FUNDACIÓN AQUAE

TESIS

WATER OPTION CONTRACTS FOR REDUCING WATER SUPPLY RISKS: AN APPLICATION TO THE TAGUS-SEGURA TRANSFER

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RESUMEN

El agua es un recurso cada vez más escaso y valioso. Por ello, los recursos hídricos disponibles deben asignarse de una forma eficiente entre los diferentes usos. El cambio climático aumentará la frecuencia y severidad de los eventos extremos, y podría incrementar la demanda de agua de los cultivos. El empleo de mecanismos flexibles de asignación de agua puede ser imprescindible para hacer frente a este aumento en la variabilidad del balance hídrico y para asegurar que los riesgos de suministro, y no solo los recursos, son compartidos de manera eficiente entre los usuarios. Los mercados de agua permiten la reasignación de los recursos hídricos, favoreciendo su transferencia desde los usos de menor a los de mayor valor. Diferentes tipos de mercados de agua se han establecido en diferentes partes del mundo, ayudando a los participantes a afrontar los problemas de escasez de agua en esas zonas.

En España, los intercambios de agua están permitidos desde 1999, aunque la participación de los usuarios en el mercado ha sido limitada. Hay varios aspectos de los mercados de agua en España que deben mejorarse. Esta tesis, además de proponer una serie de cambios en el marco regulatorio, propone la introducción de contratos de opción de agua como una posible mejora. La principal ventaja de este tipo de contratos es la estabilidad legal e institucional que éstos proporcionan tanto a compradores como vendedores. Para apoyar esta propuesta, se han llevado a cabo diferentes análisis que muestran el potencial de los contratos de opción como herramienta de reducción del riesgo asociado a una oferta de agua inestable. La Cuenca del Segura (Sureste de España), la Cuenca del Tajo y el Acueducto Tajo-Segura han sido seleccionados como casos de estudio. Tres análisis distintos aplicados a dicha región se presentan en esta tesis: a) una evaluación de los contratos de opción como mecanismo para reducir los riesgos de disponibilidad de agua sufridos por los regantes en la Cuenca del Segura; b) un marco teórico para

analizar las preferencias de los regantes por diferentes mecanismos de gestión del riesgo de disponibilidad de agua, su disposición a pagar por ellos y los precios aproximados de estos instrumentos (seguro de sequía y contratos de opción de agua); y c) una evaluación del papel de los contratos de opción en las decisiones de aprovisionamiento de agua de una comunidad de regantes ante una oferta de agua incierta. Los resultados muestran el potencial de reducción del riesgo de los contratos de opción para regantes en España, pero pueden ser extrapolados a otros sectores o regiones.

Las principales conclusiones de esta tesis son: a) la agricultura será uno de los sectores más afectados por el cambio climático. Si los precios del agua aumentan, la rentabilidad de los cultivos puede caer hasta niveles negativos, lo que podría dar lugar al abandono de cultivos de regadío en algunas zonas de España. Las políticas de cambio climático y de agua deben estar estrechamente coordinadas para asegurar un uso de agua eficiente y la rentabilidad de la agricultura; b) aunque los mercados de agua han ayudado a algunos usuarios a afrontar problemas de disponibilidad del recurso en momentos de escasez, hay varios aspectos que deben mejorarse; c) es necesario desarrollar mercados de agua más flexibles y estables para garantizar una asignación eficiente de los recursos entre los usuarios de agua; d) los resultados muestran los beneficios derivados del establecimiento de un contrato de opción entre usuarios de agua del Tajo y del Segura para reducir el riesgo de disponibilidad de agua en la cuenca receptora; e) la disposición a pagar de los regantes por un contrato de opción de agua o un seguro de sequía hidrológica, que representa el valor que tienen estos mecanismos para aquellos usuarios de agua que se enfrentan a riesgos relacionados con la disponibilidad del recurso, es consistente con los resultados obtenidos en estudios previos y superior al precio de mercado de estos instrumentos, lo que favorece la viabilidad de estos mecanismos de gestión del riesgo ; y f) los contratos de opción podrían ayudar a optimizar las decisiones de aprovisionamiento de agua bajo incertidumbre,

proporcionando más estabilidad y flexibilidad que los mercados temporales de agua.

Palabras clave: contrato de opción, Cuenca del Segura, incertidumbre, mercados de agua, riesgos de disponibilidad de agua, Trasvase Tajo-Segura.

SUMMARY

Water is becoming increasingly scarce and valuable. Thus, existing water resources need to be efficiently allocated among users. Climate change is expected to increase the frequency and severity of extreme events, and it may also increase irrigated crops' water demand. The implementation of flexible allocation mechanisms could be essential to cope with this increased variability of the water balance and ensure that supply risks, and not only water resources, are also efficiently shared and managed. Water markets allow for the reallocation of water resources from low to high value uses. Different water trading mechanisms have been created in different parts of the world and have helped users to alleviate water scarcity problems in those areas.

In Spain, water trading is allowed since 1999, although market activity has been limited. There are several issues in the Spanish water market that should be improved. This thesis, besides proposing several changes in the legislative framework, proposes the introduction of water option contracts as a potential improvement. The main advantage for both buyer and seller derived from an option contract is the institutional and legal stability it provides. To support this proposal, different analyses have been carried out that show the potential of option contracts as a risk reduction tool to manage water supply instability. The Segura Basin (Southeast Spain), the Tagus Basin and the Tagus-Segura inter-basin Transfer have been selected as the case study. Three different analyses applied to this region are presented in this thesis: a) an evaluation of option contracts as a mechanisms to reduce water supply availability risks in the Segura Basin; b) a theoretical framework for analyzing farmer's preferences for different water supply risk management tools and farmers' willingness to pay for them, together with the assessment of the prices of these mechanisms (drought insurance and water option contracts); and c) an evaluation of the role of option contracts in water procurement decisions under uncertainty. Results show the risk-reduction potential of option contracts for the agricultural sector in Spain, but these results can be extrapolated to other sectors or regions.

The main conclusions of the thesis are: a) agriculture would be one of the most affected sectors by climate change. With higher water tariffs, crop's profitability can drop to negative levels, which may result in the abandoning of the crop in many areas. Climate change and water policies must be closely coordinated to ensure efficient water use and crops' profitability; b) although Spanish water markets have alleviated water availability problems for some users during water scarcity periods, there are several issues that should be improved; c) more flexible and stable water market mechanisms are needed to allocate water resources and water supply risks among competing users; d) results show the benefits derived from the establishment of an inter-basin option contract between water users in the Tagus and the Segura basins for reducing water supply availability risks in the recipient area; e) irrigators' willingness to pay for option contracts or drought insurance, that represent the value that this kind of trading mechanisms has for water users facing water supply reliability problems, are consistent with results obtained in previous works and higher than the prices of this risk management tools, which shows the feasibility of these mechanisms; and f) option contracts would help to optimize water procurement decisions under uncertainty, providing more flexibility and stability than the spot market.

Keywords: option contracts, Segura Basin, Spain, Tagus-Segura Transfer, uncertainty, water markets, water supply risk.

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ABBREVIATIONS

CARA: Constant Absolute Risk Aversion.

CV: Coefficient of Variation.

DARA: Decreasing Absolute Risk Aversion.

E-B: *Entrepeñas-Buendía* reservoir.

ID: Irrigation District.

MGF: Moment Generating Function.

PDF: Probability Distribution Function.

RBA: River Basin Agency.

TST: Tagus-Segura Transfer.

WFD: Water Framework Directive.

WTA: Willingness To Accept.

WTP: Willingness To Pay.

WUA: Water Users Association.

1. INTRODUCTION

1.1. Water resources, climate change and the role of water markets

Many countries around the world face water scarcity problems. Population and income growth, its concentration in urban areas, the change in eating habits and climate change are some factors, among others, which will exacerbate problems related to water availability in the future (IPCC, 2007, 2014). Besides, the recognition that ecosystem services are essential for supporting the human life and the wildlife presents a challenge, especially in basins and regions already experiencing water stress (Garrik et al., 2009).

In semiarid climates, where inter-annual water availability variations are extreme, large infrastructures may prove insufficient to mitigate the economic effects of water scarcity in an unstable and environmentally limiting context (Calatrava & Garrido, 2005a). To address current and future water availability problems, there is a need for effective and flexible institutional arrangements and allocation mechanisms to mitigate and manage water scarcity (Adler, 2009; Grafton et al., 2010; United Nations, 2010; De Stefano & Llamas, 2012).

Globally, many freshwater ecosystems are suffering from significant overexploitation (Bates et al., 2008; Bogardi et al., 2012; European Commission, 2012). When all available water resources in a basin are already allocated to different users (irrigators, urban suppliers, industries, environment) and water demand increases, the only way to meet this new demand is through the reallocation of the existing water resources among competing needs. Inter-sectoral reallocation is seen as one pillar of water demand management, as opposed to supply augmentation mechanisms (Molle & Berkoff, 2006); and it can be achieved through either decentralized or other reallocation mechanisms.

