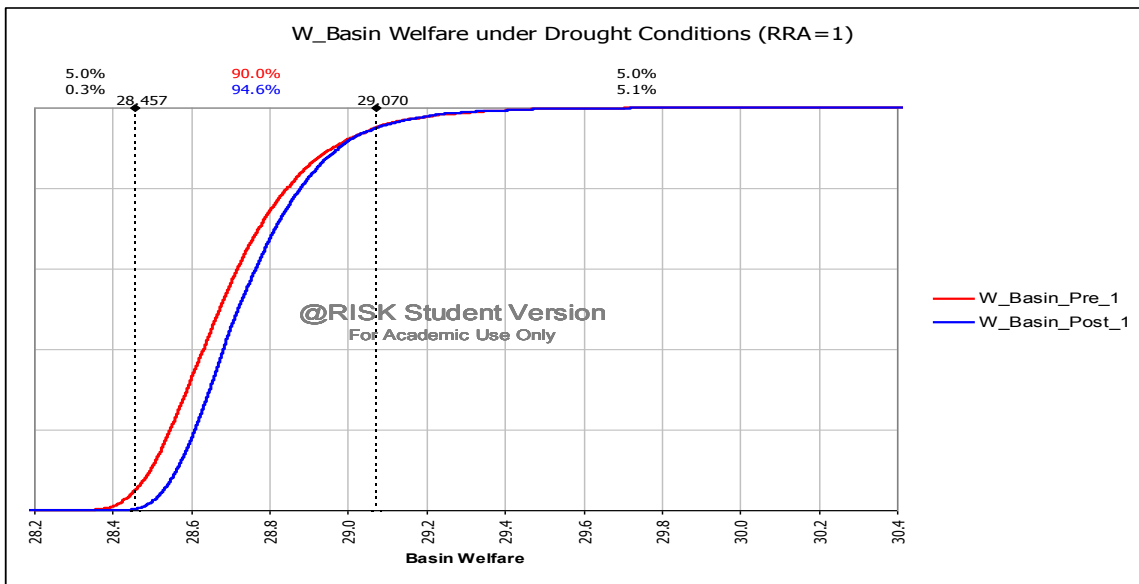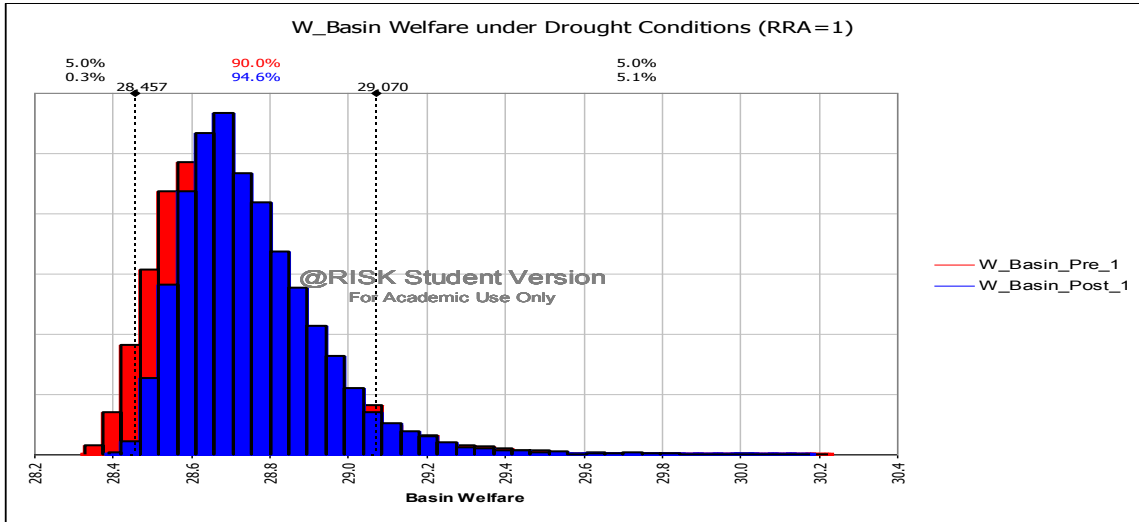
Under conditions of drought, we obtain a somewhat contrasting result. Under drought conditions, post treaty basin welfare is relatively higher compared to pre-treaty welfare. The major question facing the analyst is whether or not the gains from cooperation (adhering to the treaty) are sufficient to guarantee a stable agreement under various

drought scenarios and risk aversion levels. In order to address this question we employ cooperative game theory models that allow answering this question

7.2 A Cooperative Game Theoretic Framework:

Game theory is gradually becoming an essential tool in environmental and resource economics. This is because it can adequately model the typical features of strategic behavior associated with environmental problems, such as multi-actor decision making in situations characterized by the absence of property rights and the existence of externalities.

A crucial distinction is made in the literature between cooperative game theory and non-cooperative game theory. Non-cooperative game theory deals with the analysis of different strategies available to the players that enable them to maximize their net benefits while taking into account the strategic reaction of the other players. In contrast, cooperative game theory focuses its analysis on the possible coalitions of players that are likely to be formed, the distribution of joint outcomes within the coalition and the robustness and stability of these outcomes (Sosic and Nagarajan 2006). It is important to note that non-cooperative game theory does not necessarily imply the possibility of cooperation as an outcome, and similarly cooperative game theory might not necessarily rule out the presence of conflict or coalitional failure (Brandenburger 2007).

Early literature studying joint usage of common pool resources (CPR) mostly used non-cooperative game theory. This was based on the argument that the players are more likely to be driven by individual rationality rather than group rationality that is eventually affecting all users adversely (Ostrom, 2010). However Ostrom (1990) through extensive

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real world evidence and field studies challenged the pessimistic tragedy of the commons hypothesis. Ostrom et al. (1994) show that in addition to appropriating ownership rights to avoid tragic outcomes, development of cooperative institutions and collective actions can enable CPR users to escape the resource depletion trap and ensure sustainable use of the resource. Madani and Dinar (2012) use a numerical groundwater problem to demonstrate how CPR users can allocate gains from cooperation in a fair and efficient manner and how non-cooperative managerial characteristics affect the stability of different cooperative CPR management institutions. Parrachino et. al. (2006) and Madani (2010) provide extensive reviews of CGT applications to natural, environmental and water resource problems.

For reasons mentioned above and for the fact that water extractions from an international river basin is essentially a CPR problem, a cooperative game theoretic framework is applied to study the existing treaty in the Tajo Basin. The cooperative game theoretic model would mainly consist of two elements, a set of players (i.e the two riparian countries Spain and Portugal) and a characteristic function that essentially specifies the value created by different subsets of the players involved in the game. In the remaining part of this chapter, an attempt would be made to find how the total incremental value of the grand coalition might be divided up among the players and to explore the stability of the allocation solution obtained through the Shapley allocation scheme.

7.2.1 Methods for Allocation of Joint Gains

The literature puts forward several allocative mechanisms of joint gain sharing. For instance, the core, the Shapley value, the Nucleolus and the Nash-Harsanyi are some of the widely used ones.

7.2.2 The Core

Following Gillies (1959), the core is a solution concept that provides a locus of cooperative allocation gains as set of payoffs that no coalition can improve upon. The core could contain several allocation schemes as it merely provides an upper bound for the allocation each player would accept. Thus an imputation $x = (x_1, x_2, ..., x_n)$ that lies within the core must be satisfying the following conditions:

(i) $x_i \geq v(i)$, *for* $i = 1, 2, ..., n$ (Individual Rationality)

(ii) $\sum_{i \in S} x_i \geq v(S)$; (Group Rationality)

(iii) $\sum_{i=1}^{n} x_i = v(N)$; (Efficiency Condition)

where, x_i is the ith player's allocation of the incremental joint gains. Condition (i) ensures that none of the players individually can get a better payoff by an alternative action. Condition (ii) implies that a subset of players or coalition cannot be better off by an alternative strategy, while condition (iii) is the rationality for the grand coalition, requiring that all incremental gains have to be allocated. $v(N)$ is the most that all players (the grand coalition) can get out of the game when they all cooperate. As such through

cooperation, players could always share among themselves the incremental coalitional gains so that everyone gets more compared to any alternative set of individual rewards. The Core is a necessary condition for the stability of allocation of joint cooperative gains. In the following we introduce several allocation schemes that have been applied in the literature to allocation problems.

7.2.3 The Shapley Value

The Shapley Value allocation solution prescribes a single payoff for each player, which is the weighted average of all marginal contributions of that player to each possible coalition he or she is a member of (Shapley 1953). The Shapley Value is contained in the Core. The Shapley value allocations could be calculated as

$$\theta_j = \sum_{\substack{s \in S \\ j \in s}} \frac{(n - |s|)!(|s| - 1)!}{n!} [v(s) - v(s - \{j\})] \quad \forall j \in N,$$

Here, n is the number of players involved in the game and $|s|$ is the number of members in coalition s

7.2.4 The Nucleolus

The Nucleolus solution introduced by Schmeidler (1969) minimizes the largest inequity of the most dissatisfied coalition. It is a single solution that is within the core if the core is non-empty. It can be computed by finding ε in the optimization model below:

$$Max\varepsilon$$

$$\text{subject to; } \varepsilon \le \sum_{i \in s} x_i - v(s) \quad \forall s \in S, S \subseteq N \quad \text{and} \quad \varepsilon \gtreqless 0.$$

Where ε is the maximum tax imposed on all coalitions to keep them in the core.

7.2.5 The Nash-Harsayni (N-H) Allocation

The N-H solution introduced by Harsanyi (1959, 1963) is an extension of the two-player bargaining game discussed in Nash (1953). It is determined by maximizing the product of the benefits from cooperation obtained by each member in the grand coalition compare with the status quo. It is illustrated by the following mathematical model:

$$\Omega = Max \prod_{i=1}^{n} [x_i - v(i)]$$

subject to the core conditions (i) – (iii). The N-H allocation provides a unique solution that lies inside the core if the core is non-empty.