Currently, water trading activity is helping to alleviate water scarcity problems in many regions worldwide (Griffin et al., 2013). Market mechanisms to manage water resources are encouraged by many experts and organizations. Easter et al. (1998) assert that voluntary exchanges of water among users are a good instrument to reduce users' risk exposure. The European Environment Agency (2012) considers that water pricing and market-based instruments are essential for sustainable water management and efficient water allocation. IPCC considers that water markets may play an important role in reducing water supply vulnerabilities (IPCC, 2007; Bates et al., 2008). According to Ranjan (2010), market mechanisms are an essential tool for achieving water policy goals, and they offer the best opportunity for adapting to climate change and its impacts on water resources (Adler, 2009). Future water availability may depend on how fast regions pursue policies to improve water management (Dosi & Easter, 2000).

Water availability in the Mediterranean region is expected to diminish because of climate change, and extreme events such as drought and floods will be more frequent (Giannakopoulos et al., 2005; Iglesias et al., 2007; Bates et al., 2008; Iglesias & Quiroga, 2009; Dono & Mazzapicchio, 2010; Kolokytha, 2010; OECD, 2013). According to CEDEX (2011), in the period 2010-2040, precipitation will decrease between 7-14% in Spain, depending on the emission scenario considered; and for the period 2071-2100 this decrease could be close to 9-17% (OECD, 2013). In semiarid areas, reductions in available water resources may be equivalent to 50% of the potential resources of the region (Iglesias et al., 2005; Moreno, 2005; Garrido et al., 2012a).

Agriculture is the main water user in Spain, accounting for nearly 70% of all water uses. Existing irrigated areas are threatened by increasing water scarcity and supply instability. Besides, this sector will be one of the most affected by climate change due to its dependence on climatic conditions. Future crops' net margin will be affected by climate change impacts on crops' water needs, their water use efficiency, yield and water pricing, among other factors (Rey et al., 2011).

The role of water markets to provide irrigators with the needed water resources can be crucial to cope with cyclical periods of water scarcity by the irrigated agriculture in many Spanish regions. On the other hand, in those areas were irrigated crops would become less profitable, farmers can sell their unused water volumes in the market. Governments and public agencies still have significant administrative power to suspend, curtail or modify farmers' water rights with no statutory obligation to offer compensation in return. However, governments are usually more inclined to combine administrative measures with potentially less-conflictive demand-management and market instruments. According to the results obtained from the author's work (Rey et al., 2011), climate change could increase the water use efficiency of some crops in the Iberian Peninsula, creating new opportunities to reallocate water to other uses through the water market or any other allocation mechanism.

It is known that Spain, as many other regions of the world, is a drought-prone area (Iglesias et al., 2009). Droughts are recurrent phenomena, rather than something sporadic and isolated. This is one of the reasons why we should focus less on emergency tools and solutions applied once the problem arises, and more on stable and reliable management solutions to cope with water scarcity and drought.

A comprehensive analysis of all these issues raises a number of questions that provide the motivation of this thesis:

- With these underlying processes and phenomena related to water resources, how can water markets contribute to improve the efficiency of sustainable water use and allocation?

- Is there potential to upgrade and improve water exchanging mechanisms to introduce optioning rights as a means to cope efficiently with water supply instability?
- Would water users be interested in using option contracts as water supply risk management tools? Would they instead prefer insurance mechanisms?
- How do option and spot water markets interact, substitute or complement with other water sources for irrigation in water-scarce areas?

1.2. Aims and scope

The main objective of this research is to assess the risk-reduction potential of water option contracts for users facing water reliability problems. The benefits of this trading mechanism, the water users' willingness to pay for them, and the role that option contracts could play in improving water supply reliability are studied in this thesis, focusing on a Spanish water scarce region.

Within this general research program, the specific goals of this work are:

a) To provide a wide description of Spanish water markets: legislation, past trading experiences, barriers to trade and potential improvements (chapter 3).
b) To design useful risk management tools for users facing water reliability problems (chapter 4).
c) To assess water users' willingness to pay for different water supply risk management tools and the prices of these instruments, with a view to rank and discuss them towards defining practical applications in Southeast Spain (chapter 5).
d) To find optimal water procurement decisions of irrigation districts under uncertainty, and evaluate the complementarity and substitutability of

different supply sources, including spot markets, options, regular surface and groundwater sources and non-conventional water sources (chapter 6).

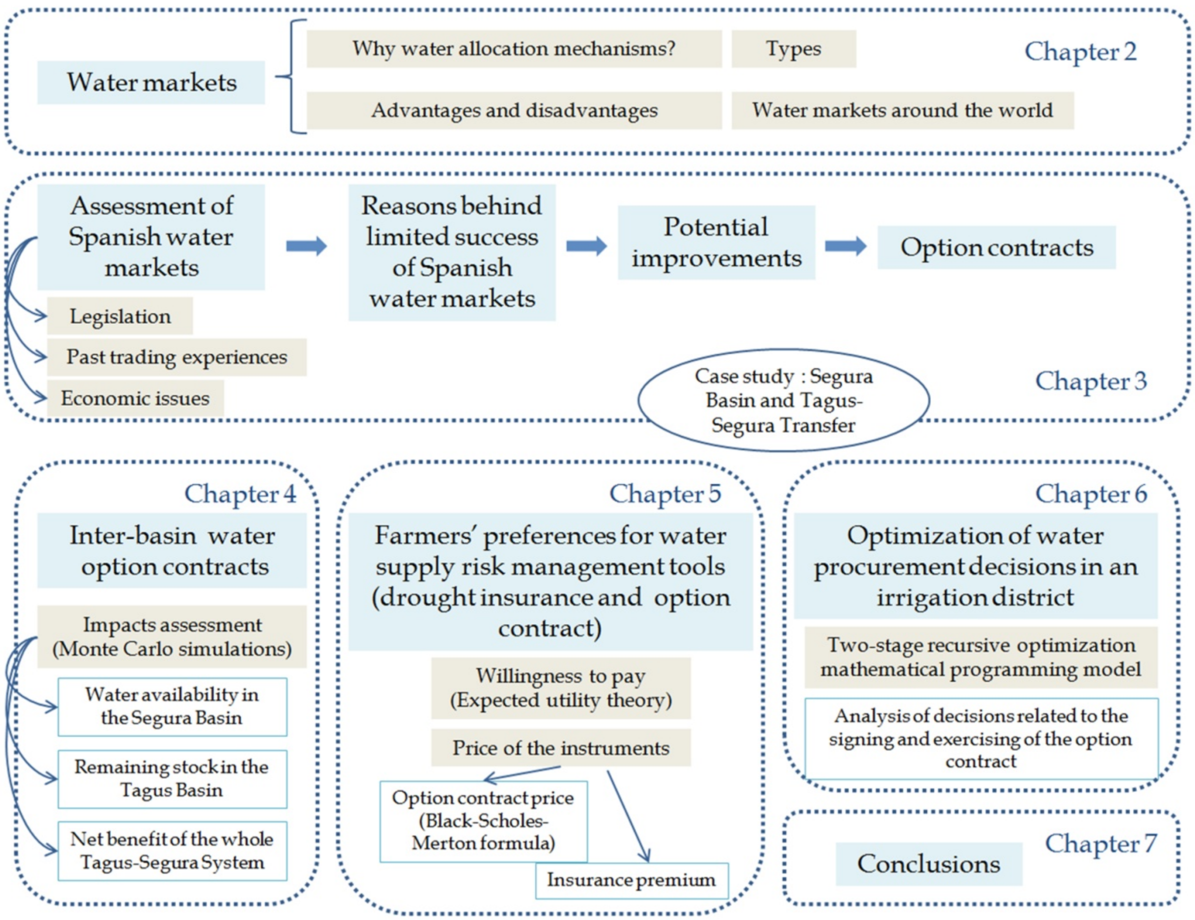
The areas of study considered in this thesis are the irrigated areas in the Segura Basin (Southeast Spain) served with water resources originating from the Tagus Basin through the Tagus-Segura Transfer. The water volumes received from the Tagus Basin each year are highly variable, and depend on the water stock jointly stored in the interconnected *Entrepeñas* and *Buendía* reservoirs in the Upper Tagus Basin, which in turn depend on runoff upstream and precipitation. The water supply instability could be exacerbated by climate change, affecting the profitability and continuity of agriculture in one of the most productive regions in the world. For instance, and focusing on a typical summer crop in Spain, the adaptation of maize to new climatic conditions could reduce climate change impact on maize's net margin in some sites in the Iberian Peninsula, but in others the effect could be the opposite. If water prices remain low, adaptation can be positive for maize's net margin. But if water prices are high in the future period, adaptation can reduce net margin in some sites of Spain (Rey et al., 2011).

The high water supply instability faced by irrigators in the Segura Basin and their participation in previous market experiences makes this region a suitable case study for this thesis. Irrigators in the Segura Basin have in fact been the most active buyers of water in the spot market, mainly during drought episodes, when they participated in inter-basin trading buying water resources from irrigation districts in the Tagus Basin.

1.3. Outline

This thesis is structured in 7 different chapters. The first chapter contains a general introduction, setting the research context, the objectives and the issues that are going to be addressed in this work. Chapters 2 to 7 represent the core of the thesis (see Figure 1).

Figure 1. Thesis outline



Source: own elaboration.