7.3 Stability of Allocation schemes

The necessary condition for acceptability of any allocation scheme is that it must lie within the core. However, even if a solution is contained within the core, it might not be acceptable if some players view it as unfair. Thus solutions within the core are not always stable. A coalition is **stable** if for all parties in the coalition there is no incentive to defect from the coalition and for all parties outside the coalition, there is no incentive to join. Carraro and Siniscalco (1993), show that such coalitions exist in the global pollution context game and that the gains from partial cooperation of a subgroup can be used to expand the coalition. If countries are not identical, side payments can be found to

increase the stability of the coalition so as to make even full cooperation among all players stable (Botteon and Carraro, 1995). A stable coalition is always individually rational but not necessarily group rational. This is because when individuals outside the coalition, join the coalition, the enlarged group can be better off. The outcome would be termed Pareto optimal if all parties cooperate thereby forming the grand coalition.

Since stability of a solution is an important consideration given fixed investment costs that can be jeopardized otherwise, we would test the stability of the solutions obtained through the allocation schemes mentioned earlier. The literature provides several measures of stability. We select two of the following commonly used indices for our analysis.

7.3.1 Loehman's Power Index:

The power index introduced by Loehman et. al. (1979) determines the power of a player in a cooperative game by comparing the gains to that individual player with gains to the coalition. The power index (α_i) is given by:

$$\alpha_i = \frac{x_i - v(\{i\})}{\sum\limits_{j \in N}(x_j - v(\{j\}))}, \quad i \in N; \quad \sum\limits_{i \in N}\alpha_i = 1,$$

If this power index is distributed equitably among all players then the coalition is likely to be stable. The stability measure (S_α) is the coefficient of variation of the power index calculated over all players in a given allocation solution:

$$S_\alpha = \frac{\sigma_\alpha}{\bar{\alpha}}.$$

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Larger values of α_i correspond to a greater degree of instability of the allocation solutions.

7.3.2 Propensity to Disrupt Index

The propensity to disrupt index introduced by Gately (1974) calculates the ratio of losses incurred by all players (other than player i) to the losses incurred by player i, when that player decides not to cooperate. Thus the propensity of player i to disrupt an existing coalition is given by:

$$PTD_i = \frac{\sum_{j \neq i} x_j - v(N-i)}{x_i - v(\{i\})} = \frac{v(N) - v(N-i)}{x_i} - 1, \quad i \in N,$$

A powerful threat for disruption of the grand coalition exists corresponding to positive and large values of this index.

7.4 Application to the Tajo Basin

In this subsection, the CGT framework is applied to the Tajo Basin. This is done in order to derive possible schemes of allocating the payoffs from forming the grand coalition in a fair manner and to test for the efficiency and stability of such allocation schemes. In order to do this, the Shapley values are computed for the two riparians (Spainand Portugal) under normal as well as drought conditions for several values of the risk aversion parameter (RRA=0, RRA=0.5 and RRA=1). [18] After obtaining the Shapley solution, we

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[18] In this case with two riparians the Nucleolus as well as the N-H Solution are the same as the Shapley solution

test whether or not the solution lies within the core. The acceptability and stability of the solution is tested further using Loehman's Power and Stability Index and the Propensity to Disrupt Index. Thus through the CGT framework, the stability of the AC treaty is tested under normal as well as drought conditions for different levels of risk aversion.

7.4.1 Applying the Allocation Schemes

In this section we apply the solution concepts discussed earlier to derive the cooperative allocations both under normal conditions as well as under drought conditions that existed during the year 1995. We make these calculations under the assumption of risk neutrality (i.e. for RRA=0) and explore the repercussions on stability in the presence of risk aversion (i.e. for RRA=0.5 and RRA=1)

7.4.1.1 Shapley Value (RRA=0)

able 7.1 and 7.2 present the values of the characteristic function for the possible coalitions under normal and drought conditions respectively. IN the case of the Tajo, possible coalitions include {Spain}, {Portugal}, and {Spain, Portugal}

Here the characteristic function is derived from the Expected Welfare of the riparian assuming risk neutrality. The pre-treaty expected welfare value is taken as the value function under noncooperation whereas the sum of post-treaty expected welfares forms the joint gross revenue under cooperation. From Table 7.1a and 7.1b it is evident that both during normal and drought conditions, though the downstream riparian, Portugal is better off as a result of the treaty while the upstream country, Spain is worse off. It can

also be noted that the welfares for each country are lower under drought compared to normal conditions.

Table 7.1: Welfare Values of Different Coalitional Settings (Normal Conditions)

Coalition	Welfare Values		Total Coalition Value
	Spain	Portugal	
Spain	3397666	-	3397666
Portugal	-	2500457	2500457
Grand	2133788	3095991	5229779

Table 7.2: Welfare Values of Different Coalitional Settings (Drought Conditions)

Coalition	Spain	Welfare Values Portugal	Total Coalition Value
Spain	1787516	-	1787516
Portugal	-	1676231	1676231
Grand	1375200	2272013	3647212

In the table below the incremental contributions made to the grand coalition by each riparian and also their Shapley values both under normal as well as drought conditions are calculated.

Table 7.3 presents for each riparian, the incremental contributions and the Shapley Value calculated using those contributions. From the above table it can be noted that the Shapley value imputations are positive for both Spain and Portugal. During drought conditions the imputation for Spain and Portugal is lower compared to that under normal conditions

Table 7.3: Value Functions and Calculation of Shapley Value

	Normal Conditions	Drought Conditions
V(Grand)	5229779	3647212
V(Spain)	3397666	1787516
V(Portugal)	2500457	1676231
V(Grand)-V(Spain)	1832113	1859697
V(Grand)-V(Portugal)	2729322	1970982
Shapley (Spain)	3063494	1879249
Shapley (Portugal)	2166285	1767964
Shapley(Spain)-V(Spain)	125181698606	3900471830
Shapley (Portugal)-V(Portugal)	125181698606	3900471830

7.4.1.2 Shapley Value (RRA=0.5)

Now we proceed to find the Shapley allocations under a very low level of risk aversion (i.e. RRA=0.5).

Table 7.4: Characteristic Function of Different Coalitional Settings (Normal Conditions)

		Welfare Values	Total Coalition Value
Coalition	Spain	Portugal	
Spain	3665	-	3665
Portugal	-	3139	3139
Grand	2915	3493	6408

Table 7.5 Characteristic Function of Different Coalitional Settings (Drought Conditions)

Coalition	Spain	Welfare Values Portugal	Total Coalition Value
Spain	2671	-	2671
Portugal	-	2578	2578
Grand	2343	3004	5347

The value functions exhibit similar properties as those under risk neutrality. From Table 7.4 and 7.5 it is evident that both under normal as well as drought conditions, Portugal is better off while Spain is worse off being in the grand coalition

Table 7.6: Value Functions & Calculation of Shapley Value

	Normal Conditions	Drought Conditions
V(Grand)	6408	5347
V(Spain)	3665	2671
V(Portugal)	3139	2578
V(Grand)-V(Spain)	2744	2677
V(Grand)-V(Portugal)	3270	2769
Shapley (Spain)	3467	2720
Shapley (Portugal)	2941	2627
Shapley(Spain)-V(Spain)	-197	49
Shapley (Portugal)-V(Portugal)	-197	49

From Table 7.6 it can be observed that both under normal as well as drought conditions, the Shapley allocation to Spain are higher than that of Portugal. Moreover, he allocation to each riparian reduces during drought compared to normal conditions

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7.4.1.3 Shapley Value (RRA=1)

The characteristic function values derived from welfare calculations for a relatively higher level of risk aversion are presented in the table below.

Table 7.7: Characteristic Function of Different Coalitional Settings (Normal Conditions)

Coalition	Spain	Welfare Values Portugal	Total Coalition Value
Spain	15.02	-	15.02
Portugal	-	14.70	14.70
Grand	14.56	14.92	29.48

Table 7.8: Characteristic Function of Different Coalitional Settings (Drought Conditions)

Coalition	Spain	Welfare Values Portugal	Total Coalition Value
Spain	14.39	-	14.39
Portugal	-	14.32	14.32
Grand	14.13	14.62	28.75

From Table 7.7 and Table 7.8 it is evident that by forming the grand coalition, Spain is worse off while Portugal is better of than before

Table 7.9 presents the Incremental contributions and the Shapley allocations for each riparian. For Spain the allocations are higher than Portugal under both scenarios, and these allocations are lower under conditions of drought

Table 7.9: Value Functions & Calculation of Shapley Value

	Normal Conditions	Drought Conditions
V(Grand)	29	29
V(Spain)	15	14
V(Portugal)	15	14
V(Grand)-V(Spain)	14	14
V(Grand)-V(Portugal)	15	14
Shapley (Spain)	14.90	14.41
Shapley (Portugal)	14.58	14.34
Shapley(Spain)-V(Spain)	0	0
Shapley (Portugal)-V(Portugal)	0	0

7.4.2 Testing Acceptability & Stability of Allocation Schemes

The Shapley value suggests a fair way of dividing the payoffs from the grand coalition. However, it ignores stability considerations. In this section we check if the imputations using the Shapley scheme lie within the core to verify if this allocation would be acceptable to the riparians. Moreover, we use several stability indices namely Loehman's Power and Stability Indices and the Propensity to Disrupt Index in order to verify the stability of the treaty for each of the allocation schemes computed.

7.4.2.1 Shapley Value (RRA=0)

We start with exploring the acceptability and stability of the Shapley allocation under risk neutrality.

I. Testing Core Conditions

In order to test the acceptability of the Shapley allocation, we first check the necessary condition i.e. whether it is a part of the core. The extreme points (lower bounds) of the core are given in the equations below.