The thesis document is organized as follows: chapter 2 provides a discussion on the need for water allocation mechanisms to manage scarce water resources, a general description of water markets and the main related experiences around the world. Chapter 3 focuses on the Spanish case. The chapter begins with a description of the Spanish water market legislation, and continues with an evaluation of past experiences based on published literature and the author's own standpoints. This evaluation leads to suggest the reasons behind the limited success of water markets in Spain, and the potential improvements for the future.

Chapters 4, 5 and 6 contain the main original and empirical contributions of the thesis. Because each one has its own objectives, scope and methods, they are structured canonically with an introduction and subsequent sections containing the methodology, results, discussion and conclusions respectively. Chapter 4 proposes an innovative water option contract between the Tagus and Segura basins aimed to reduce the potential impacts of a change of the Tagus-Segura Transfer's management rules. In chapter 5, I develop an original theoretical analysis of irrigators' preferences for two different water supply risk management tools: drought insurance and water supply option contracts. An application of this theoretical approach to an irrigation district in the Segura Basin is also presented. In addition, the tentative prices and costs of these water supply risk reduction mechanisms are calculated. Chapter 6 puts the option and spot water market within the context of another complex irrigation district in the Segura Basin, which has up to nine different water sources, each with its own cost and reliability. The chapter presents an optimization model for minimizing irrigation district's water procurement costs, which is used to investigate, among other issues, the complementarity and substitutability of the analyzed sources of water. The decisions regarding the signing and exercising of the option contract are carefully analyzed within a much broader context than in chapters 4 and 5.

Lastly, chapter 7 contains the main conclusions derived from the above-mentioned analyses. At the end of the document, there are some appendixes with additional results from chapters 5 and 6.

1.4. Research context and publications

During my predoctoral and training activies at CEIGRAM (Research Centre for the Management of Agricultural and Environmental Risks, a Joint Research Centre of the Technical University of Madrid), I have been involved in two research projects.

First, I worked in the project "Minimising uncertainties in the analyses of climate change impact and adaptation in the agricultural systems of the Iberian Peninsula. Tool for Scientific Support to Policies"(MINUNIMAD-CC AGL2008-00385/AGR), 2009-2012, coordinated by Prof. M.I. Mínguez. The project's main objective was to assess the potential impacts of climate change on different aspects of Spanish agriculture: crop yields, crop water requirements, crop insurance and crop profitability under different water prices. We worked with climate projections of 10 different Regional Climate Models, and we evaluated the impact of rainfall and temperature changes on Spanish crops. Also, an adaptation strategy for maize in the Iberian Peninsula was assessed. Besides, we evaluated the uncertainty derived from climate projections obtained from this ensemble of Regional Climate Models. Apart from my Master degree thesis, two peer-reviewed journal papers and two book chapters were derived from this project:

- Garrido A., Willaarts B., López-Gunn E. and Rey D. (2012). Considerations on climate variability and change in Spain. In: De Stefano L. and Llamas M.R. (eds.), *Water, Agriculture and the Environment in Spain: can we square the circle?* Botín Foundation, CRC Press, pp. 191-202.

- Garrido A., Bielza M., Rey D., Mínguez M.I and Ruiz-Ramos, M. (2012). Insurance as an Adaptation to Climate Variability in Agriculture. In: Mendelsohn R. and Dinar A. (eds.), *Handbook on Climate Change and Agriculture*. Edward Elgar, pp. 420-445.

- Rey D., Garrido A., Mínguez M.I. and Ruiz-Ramos M. (2011). Impacts of climate change on maize´s water needs and yield and its profitability under various water prices in Spain. *Spanish Journal of Agricultural Research*, 9(4): 1047:1058.

- Garrido A., Rey D., Ruiz-Ramos M. and Mínguez M.I. (2011). Climate change impact and adaptation of crops in Spain: Consistency of Regional Climate Models. *Climate Research*, 49(3): 211-227.

In the second and most important part of my research timetable, I worked in a European research project entitled "Water market scenarios for southern Europe: new solutions for coping with water scarcity and drought risk? – Water Cap & Trade" (P100220C-631), 2010-2013, coordinated by Dr. Jean-Daniel Rinaudo (BRGM, France) and by Prof. Alberto Garrido (UPM team). This research project aimed at evaluating the best suited water market scenarios for European Mediterranean countries, the economic potential of these market mechanisms and the acceptability issues affecting the implementation of water markets in those countries.

Six partners from Italy, France and Spain participated in this project from January 2011 to December 2013. Both the Italian and the French teams studied the potential for the implementation of water markets in their respective countries, where they do not currently exist. The two Spanish teams (Technical University of Madrid (UPM), with the collaboration of the Technical University of Cartagena (UPCT), and University of Córdoba (UCO)) evaluated the water trading system in our country and investigated its weaknesses in order to obtain some recommendations of the modifications that should be accomplished to improve the functioning of Spanish water markets.

As a part of the Project's work programme, the UPM team held several meetings with Spanish water market stakeholders, related institutions' representatives and researchers. From those meetings, some conclusions regarding the role of water markets in our country have been obtained, and they are included in this work.

From my participation in the Project, I wrote the following papers and book chapters co-authored with my thesis supervisors:

- Rey D., Garrido A. and Calatrava J. Assessment of irrigators' preferences for different water supply risk management tools: option contract and insurance. *Environment & Resources Economics* (2nd round).

- Rey D., Calatrava J. and Garrido A. Optimization of water procurement decisions in an irrigation district: the role of option contracts. *Australian Journal of Agricultural and Resource Economics* (submitted).

- Rey D., Garrido A. and Calatrava J. (2014). The Water Markets in Spain: moving towards 21st century mechanisms and approaches with 20th century regulations. In: *Water Markets for the 21st. Century: What Have We Learned?* Easter W. and Huang Q. (Eds.). Springer. In press.

- Garrido A., Calatrava J. and Rey D. (2013). La flexibilización del régimen de concesiones y el mercado de aguas en los usos de regadío *(The flexibilization of the water consession regime and the water market for irrigation)*. In: Embid A. (ed.), *Usos del Agua (Concesiones, Autorizaciones y Mercados de Agua*. Universidad de Zaragoza and Confederación Hidrográfica del Ebro. Thomson Reuters, pp. 177-197.

- Garrido A., Rey D., Calatrava J. (2012). Water trading in Spain. In: De Stefano L. and Llamas M.R. (eds.), *Water, Agriculture and the Environment in Spain: can we square the circle?* Botín Foundation, CRC Press, pp. 205-216.

- Rey D., Garrido A. and Calatrava J. (in preparation). Option contracts for allocating water in inter-basin transfers: the case of the Tagus-Segura Transfer in Spain.

  Besides, part of the results has been presented in two conferences:

- Rey D., Garrido A. and Calatrava J. (2014). Option contracts for allocating water in inter-basin transfers: the case of the Tagus-Segura Transfer in Spain. Poster presented at the European Geosciences Union General Assembly. Vienna, Austria, 27th April – 2nd May 2014.

- Rey D., Garrido A. and Calatrava J. (2013). Comparison of different water supply risk management tools for irrigators: option contracts and insurance. IX Spanish National Congress of Agricultural Economics, Castelldefels, 3-5th September 2013.

In 2012, I spent three months as a visiting scholar at the Agricultural and Resource Economics Department, University of California at Berkeley, hosted by Professor David L. Sunding. During my stay, I had the opportunity to learn about the main features of water markets in this State and to meet other colleagues working on water trading issues at the University of California. This stay was funded by a programme for short-term research periods abroad of the UPM targeted to PhD students.

2. WATER MARKETS

2.1. Water markets definition

According to Brown (2006), the term ‘‘water market’’ does not have a precise definition. The National Research Council of the USA defined a water transfer as any change in the point of, in the type or in the location of use (National Research Council, 1992). Sumpsi et al. (1998; p. 73) defined a water market as “an institutional framework which allows water right holders, under certain established rules, to transfer their water rights to other economic agents or water users, receiving an economic compensation in exchange”. Water markets “permit the temporary, long-term, or permanent transfer of water from the existing rights-holders to other water users in exchange for payment” (Hanak, 2003 p. 2).

Water markets reveal the opportunity cost of water, allowing for a more efficient use of the available resources through the transfer of water from low to high value uses (Molle & Berkoff, 2006; Maestu et al., 2008; Adler, 2009; Möller-Gulland, 2010). According to Molle & Berkoff (2006) and Ranjan (2010), water trading has been mainly proposed as a flexible mean for mitigating water-supply shortages to non-agricultural users, by transferring water resources from agriculture to other sectors, and reducing the negative economic impacts of such shortages. Water trading takes place if there is a difference, after transaction, transport, and risk costs have been accounted for, between buyer’s willingness to pay and a seller’s willingness to accept payment for not having that water available (Calatrava & Garrido, 2005a).

Similarly to other allocation mechanism, water markets have some advantages and disadvantages that should be taken into account. Section 2.3 addresses this issue.