Core of the Game (Normal Conditions)

$$x_{Spain} \geq 3397666$$

$$x_{Portugal} \geq 2500457$$

$$x_{Spain} + x_{Portugal} \geq 5898123$$

Core of the Game (Drought Conditions)

$$x_{Spain} \geq 1787516$$

$$x_{Portugal} \geq 1676231$$

$$x_{Spain} + x_{Portugal} \geq 3463746$$

Comparing these equations with the Shapley allocation from Table 7.2, it is evident that the Shapley allocation neither satisfies individual rationality nor does it satisfy group rationality. However under conditions of scarcity it satisfies both individual and group rationality conditions. Thus it can be concluded that under risk neutrality the Shapley allocation efficient and lies within the only under drought conditions. The stability of the allocation solution is tested further, since fulfillment of the efficiency conditions during drought conditions do not guarantee stability of the allocations. For this we use Loehman's Power and Stability Index and the Propensity to Disrupt Index.

II. Loehman's Stability Index

Loehman's Power Index examines the power of a player by comparing individual gains with coalitional gains.

Table 7.10Computation of Loehman's Power & Stability Index

	Power Index		Stability Index
	Normal Conditions	Drought Conditions	
Spain	0.50	0.50	0.00
Portugal	0.50	0.50	0.00

Table 7.10 presents the Power Indices (under normal and drought conditions) and the Stability Index associated with each player. The power index is apparently distributed equally under both scenarios and this is expected since the Shapley value ensures a fair distribution of coalitional payoffs. A low value of the stability index exhibits a low level of instability of the allocation solution.

III. Propensity to Disrupt Index

The propensity to disrupt index compares the losses to all other members of a coalition compared to individual losses when that player declines from cooperation. Table 7.11 shows the values of the propensity to disrupt (PTD) Index computed both under normal and drought situations.

Negative values of the PTD reflect eagerness for the given allocation, whereas high positive values indicate a potential threat to disintegrate the grand coalition. The PTD values as observed from Table 7.11 are positive, indicating that none of the riparian countries are too eager to cooperate under the proposed Shapley allocation. While there might be a possibility for either country to defect from the coalition under this allocation scheme, it is quite low.

Table 7.11 Propensity to Disrupt to Index

	Normal Conditions	Drought Conditions
PTD (Spain)	0.99	0.05
PTD (Portugal)	1.01	0.05

7.4.2.2 Shapley Value (RRA=0.5)

Here we test the acceptability and the stability of the Shapley allocation scheme under a low level of risk aversion

I. Testing Core Conditions

Core of the Game (Normal Conditions)

$$x_{Spain} \geq 3665$$

$$x_{Portugal} \geq 3139$$

$$x_{Spain} + x_{Portugal} \geq 6803$$

Core of the Game (Drought Conditions)

$$x_{Spain} \geq 2671$$

$$x_{Portugal} \geq 2578$$

$$x_{Spain} + x_{Portugal} \geq 5249$$

Comparing the Shapley allocations from Table 7.4, it can be noticed that the Shapley allocations do not satisfy the conditions of individual or group rationality under normal conditions of water availability. However under conditions of scarcity the allocation does satisfy individual and group rationality. Thus the solution lies within the core and is efficient only during drought scenarios. Since efficiency does not guarantee stability, we proceed to test the stability of the allocation scheme using the following indices.

II. Loehman's Stability Index

The table below presents Loehman's Power and Stability indices for a low level of risk aversion. A lower value of the power index reflects higher chances of adhering to the coalition.

| | Power Index | | Stability Index |
	Normal Conditions	Drought Conditions	
Spain	0.50	0.50	0.00
Portugal	0.50	0.50	0.00

Table 7.12 Computation of Loehman's Power & Stability Index

Since payoffs according to the Shapley value are distributed fairly, it is expected that the power index is equal for the two riparians both under normal as well as drought

conditions. Low values of the stability index as observed from the above table indicate lower chances of instability.

III. Propensity to Disrupt Index

Results of the stability test using the Propensity to Disrupt (PTD) Index are presented by the table below.

Table 7.13 Propensity to Disrupt to Index

	Normal Conditions	Drought Conditions
PTD (Spain)	-0.06	0.02
PTD (Portugal)	-0.07	0.02

Negative PTD values under risk aversion illustrate the eagerness of the riparians to cooperate, while higher positive values exhibit a greater threat for the coalition to break down. From the above table it can be noted that during periods of drought both Spain and Portugal exhibit a low propensity to defect from the treaty specifications.

7.4.2.3 Shapley Value (RRA=1)

I. Testing Core Conditions

Core of the Game (Normal Conditions)

$$x_{Spain} \geq 15.02$$

$$x_{Portugal} \geq 14.70$$

$$x_{Spain} + x_{Portugal} \geq 29.72$$

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Core of the Game (Drought Conditions)

$$x_{Spain} \geq 14.39$$

$$x_{Portugal} \geq 14.32$$

$$x_{Spain} + x_{Portugal} \geq 28.71$$

II. Loehman's Stability Index

Table below presents Loehman's Power and Stability indices for RRA=1. Both indices show equal distribution of power as observed for lower levels of risk aversion.

Table 7.11: Computation of Loehman's Power & Stability Index

	Power Index		Stability Index
	Normal Conditions	Drought Conditions	
Spain	0.50	0.50	0.00
Portugal	0.50	0.50	0.00

The stability index also takes on the lowest possible value, indicating stability of the coalitional arrangement under the Shapley allocation scheme.