2.2. Why water allocation mechanisms?

Freshwater is a scarce resource and essential for all its users. Traditionally, priority was given to economic uses, disregarding aquatic ecosystems' services and the sustainability of water bodies. In the last decades, environmental concerns have increased and governments have started to rethink the way water is shared among the competing users, changing from a supply management approach to a demand management perspective. Managing demand involves implementing water conservation measures, providing economic incentives and reforming water pricing schemes, using existing infrastructures more wisely, and reallocating water rights (Getches, 2004). Integrated water resources management aims at allocating water attributes (quantity, quality and accessibility) under economic and social efficiency criteria, and protecting the environment (Maestu et al., 2008).

Competition for water has always existed, and conflicts will be more frequent in the future due to climate change, population and economic growth, and increasing environmental concerns. According to Bogardi et al. (2012), the lack of legislation or its limited implementation could increase the potential for conflicts among water users at all scales during water scarcity periods.

As long as the resource is plentiful, there is little pressure to define or enforce water rights. When water becomes scarcer, and competition for it increases, property rights can clarify expectations and reduce conflicts (Bruns & Meinzen-Dick, 2005). A major problem is that, currently, around the world water is often allocated based on institutions established when water was not considered to be a scarce resource (Frederick, 2001).

In order to avoid conflicts and to allocate public water resources among users, different property rights regimes have been implemented in different parts of the world: water use rights, private rights or quotas. Property rights regimes can be classified as public (State holds water rights), private (individuals), and common property (rights are held by a group of people) (Bruns & Meinzen-Dick, 2005). In many countries, increasing attention is being paid to the need to improve and clarify water rights.

Water rights are the heart of any allocation system, and essential for a successful reallocation (Meinzen-Dick & Bakker, 2000). Once water rights are clearly defined, water markets can be established to allow for the reallocation of water among users. “The great virtue of creating property rights in water is that it can be bought and sold” (Getches, 2004 p.12). The European Commission, in its *Blueprint to Safeguard Europe’s water resources*, considers water markets as a tool that could help to improve water use efficiency and overcome water stress, if a cap for water use is implemented (European Commission, 2012). However, there are institutional, physical and social barriers that impede or hamper the implementation of a market for water (Möller-Gulland, 2010).

In the absence of price or market signals, governments are left with statutory or arbitrary rules to ration water among potential users (Garrido, 2000; Riesgo & Gómez-Limón, 2001). There is a growing consensus that greater reliance on economic principles in managing and allocating water is critical for more efficient and sustainable use. For instance, an important innovation of the European WFD (Water Framework Directive) is the central role of economics in water management (Berbel et al., 2009). Markets and water prices have been used to manage demand, allocate water resources, and provide incentives to conserve and invest in new supplies and incentivize environmentally positive externalities (Frederick, 2001; Garrido et al., 2014). Specifically, water markets have been created in different parts of the world, mainly in those areas with water scarcity problems. In most cases, the establishment of water markets has resulted in effective water conservation, rising awareness of its real value, and investment in water saving and water reuse technologies (Rico & Gómez-Limón, 2005). In section 2.5, a description of the most developed water markets systems (Australia, Chile, USA) is presented.

The Water Cap & Trade Project aimed at assessing the potential of water markets as a solution to cope with water scarcity and drought in European countries. The main general conclusions from this project are summarized here (Water Cap & Trade, 2014):

a) Water markets have been operating for more than three decades in western States of the USA, in Australia and in Chile. They were established under natural, economic and institutional conditions which significantly differ from those prevailing in most European countries: (i) much higher water scarcity; (ii) clearly defined water property rights; (iii) cultural, ideological and legal context favourable to trading mechanisms.

b) In all countries where water markets have been established, trading activity remains relatively limited (typically 1-5% of allocated volumes). Water markets provide some flexibility, but their potential has been limited.

c) In Europe, only Spain has a market for water and enabling legislation to facilitate water trading. This is due to: (i) high water scarcity level associated to a high level of water productivity comparable to Western US and Australia; (ii) the existence of a vast interconnected water infrastructure (dams, canals, inter-basin transfers); and (iii) the historical existence of water markets (auctions) in some regions of Spain.

d) In France, in basins characterized with increasing tensions over water use, resource augmentation options (inter-basin transfers, small scale reservoirs) often remain affordable solutions in the medium term. This situation will last as long as resource augmentation will continue to be subsidized. The global "cap" is still contested, in particular in groundwater basins where insufficient scientific knowledge underpins its calculation. Potential market participants would thus prefer investing in lobbying activities aiming at increasing the cap rather than engaging into water trading. Individual water quotas are not properly defined and enforced. In addition, the "use it or lose it" rule represents an important barrier to trade. In basins where demand outweighs available resources, yearly water allocation is highly uncertain (inter-annual and intra-annual variability), which reduces the potential for trading.

e) In Italy, the socio-political context in which water markets are discussed is generally opposing the establishment of water markets. Due to recent drought events, stakeholders closer to the agricultural sector are exploring all the possible institutional arrangements for water management, including water markets. The conditions needed to establish water markets are not in place in the Italian context. From a legal perspective, water is publicly owned. Water use rights are requested and granted through concessions. Water market would require a substantial change in the concessions' definition. Moreover, one of the preconditions for water markets is the establishment of a "cap" on water uses. Currently, most of the concessions are not monitored, so there is no legal definition of the cap (though in many areas there exist a de facto cap in the irrigation season).

f) In France and Italy, a majority of stakeholders opposes to water trading on ethical or ideological grounds. Water trading is often assimilated to privatization. This triggers strong opposition since water has a legal status of public trust in both countries. The opposition is particularly strong in the agricultural sector where farmers fear that increased competition for water would weaken agricultural solidarity and cooperative behaviours and lead to the concentration of water rights. This opposition undermines the acceptability of market instruments. The situation is much different in Spain although a similar opposition has been reported after water trading was officially allowed 15 years ago (Iglesias et al., 1996).

2.3. Advantages and disadvantages of water markets as allocation mechanisms

Designing efficient market institutions to replace traditional water allocation rules is a daunting task (Garrido, 2007): establishing market rules to make it efficient and at the same time to protect other water users and to enhance the conservation of the resource is not easy. Table 1 shows the advantages and disadvantages of water trading mechanisms in comparison with administrative allocation mechanisms.

Table 1. Advantages and disadvantages of water trading mechanisms to ensure efficient, equitable and sustainable water allocation

	Trading mechanisms	Administrative mechanisms
Economic efficiency	• Net benefit of water use increases (WWF, 2007) • Water markets are expected to lead to socially optimal and efficient allocation (Möller-Gulland, 2010). • Facilitation of water reallocation from low to high value uses (Maestu et al., 2008; Stickney, 2008) • Efficient under low transaction costs	• Less efficient allocation

	Trading mechanisms	Administrative mechanisms
	(Pujol et al., 2005; Freebairn & Quiggin, 2006; Musole, 2009; Slaughter, 2009) • Excessive regulatory control and subsides may result in inefficient markets (Möller-Gulland, 2010)	
Water use efficiency	• Most likely in the long term (if markets are sustained and reliable). Water efficiency measures stimulated by the market may make additional water available for the environment without reducing overall economic activity (WWF, 2007) • Should be secure to provide users incentives to invest in water conservation practices (Dosi & Easter, 2000)	• Weak incentives unless water is scarce
Equity	• Equitable if properly regulated and if the distribution of rights is fair (may work against equity in some cases) (Grafton et al., 2010) • In agriculture, water markets may lead to the concentration of water in more efficient and intensive farms (Pujol et al., 2005) • They can generate third-party effects or externalities if not properly regulated (Maestu et al., 2008; Janmaat, 2011) • They can generate unjustified (undeserved) profits on sellers	• More equitable
Environmental effects	• Third party externalities (Riesgo & Gómez-Limón, 2001; Hanak, 2003; Heaney et al., 2006)	• More easily controlled

	Trading mechanisms	Administrative mechanisms
	• Return flows (Tisdell, 2001; Bjornlund, 2008) • Awakening of sleeping water rights (Bjornlund, 2008)	
Flexibility	• Much more flexible. Easier to adapt to water scarcity and drought situations	• More rigid. More inefficient unless very strong institutions operate the allocations. Difficult to adapt to particular conditions (Bruns & Meinzen-Dick, 2005)
Market power/ Abusive behavior	• Market power is an important source of friction in water markets (Ansink & Houba, 2011). • Speculative behavior	• Governments could favor certain sectors or economic activities when deciding how to allocate water resources

Source: Own elaboration.

To create an active water market, it is very important how water rights are defined: a) they must be separated from land; b) they should be granted for long enough time; c) they must be tradable because, in some cases, property rights structure was not designed for market transactions (Matthews, 2004, Calatrava & Garrido 2006; Garrido, 2007). Besides, there should be enough conveyance infrastructures to allow water transfers between users in different areas (Johansson et al., 2002; Pujol et al., 2005).

When a market for water is created, welfare gains can be achieved through water trading (Hearne & Easter, 1995; Garrido, 1998). Water markets can generate significant gains for buyers and sellers that would not otherwise occur. These gains increase when water availability is low (Garrido & Gómez Ramos, 2009a; Grafton et al., 2010).

Water is not like other commodities because of the importance that this resource has for every aspect of our lives. That is one of the main reasons of opposition to make water tradable through water markets (Briscoe, 1997; Bauer, 1998; Savenije & Van der Zaag, 2002; Water Cap & Trade, 2014). Besides, in most countries water is a public good, and it is the State who gives users the right to use water for free (Thobani, 1997). Thus, some stakeholders stand against the possibility of selling a water right for a monetary compensation.

Economic criticisms of water markets are based on the argument that transactions costs may be higher than those derived from other water allocation mechanisms (Pujol et al., 2005), and that they can generate third-party effects or externalities, exceeding in some cases the social benefits derived from the exchange (Rosegrant & Binswanger, 1994). Each step in water trading entails a cost on participants, either directly through government fees and brokerage charges, or indirectly through the cost of time associated with undertaking the transactions (The Allen Consulting Group, 2006). Coase (1960) demonstrated that, in absence of transactions costs, the initial distribution of rights between parties would not matter in terms of the final market allocation efficiency. In the real world, transaction costs exist and are crucial for the feasibility of trading. If transactions costs are greater than gains from trade, the transactions will not be profitable and will not take place (Beare et al., 2003; Martin et al., 2008; Lefebvre, 2011). Transaction costs are real resource costs that act as barriers to efficiency-improving trading. So, they must be quantified and included in the economic analysis of market exchanges (McCann & Easter, 2004; Freebairn & Quiggin, 2006).

2.4. Types of water markets

We can distinguish three main types of water trading mechanisms: spot or lease agreements, permanent transfers and water banks. Spot markets are temporary water exchanges, which mainly occur during a period of drought. The seller gives the buyer the right to use the water for a short period of time (e.g., one season). Temporary water markets allow for a more efficient distribution of risk than permanent transfers (Maestu et al., 2008).

Permanent transfers involve the transfer of ownership of the water right, so the buyer can use this water allotment until the water right expires. In these exchanges, transaction costs are very high due to the difficulties of getting an agreement between the involved parties. Permanent transfers are more common in developed countries because they need complex institutional settings (Bjornlund, 2006).

A water bank is a highly regulated institutional mechanism that facilitates water exchanges among different right holders (Yoskowitz, 2001; Dourojeanni, 2009). The water bank connects buyers and sellers, provides information and facilitates the regulatory requirements of the trading activity, reducing transaction costs and encouraging water exchanges (Yoskowitz, 2001; Clifford et al., 2004; Watson & Scarborough, 2005). In practice, most water banks do not function only as an intermediary between buyers and sellers, but also as water trader that centralizes selling bids and purchase offers (Clifford et al., 2004). Water banks exist in many countries around the world, like USA, Chile, Canada and Australia (Dourojeanni, 2009). A pioneering experience is the California Drought Water Bank established in 1991. It was an emergency water bank with the aim of enabling water transfers from agricultural users in the north of California to urban users in the south. This bank generated direct benefits for the State. However, it also had negative economic impacts on the local economy in the areas-of-origin of the water (Carter et al., 1994; Graham, 1998). Next chapter reviews the experience of Spanish water banks (water exchange centers, section 3.2.1).

Normally, the trading activity is concentrated in the spot market. Agriculture is the main water seller, as it is the sector with higher consumption in most countries (Molle & Berkoff, 2006; Calzadilla et al., 2010). When the market price for annual crops is going to be presumably low, or when rotation of perennial crops is necessary or timely, a farmer may choose to fallow his lands and sell his water allotment (Singletary, 2005). In general, exchanges take place between farmers (intra-sector) or between farmers and urban water suppliers (inter-sector).

2.5. Water markets around the world[1]

Establishing water markets is an alternative mean for improving water economic efficiency. However, very few countries have established formal water markets. Besides, in countries where water markets are regulated and authorized, exchanges are not quantitatively that important (Garrido et al., 2012b).

Water markets have been created in different parts of the world, mainly in those areas with water scarcity problems or with an irregular distribution of water resources among seasons, users or regions. In countries like India and Pakistan, informal water markets have evolved, being characterized by the lack of official government administration (Stickney, 2008). In many developing countries, with limited social and institutional capacities, the adoption of markets for permanent water rights has been hesitant; while informal markets for temporary transfers have been more widely adopted, since no change of ownership takes place (Bjornlund, 2003). In USA, Australia, Chile, Mexico and Spain, formal water markets operate under very different formats and rules. In Chile and Australia, the management of these markets is more decentralized. In this latter country, water markets are probably the most developed in the world, and in some basins

[1] Most of the information in this section is part of a deliverable of the Water Cap & Trade project: Rey D., Calatrava J. and Garrido A. (2011). Water markets in Australia, Chile and the USA.

exchanges can be ordered, managed and monitored electronically and web supported.

Australia, Chile and USA have long-active water markets of very different nature and with particular institutional settings and different degrees of market intervention (Grafton et al., 2009). Despite this, there are similarities related to the problems in the definition and registration of water rights and their supply reliability, the predominant role of agriculture as the main water seller, the prevalence of temporary exchanges of water, the prices dispersion and, in some cases, the increasing concern for the environmental impacts (see Table 2).

The system of water rights in Chile presents private rights with different levels of reliability and thus a priority access to water resources exists depending on the attributes of the right hold by a user. In the case of Australia, one of the major problems is the over-allocation of water entitlements and the low reliability of a significant proportion of them, what causes that in very dry years the water allocated by entitlement is notably reduced. As in the other two countries, there is a wide variety of water rights in the USA (prior allocation, appropriative, riparian, groundwater, Federal Reserve rights), what results in an uneven access to water among right-holders and in a notable price dispersion because of the different characteristics of the traded rights.

Even though there are not specific provisions for environmental protection from water trading in the USA, environmental uses are a major "purchaser", especially in temporary markets. Apart from these, other relevant restrictions to water trading are the lack of information regarding the existing amount of rights in many areas of Chile and the USA, the thinness and resulting price dispersion of many markets in these two countries and the slower procedures for the authorization and registration of transactions in the USA when compared with Australia.

Table 2. Main characteristics of water markets in Australia, Chile and USA

Country	Description	Trading activity	Restrictions	Sources
Australia	• 3 types of water exchanges[2]: trade of water access entitlements (permanent markets), trade of seasonal water allocation (spot markets), and environmental water buybacks by the Government • Each State and Territory is responsible for the legislative and administrative arrangements for water rights and water trading • One of the strengths of the Australian water market is the availability of information related to water prices and exchanged volumes. This transparency encourages the participation of water users in the market	• Trading of seasonal allocations predominates over trading of water rights because of the existing fees and restrictions to trade • Trade of entitlements is becoming significant (7 % of entitlements in 2009-2010) • Water scarcity is the dominant driver of allocation trading activity. In 2007 accounted for about half of all the water diverted in 2007-2008 • Interstate trade represents less than 1% of all permanent water trades • Agriculture is the main water seller	• Inter-basin water trading is forbidden • Restrictions on water entitlements trading (trade in permanent entitlements out of irrigation areas is currently capped at 4% of total water entitlements in one year) • Restrictions to limit trading of water entitlements from agriculture to other sectors	Grafton et al. (2009, 2011); Hughes & Goesch (2009); NWC (2010); Bjornlund et al. (2013)
Chile	• Free market orientation, subject to forces of supply and demand • Water rights are initially allocated free of charge, with no expiration date on them • There is an uneven spread of pricing information in the market that particularly disadvantages market participants with fewer	• Despite its free-market orientation for water trading, market activity in Chile is quite reduced • Agricultural sector dominates water markets • Inter-sectoral trading has transferred water to growing urban areas in some basins,	• No provisions are made to restrict water trading based on its environmental impacts or on potential third-party effects.	Bauer (2003); Hearne & Donoso (2005); FAO (2006); Grafton et al. (2010, 2011); Oficinas de Estudios y

2 http://www.nationalwatermarket.gov.au/about/

Country	Description	Trading activity	Restrictions	Sources
	resources and also increases transaction costs	which accounted for 76% of the rights traded. • Existing infrastructure made difficult significant movements of resources. The geography of this country hampers from effecting movements of water from a basin to another at reasonable costs		Políticas Agrarias (2010); Donoso et al. (2012); Garrido et al. (2014)
USA	• Many types of water markets can be found in the USA (permanent, one-year leases, leases for longer periods, water banks, option markets), although the most active ones are still the temporary or spot markets	• Market activity is not significant in relative terms but it is steadily increasing. It is concentrated in the Western States, being California and Colorado the most active markets • Municipalities are the major buyers and irrigators the major sellers. Agriculture- to- urban transfers are the most frequent in most States. Most permanent transfers involve municipalities purchasing water from irrigators	• Some States do not restrict exchanges among users or even basins, although in others there are very strict provisions to restrict the spatial extent of the trading activity.	Libecap (2010); Thompson (2010); Hanak & Stryjewski (2012)

Source: Own elaboration.

2.6. Option contracts for water

A water right can be associated to a bundle of rights. Among these stand the following: access, quality, location, reliability, use of returns, price, seniority, duration. A water market can be established to facilitate the transfer of all or part of these attributes within the bundle (Gómez-Ramos, 2004).

Spot water markets facilitate the efficient allocation of this resource and have some supply risk reduction properties but do not provide efficient risk allocation mechanisms per se, which exploit differences in risk tolerance and exposure (Calatrava & Garrido, 2006). Most of the risk is borne by the buyer due to the thin market characteristics of such transactions. In the case of a permanent market, the rights seller needs to evaluate his rights' value given current and expected future demands. Options markets can help lower these risks.