III. Propensity to Disrupt Index

Table 7.14 below presents the Propensity to Disrupt Index for a relatively higher level of risk aversion.

Table 7.14 Propensity to Disrupt to Index

	Normal Conditions	Drought Conditions
PTD (Spain)	-0.01	0.00
PTD (Portugal)	-0.01	0.00

The PTD values suggest that during drought conditions there could be a low possibility of defecting from the treaty specifications. However compared to no or lower levels of risk aversion, the threat of defection is reduced under a relatively high level of risk aversion

CHAPTER 8. CONCLUSIONS AND POLICY IMPLICATIONS

This dissertation set out to find answers to several questions for instance how does an international water treaty alter the welfare distributions of its signatories; how differently is an upstream country affected by the treaty as opposed to a downstream one; what could be the conditions under which a riparian might agree to comply with the treaty; could it be possible to compute the probability of breakdown of a treaty; could the treaty be stable even under conditions of scarcity and how do risk preferences influence the compliance behavior and the stability of the treaty. In order to answer these questions an analysis was conducted on the Tajo Basin shared between Spain and Portugal. The Albufeira Convention signed between the riparians and put into practice in the year 2000 rendered it possible to conduct such a comparative study of the pre and post cooperative scenarios.

To summarize, this dissertation explored the impact of an existing international water treaty (the Albufeira Convention) on the agricultural welfare of its signatories namely Spain and Portugal and examined how water scarcity affected this welfare. Since, the asymmetrical gains from the treaty between an upstream and a ownstream riparian poses a potential threat for the breakdown of the treaty, the study was directed to computing for each riparian, the likelihood of compliance to the treaty. This was done by identifying and comparing how much each riparian would be willing to forego in order insure against future adversities in the face of water scarcity and how much it is actually foregoing by entering into the treaty. This estimation of the likelihood of compliance enabled us to compute the risk of disintegration of the treaty. Finally, a cooperative game theoretic framework was applied to find how the payoffs from cooperation could be fairly

distributed between the two riparians and to check if this allocation solution is stable. The analysis is repeated assuming a drought scenario that existed during the year 1995 to conduct a comparative study of how the welfare distributions, the risk to the treaty and the stability of the treaty are affected under conditions of water scarcity as opposed to normal conditions of water availability.

Treaty Impacts on crop yields were estimated by adopting the Difference in Differences Approach using the variation in yields on rainfed and irrigated lands. The results using data from Spain suggest that the modified treaty (2008) has a significant impact on crop yields. Thus we proceed by comparing the agricultural welfares before and after the modified treaty. The 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-à-vis under cooperation and the comparison of risk premiums under the status quo vis-à-vis under cooperation between the riparians.

The simulations of pre and post treaty welfare distribution for Spain under normal conditions of water availability and a comparison of the same suggest that post treaty agricultural welfares are lower on average compared to the pre treaty welfare for no or low levels of risk aversion. However for very high levels of risk aversion pre treaty welfare is comparatively lower than post treaty welfare. Similar results are obtained under drought conditions and for different levels of risk aversion. Thus these results suggest that under both scenarios of water availability Spain is worse off in the post treaty period under risk neutrality and also for lower levels of risk aversion. However, for

Portugal the simulated post treaty welfare distribution exhibit higher average welfares than the pre treaty one. This result holds even under drought conditions and for different levels of risk aversion. This suggests that Portugal is better off in the pre treaty period.

For Spain, the risk premium obtained under normal conditions of water availability is lower in the post treaty period compared to the pre-treaty period for all levels of risk aversion. However, during drought conditions for very high levels of risk aversion the post treaty risk premium is higher than the pre treaty risk premium. This indicates that Spain under high levels of risk aversion has a higher perception of risk from variability in agricultural revenue in the post treaty period. On the contrary, for Portugal, the post treaty risk premium is lower for all levels of risk aversion.

The results from the CGT analysis suggest that under normal conditions of water availability the Shapley allocation scheme is not within the core and hence is not efficient. This result holds true for all levels of risk aversion. However during drought conditions, the Shapley allocation does provide an efficient solution for all levels of risk aversion as they are within the core. Thus we discuss only the stability of the Shapley allocations under scarcity. The PTD values exhibit a low possibility of defection from the treaty. Comparisons of the PTD values across the different risk aversion parameters indicate that the Shapley solution is more stable for higher levels of risk aversion. Thus cooperation is apparently a stable outcome in case of a high level of risk aversion and only under scarce conditions.

The existing literature, to the best of our knowledge, has not dealt with the assessment of the impact of an international water treaty at a basin level, nor has it dealt with the

formulation and computation of the risk of such a treaty falling apart. Thus the main contributions of this dissertation to the existing literature are fourfold. First, the assessment of the impacts of the AC treaty on the agricultural welfare of each riparian as well as of the basin as a whole. Second, the development of an analytical framework for evaluating the likelihood of compliance and the risk of disintegration of the treaty. Third, finding if there exists a fair and efficient allocation of payoffs from cooperation that ensures stability of the AC treaty. Fourth, incorporation of risk preferences in computing the treaty risk and assessing the stability of the treaty.