Options are one type of derivative contract that give the holder the right (not the obligation) to buy or sell the underlying asset (Williamson et al., 2008; Cui & Schreider, 2009; Cheng et al., 2011). Water option contracts do not imply the transfer of ownership and therefore, the right-holders retain control of the water allotment should the option not be exercised (Gómez-Ramos & Garrido, 2004; Hafi et al., 2005; Leroux & Crase, 2007). Options contracts can be classified into puts and calls. Option contracts for water have been generally proposed of the "call" type. A call gives the holder the right (not the obligation) to purchase the optioned volume, while the holder of a put option has the right (not the obligation) to sell the optioned water volume (Cui & Schreider, 2009).

The interaction between buyer and seller in an option contract takes place in two steps. First, the buyer and the seller establish all the contract terms: the premium, the exercise price and the optioned volume. Both the buyer's demand and the spot market price for water are uncertain at this point. Normally, the buyer pays the option premium at the beginning of the hydrological year for the right to purchase water from the seller at the maturity date if needed and as a compensation for the seller to relinquish a part of his water allotment. In the second period, when the uncertainties of demand disappear, the buyer announces the quantity of options to exercise (Tomkins & Weber, 2010). The option will be exercised if the holder of the option needs additional water resources to satisfy his requirements and if some pre-established conditions (trigger) are met.

Most examples of optioning water rights are subject to a condition or trigger. The trigger is an external condition that should be met to exercise the option. The rationale of using a trigger that enables the holder of a call option to exercise the option when there is less water available is to ensure that the other party of the contract uses the water in normal or abundant conditions (Gómez-Ramos & Garrido, 2004; Hafi et al., 2005; Leroux & Crase, 2007).

The premium represents the value of the flexibility gained by the buyer from postponing the decision to purchase water (Hansen et al., 2006). Michelsen & Young (1993) define the option exercise cost as the minimum amount that must be paid to the farmer to maintain the same income level if the option is exercised and to compensate him for the additional risk imposed by the contract (Gómez-Ramos & Garrido, 2004). From the point of view of the seller, usually a farmer, the price of the option is the opportunity cost of forgoing the use of the water for agriculture (Heaney & Hafi, 2005). For option holders, no matter how adverse the water price movement might be, their loss is limited to the amount they paid for the option (Cui & Schreider, 2009).

The required conditions to establish a water supply option contract were defined by Michelsen & Young (1993): i) water supply must be reliable enough to provide sufficient water for the option holder in drought years and plentiful enough in average years to supply the lower valued use; ii) water rights must be well-defined and tradable; iii) agricultural activity must be capable of being temporarily suspended; iv) both parties must know water use values and alternative water supply costs; v) the probability and severity of drought must be calculable; vi) the option contract costs must be lower than the costs of the cheapest water supply alternative.

Option contracts in water markets have been implemented in different countries. In the USA, options have been developed in Colorado, California and Texas. In these markets, options are generally contracted by urban water agencies to increase water supplies during periods of drought (Hafi et al., 2005). Although option contracts between urban and agricultural users have received limited attention in Australia (Leroux & Crase, 2007), environmental water option contracts have been seriously considered in this country (Hafi et al., 2005). In the Spanish water market, option contracts are not a common type of exchange but there has been one experience of a multi-annual contract that resembles an option contract. In Spain, option mechanisms have been suggested by Gómez-Ramos & Garrido (2004) and Cubillo (2010).

After reviewing the existing literature, we can classify the main benefits derived from option contracts in water markets in three groups: risk-reduction benefits, economic benefits, and institutional/regulatory benefits:

a) Risk-reduction benefits

- Option markets can help lower the risks arising from water supply reliability and price uncertainties to both parties providing maximum flexibility in responding to uncertain conditions (Howitt, 1998; Hollinshead & Lund, 2006; Brown & Carriquiry, 2007; Hui et al., 2007; Ranjan, 2010).

- Because the buyer has the right to decide whether to exercise the option or not, this contract provides flexibility associated with the use of the contracted commodity (water) and increases the reliability of obtaining it.

b) Economic benefits

- Water remains productive in different uses during normal water supply situations, but changes to the highest values in drought years (Michelsen & Young, 1993; Gómez-Ramos & Garrido, 2004).

- Gains from trade are on average higher when options themselves can be traded, by 46% in competitive markets and by 63% in dominant buyer markets (Hansen et al., 2008).

- Option agreements may act as a substitute of more expensive water sources (Hansen et al., 2006). Options provide secure urban drought water supplies at a lower cost than water rights purchases while maintaining agricultural production (Michelsen & Young, 1993). For an urban water supply agency, the ability to access additional water resources in drought years may be a cost minimizing strategy for managing water supply variability (Michelsen & Young, 1993; Gómez-Ramos & Garrido, 2004; Brown & Carriquiry, 2007).

- Right holders have more choices on trading water allocation, as they can participate in both physical and option markets (Cui & Schreider, 2009).

c) Institutional/regulatory benefits

- Options often require less regulatory oversight than permanent transfers (Hansen et al., 2008). Unlike permanent transfers, they never result in irreversible water transfers.

- Once the contract has been negotiated and signed, transaction costs associated to the water transfers will be lower than those associated to other types of exchanges (Garrido & Gómez-Ramos, 2009b)

- In the case of environmental water options, there is no need for the environmental manager to own a permanent water entitlement (Hafi et al., 2005; Heaney & Hafi, 2005).

3. WATER MARKETS IN SPAIN[3]

3.1. Legislation

Water rights issued by the Spanish Water Authorities[4] are made available through publicly built infrastructures (dams or water transfers) or privately built with permission of the state (hydroelectricity). Accordingly with the 1985 Water Act, rights can also be granted to pump groundwater or divert resources directly from surface water bodies. A competitive process (public tender for licenses) for potentially interested agents at the time of issuance is used only for hydropower applicants. Irrigators and urban suppliers must go through a technical and administrative process, which includes also public information and aims at establishing the socio-economic interest of the request and its technical and environmental feasibility.

Water use rights are defined detailing the point of withdrawal, type of use, calendar, engineering setup, plots and crops to be irrigated and irrigation technologies, usable volume or flow and return flows. The type of use, location,

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[3] This chapter is the result of three book chapters written by the author and the co-directors of this thesis:

Garrido A., Rey D. and Calatrava J. (2012b). Water trading in Spain. In: De Stefano, L. and Llamas, M. R. (eds), Water, Agriculture and the Environment in Spain: can we square the circle? CRC Press, Botín Foundation, pp. 205-216.

Garrido A., Calatrava J. and Rey D. (2013). La flexibilización del régimen de concesiones y el mercado de aguas en los usos en regadío. In: Embid A. (ed.), Usos del Agua (Concesiones, Autorizaciones y Mercados de Agua). Universidad de Zaragoza and Confederación Hidrográfica del Ebro. Thomson Reuters, pp 177-197.

Rey D., Garrido A. and Calatrava J. (2014). The Water Markets in Spain: moving towards 21st century mechanisms and approaches with 20th century regulations. In: Water Markets for the 21st. Century: What Have We Learned? Easter W. and Huang Q. (eds.). Springer. In press.

[4] By Water Authorities in Spain, we refer to the River Basin Agencies, or in basins entirely contained in a single Autonomous Community, to the regional water agency. See Garrido and Llamas (2009) for a detailed description of the institutional framework in Spain.

withdrawal or return points cannot be changed without an explicit approval by the corresponding River Basin Agency (RBA). Rights differ in the priority of their access to water depending on the type of use (domestic, environmental, agricultural, hydropower or industrial).

With the approval of the 1985 Water Act, water became a good belonging to the public domain. Nonetheless, holders of private rights over groundwater (mostly farmers and private companies) were given the choice of keeping them as a private right or else converting them into temporal water concessions[5]. A vast majority (more than 80% of right holders according to Llamas et al., 2001) opted for the first option. Any new right over groundwater granted after 1985 would exclusively be a concession of use of a public good - water.

The drought episode that took place in Spain in 1992-1995 had vast consequences, both because of its intensity and a poor management of it (Giansante et al., 2002). After that, the need for a more flexible water rights regime in the country became urgent. The 1999 reform of the Water Act introduced the legal possibility of voluntary exchanges of public water rights (concessions), but with many restrictions. It only allows the temporary exchanges of public water use rights: the public nature of water is upheld, and the concession to use it is leased for a limited period of time (Albiac et al., 2006). Before the 1999 reform only private rights could be formally traded; water flows pumped from private wells could be leased, auctioned or sold.

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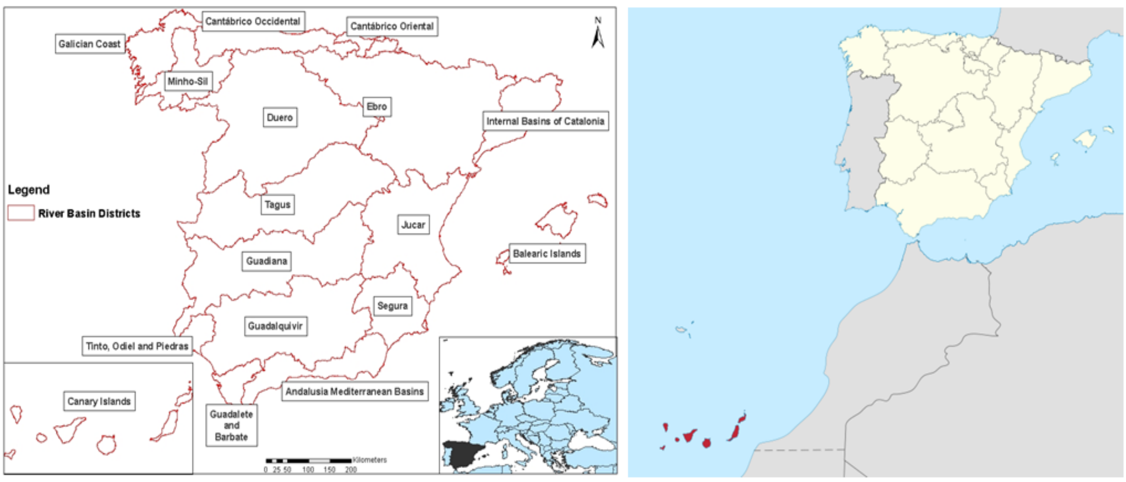
[5] The differences between water rights and public rights are the following: public rights are use permits granted by the State for a duration of 30 years; they can be revoked, transformed, amended or interrupted by the Basin Agencies if conditions advised those decisions; their legal foundation stems from the 1985 Water Act, which declared all water resources as part of the public domain; they are registered in a separate section of the section of private rights. These, in contrast, have a longer maturity, existed before the entering into force of the 1985 Water Act, are considered private property, can be sold, leased and form part of a company or cooperative assets. Maintaining the status of water rights requires that the technical conditions of use (depth and location of wells, power of pumps, pumped volume) not be altered.

The 1999 Water Law reform explicitly identified only two ways to exchange public water use rights. The first one involves two right-holders that voluntarily agree on specific terms of trade and jointly file a request in the Agency to exchange their water rights, or leased-out for a number of years the water to which right-holders are entitled. The second way for exchanging water rights involves publicly run and administered water banks (or *water exchange centers*, as they are called in the Water Law). Users of private groundwater rights, individually or as firms or cooperatives, can sell, lease or rent pumped water, although such trading is subject to specific restrictions.

Water banks are supposed to be administered by the RBAs and operate in exceptional situations of drought or overexploitation of aquifers (WWF, 2005). Water banks are set up as public tenders for potentially interested right-holders who would be willing to relinquish their water rights temporally or for the remaining maturity period. The bank's water supply operation involves procuring water flows and volumes from voluntary sellers, and making them available for other users, including environmental restoration purposes. Bank's operations may also acquire permanent water rights. A variant of the water exchange centers involves a similar procedure to that of regular water banks, but instead of purchasing or leasing out the offered water rights, it purchases the land to which the water is appurtenant. In practice, these water exchange centers have only functioned as buyers of water or water rights. Water has not been sold to other users. Instead, purchased water has been made available to other users in the form of new water concessions or devoted to maintaining environmental flows.

At the national level, the last Reform of the Spanish Water Law of May 2012 highlights the need to simplify and accelerate the administrative procedures, and to add more flexibility and efficiency to the water management system. The reform focuses mainly on groundwater resources. It proposed several measures to deal with water availability problems, including the encouragement of transformation of private water rights into public water concessions. Although this reform is meant to improve water management, there are also some details that could threaten groundwater resources sustainability, and be in breach of the mandates of the European WFD, one of which is to avoid any further deterioration of a water body already heavily damaged. The new regulation establishes the possibility of recharging aquifers with external water resources in order to avoid the risk of not achieving a good quantitative status for these aquifers. This could potentially persuade water users that the best solution for declining groundwater tables is always to provide external resources, and thus it is not necessary to change the exploitation rate of aquifers. Also, the 2012 Law Reform grants new water concessions under certain circumstances in groundwater reservoirs at risk, which presumably will cause a higher overexploitation of groundwater resources (FNCA, 2012).

Figure 2. Spanish River Basins (left), including the Canary Islands (right)



Source: Own elaboration.

The regional government of Andalusia passed more advanced legislation in 2010. This new Andalusian Water Law includes some differences from the National Law that result in more flexible trading mechanisms. However, the water market regulation in Andalusia is only applicable in the Andalusian

Mediterranean Basins (see Figure 2). This approach could hopefully serve as a precedent for future amendments to the market regulation in the rest of Spain. The main innovations introduced by this reform are summarized in Table 3[6].

Table 3. Main differences between the National Law and the Andalusian Law related to water markets

Andalusian Law*	National Law
Agriculture, industry and tourism are considered at the same level in the water uses priority range	Agriculture is in a higher level, so farmers cannot sell their water rights for industrial or touristic activities
Water Banks are conceived as a mechanism to trade water under every circumstance	Water Banks are conceived as a mechanism to trade water only during drought periods
For acquiring water through a water bank, there is no need to be a water user with formal rights	Only users with formal water rights have access to the Water Bank or to purchase from other user

* The Andalusian Water Law take precedent over the National Law only in the basins that are contained entirely within Andalusia's borders as its regional government has jurisdiction over all water management in these basins.

Source: Rey et al. (2014).

The differences in the Andalusian Law from the National Law provide flexibility for the water market system, allowing farmers (the main water rights holders) to sell water to industries, renewable energy plants (thermo-solar installations) or to the tourist sector. The most relevant criteria to determine the priority among these uses are: the impact on sustainability of the resource, maintenance of territorial cohesion and the higher added value in terms of job and wealth creation for the region. As in the National legislation, the Andalusian Law always guarantees the primary water requirements for the

[6] BOJA num. 155. Law 9/2010, July 30th. Andalusian Water Law.

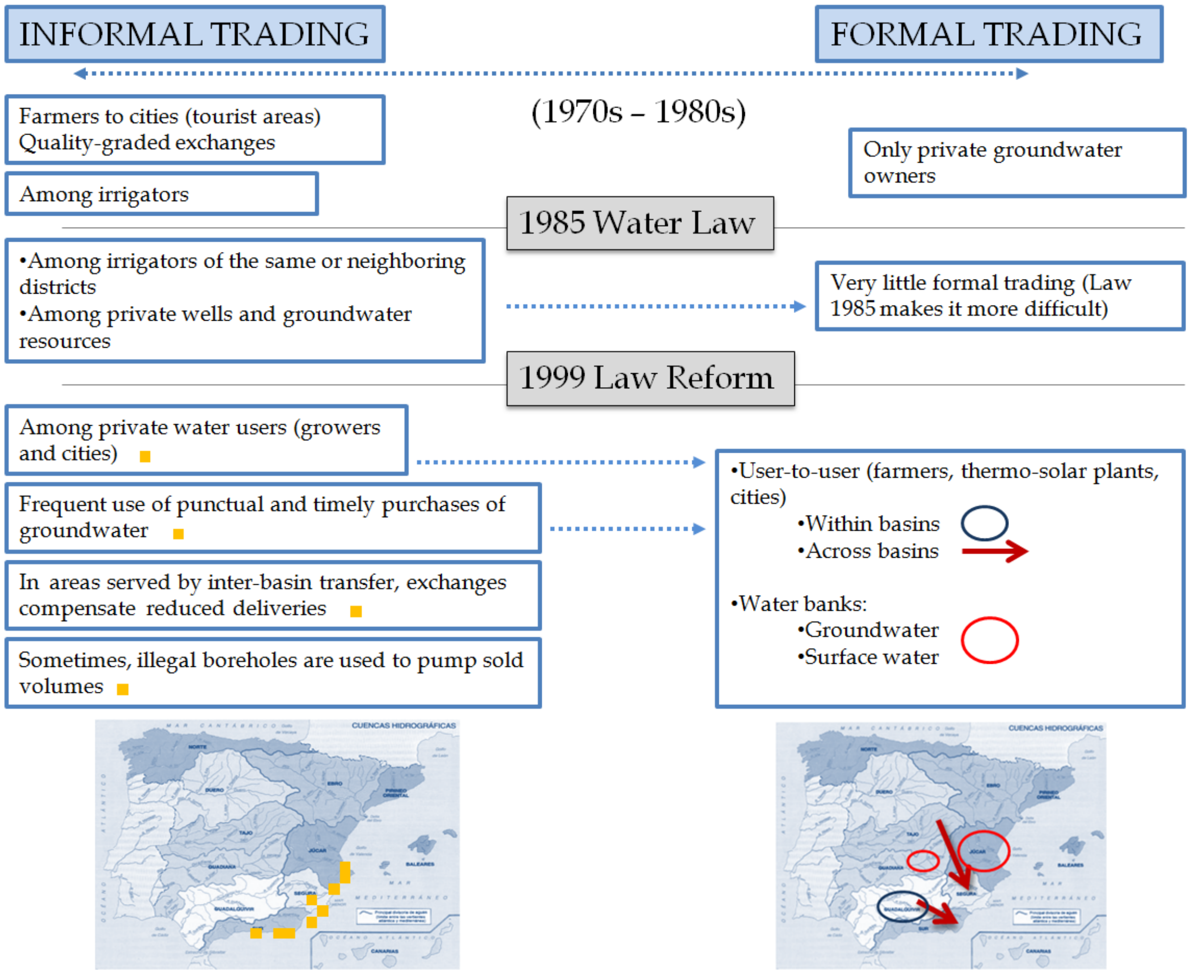
urban sector, and also for environmental purposes in order to achieve a good ecological status for all water bodies.