The framework of the analysis conducted in this dissertation can easily be generalized and extended to the case of a river basin with more than two riparians. Through the CGT framework, it is possible to rule out highly unstable arrangements and come up with solutions that minimize incentives to defect from the treaty. Thus, such analysis could enable the formulation of well defined rules for joint use of a river basin. If cooperation is indeed a preferable solution, it could provide incentives for establishing proper institutions that centre on the improvement of monitoring and law enforcement mechanisms. Further it could help alleviate the adverse effects of water scarcity on international security through well designed methods of anticipating and dealing with disputes before they crop up.

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 and design ways to diminish conflicts and their potential to disrupt global peace.

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. It is uncertain if cooperation would still be the preferred decision choice under future climatic conditions when scarcity levels are likely to be raised. A future study could 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 predicted extreme variability in water availability. It could be interesting to check if scarcity and cooperation indeed demonstrates a hill shaped relation in this case as suggested by the institutionalist school of thought. If water scarcity does turn out to be a matter of concern, there is likely to be a clash in interest between the riparians and several studies predict that this would leave the riparians with a conflictual zero-sum mindset (e.g. Cooley 1984; Klare 2001; Lonergan 2001). Under such a situation an upstream downstream relation between treaty signatories could turn out to be rather challenging since it could permit the upstream state to inflict negative externalities on the downstream state (Mitchell and Keilbach 2001; Stinnett and Tir 2009). It would also be interesting to perform a comparative analysis of welfares and the treaty stability with and without the presence of trade relations, since trade relationships

can act as signals of a country's trustworthiness and create environments in which cooperation can thrive and the cost of conflict is raised (Gartzke, Li, and Boehmer 2001).

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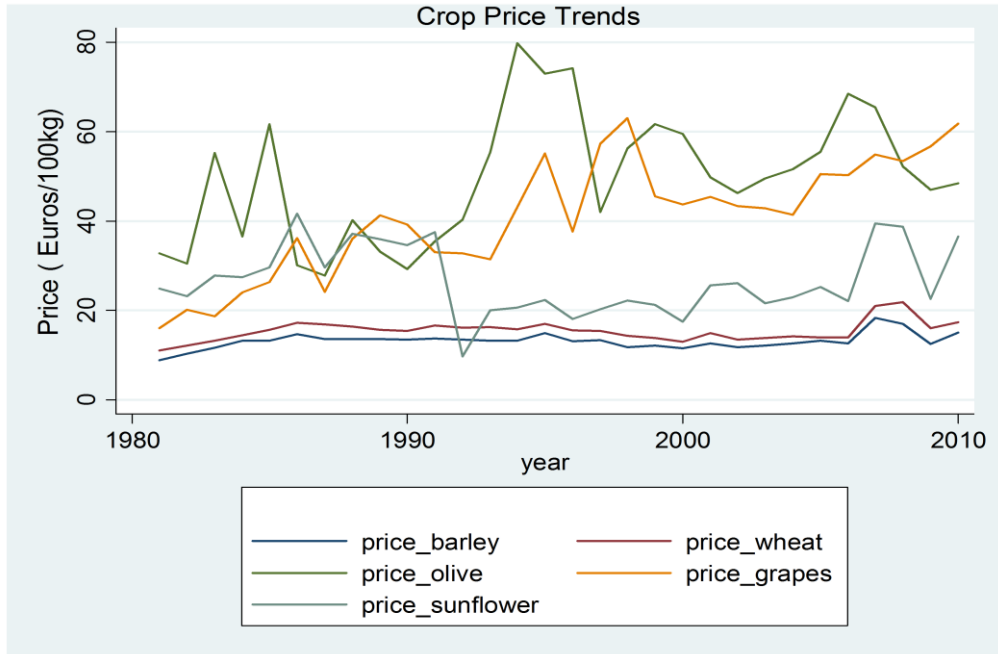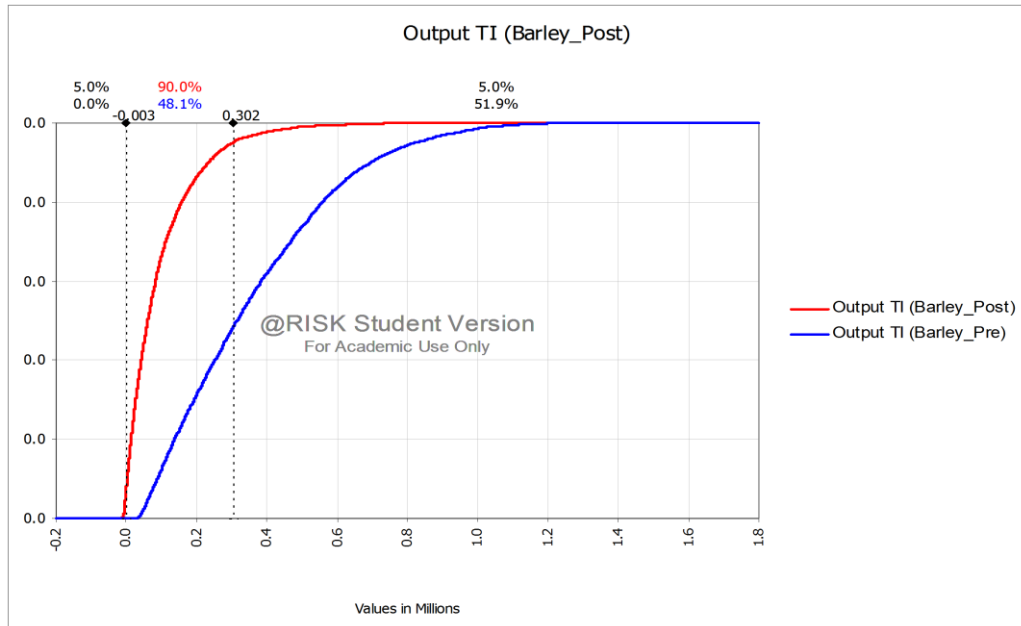
APPENDIX

A.1   Spatial Distribution of Soil Wetness Values
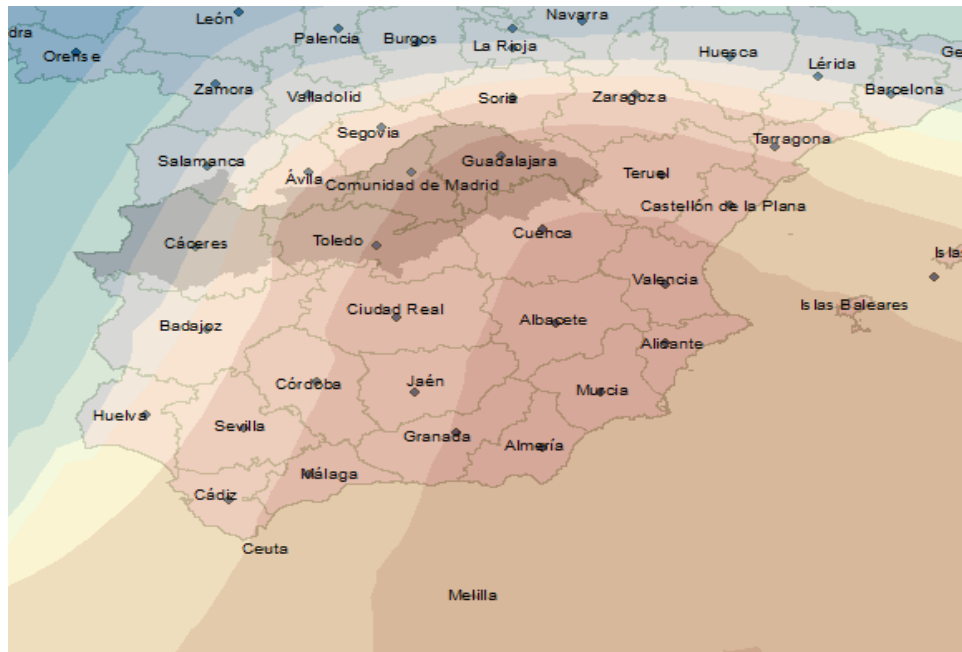
A.2   Distribution of Drought Index Values

A.3   Crop Prices over the years in Spain

A.4   Cumulative Distribution of Gross Revenue for Barley in Caceres Province

A.1 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

A.2 Random Effects GLS with Precipitation as the Hydrological Indicator

Variables	Barley Pre-Treaty	Barley Post Treaty	Wheat Pre-Treaty	Wheat Post Treaty	Olives Pre-Treaty	Olives 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	0	0	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	0	-0.03 *
	(0.01)	(0.01)	(0.01)	(0.01)	(0.03)	(0.02)
Precip Square	0 ***	0.00 ***	0.00 **	0.00 ***	0	0.00 *
	0.00	0.00	0.00	0.00	0.00	0.00
Land Dummy	1.49 ***	0.96 ***	0.5	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	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	0.5
N	238	160	238	162	180	137
Wald Chi2	721.07	1778.75	1796.95	394.75	77.33	1445.6
Prob	0.00	0.00	0.00	0.00	0.00	0.00

A.3   Cobb Douglas Production Function with SPI as the Hydrological Indicator

Variables	Barley Pre-Treaty	Barley Post Treaty	Wheat Pre-Treaty	Wheat Post Treaty	Olives Pre-Treaty	Olives Post Treaty
Log (SPI)	-0.02	0	-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	0	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	0	0	0	0	0

A.4   ANOVA & t-test Results for Differences in Mean & s.d. of Rainfed & Irrigated Land Usage

Crop	Statistic	Yield			Gross Revenue		
		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	0.3	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	7.4	-0.08 *	1700276	1236932	-463344 **

A.0.5 ANOVA & t-test Results for Yield and Gross Revenue on Irrigated Land

| Crop | Statistic | Yield | | | Gross Revenue | | |
		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	0.3	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	7.4	-0.08 *	1700276	1236932	-463344 **