Water banks are considered an important tool not only for solving drought or environmental problems in Andalusia, but also to create a water stock for future purposes, to sell water use rights to users for a given price, and to avoid imbalances in the distribution of water resources. Through water exchange centers the regional government can make offers for public purchase of rights, and expropriate or revise water concessions. The possibility of purchasing water through the water bank without previously being a right holder allows users facing new emerging water demands to obtain water. Currently there is an initiative to establish three water exchange centers in three different basins in Andalusia.

3.2. Past trading experiences: overview and evaluation

Since the approval of the 1999 Reform of the Water Act, several water rights exchanges have taken place in the Spanish territory, involving different water users, water resources and basins. Below is a description of the most important water exchange experiences that could help the reader to better understand the functioning of Spanish water markets.

Figure 3. Formal and informal water trading in Spain.



Source: Rey et al. (2014).

3.2.1. Water exchange centers

Three water banks, or water exchange centers, have been established in different Spanish river basins (Guadiana, Júcar and Segura), with the main objective of solving an environmental problem. Table 4 shows the objectives, budget, prices, volumes and other features of each of them.

Table 4. Description of the water exchange centers in the Guadiana, Júcar and Segura Basins

	Guadiana Basin	Júcar Basin	Segura Basin
Objective	"Special plan of the Upper Guadiana" approved in 2008 to solve environmental problems affecting the remarkable wetlands in the *Tablas de Daimiel* National Park (Martínez-Santos et al., 2008; Llamas et al., 2010) by reducing pumping rates in 250 hm^3 by 2027	To increase the upstream water table levels to ensure that the river did not dry out during the dry spell of 2005-2008, as it had occurred in the 1990s. The purchases aimed at reducing extractions by 100 hm^3 in the Upper Júcar aquifer to enhance flows to the lower part of the basin	To improve water availability, as this is the most water scarce basin in Spain
Public offers	Three public offers (October, 2006; March, 2007; September, 2007) targeted to irrigators, but the means required to acquire land rights with appurtenant water rights, to prevent further irrigation consumption in these lands. The idea was to purchase water rights to be reallocated to other farmers (30%) and to the environment (70%) (López-Gunn et al., 2012)	Several offers in the 2006-2007 and 2007-2008 irrigation seasons	Two public offers (2007 and 2008)
Potential sellers	Irrigators. Right-holders located in areas closer to river banks or protected areas were prioritized. It included the purchase of irrigated land, not only of pumping rights	Farmers were given the option to lease-out their rights for one year in return for an economic compensation	Targeted to rice farmers in the Upper part of the basin who were willing to temporary lease their surface water
Budget	2010: 84.5 € mill (only 66 €mill were spent to acquire 6,900 hectares)	12 million € in 2006-2007 (only 5.5 million € were spent). Similar budget in 2007-2008 (12.7 million € were spent) (CHJ, 2010)	700,000 € each year (495,040 € were spent in 2007; very similar in 2008) (Calatrava & Gómez-Ramos, 2009)

Prices	Maximum: 10,000 €/ha (land without permanent crops) or 6,000 €/ha (land with permanent crops). Minimum: 3,000 €/ha	0.13 to 0.19 €/m³, depending on the distance of the seller's location to the associated wetlands or to the river alluvial plain	0.168 €/m³ in 2007; very similar in 2008 (Maximum: 0.18 €/m³)
Volumes	29 hm³ of registered groundwater rights (13.6 hm³ were transferred to the Regional Government of Castilla-La Mancha that allocated them in the form of public concessions to other farmers)[a]. According to WWF (2012), only 1.1 hm³ have been purchased at a cost of around 6 € million in public funds	27.3 hm³ in 2006-2007; 50.6 hm³ in 2007-2008	2007: 2.93 hm³ (41 contracts were signed with small individual farmers, 371.5 has.)
Results	While farmers entering the program must surrender their private rights, those that gain access to them will be granted 30-year 'concession' rights (which is more attenuated property than the others). So the RBA will have more users with 'concessions' than with private rights (Garrido & Calatrava, 2009). The public offerings were planned to continue in 2008 and following years with a budget of 810 € million for 2008-2027, but the effects of the global economic crisis brought the Special Plan for the Upper Guadiana to a sudden stop	The Júcar exchange center did not meet its purchase objectives, as there were not enough bidders to cover the entire budget and target volume	Purchased volumes were intended for maintaining environmental flows in the Segura and Mundo River in the Albacete province (Castilla-La Mancha) but only once the domestic demands were satisfied. In practice, all the purchased volumes were for maintaining environmental flows

[a] The remaining 15.4 mill m³ correspond to the difference between the nominal water allotment of the purchased water rights (4500 m³/ha) and the effective amount of water available to farmers because of the existing pumping restrictions in the aquifer (about 2200 m³/ha).

Source: Own elaboration based on Garrido et al. (2012b).

The major difference between the Júcar and Guadiana experiences is that the former aimed at reducing the environmental consequences of a drought period by temporarily purchasing water from farmers, whereas the latter was trying to solve a structural aquifer overdraft problem by permanent purchases of land and its associated water rights.

The experience in the Upper Guadiana Basin should be judged against the complex institutional and environmental setting prevailing in the basin since the late 1980s. A number of authors have analyzed the remarkable continuity and importance of aquifers' use without appropriate permits or rights (Molina et al., 2009); the long-evolving and relentless trend of groundwater use (Garrido et al., 2006); the succession of failed attempts to curtail extraction rates (Martínez-Santos et al., 2008); the need to transfer from the Tagus Basin to ensure the conservation of the *Tablas de Daimiel* Wetland in the Guadiana Basin, without which it may have lost its UNESCO's qualification and all its flooded area (López-Gunn et al., 2012).

3.2.2. Formal lease contracts under the 1999 Reformed Water Law's provision

The number of formal lease contracts was expected to increase significantly upon the approval of the 1999 Reform, especially within each river basin, but in practice they declined significantly. Irrigation districts have been the main water sellers; and other districts, urban suppliers and thermo-solar plants being the main purchasers. In general, prices have been high because most exchanges have occurred during drought periods, when water supply is low and demand is high.

There are only a few documented experiences of formal lease contracts. One of the most important experiences in terms of traded volume was in the Tagus Basin in 2002, between a large urban retailer (*Mancomunidad de Canales del Sorbe*, buyer), and the irrigation district of *Canal de Henares* (seller). 20 hm^3 were transferred, at a fixed cost of 38,000 €/year, plus a volumetric charge of 0.04 €/m^3 for the first 4 hm^3, and 0.02 €/m^3 for the remaining 16 hm^3. In the Segura basin, 35 formal lease contracts were authorized between 2000 and 2005, for a total volume of 10.1 hm^3, less than 1% of total annual water consumption in the basin (Calatrava & Gómez-Ramos, 2009). In the Guadalquivir Basin, several exchanges were approved that included just one right-holder permuting his rights from the lower basin (with higher salinity concentration) with his rights in the upper basin. As a result, more water is used in the upper sections of the basin, affecting water users downstream.

3.2.3. Inter-basin exchanges under Royal Decree 15/2005

According to the 1999 Reformed Water Law, exchanges involving right-holders located in different river basins (jurisdictions) require the explicit approval of the Ministry of Environment. In 2005-2008, Spain suffered a drought that prompted the Spanish Government to permit water inter-basin exchanges using previously existing infrastructures (Royal Decree 15/2005). In Spain, there are two important inter-basin aqueducts that would enable water rights exchange across basins (the Tagus-Segura Transfer and the Negratín-Almanzora Transfer, the latter between the Lower Guadalquivir Basin and the Almanzora Basin, in Almería). There are others operating in the country, but no exchange request has yet been filed.

Inter-basin exchanges were contracted in 2006 (six in number, totaling 75.5 hm^3), 2007 (17 in number, representing 102 hm^3), and 2008 (two, with 68 hm^3). In all of them, farmers in the area-of-origin (Tagus and Upper Guadalquivir basins) leased out their water rights to farmers and urban users in the Segura Basin (*Sindicato Central de Regantes del Acueducto Tajo-Segura* and *Mancomunidad de los Canales del Taibilla*) and the Andalusian Mediterrananean Basins (*Aguas del Almanzora*, which mainly services irrigators) respectively.

In the Tagus Basin, the sellers were the over-supplied irrigation districts of *Canal de Estremera* and *Canal de las Aves*, where farmers received a payment equivalent to 2,400 €/ha for fallowing their irrigated land, which is more than the value of the crops (maize) they would have grown under normal conditions.

The volumes bought by users in the Segura Basin from users in the Tagus Basin only in 2006 largely surpassed those of all the exchanges approved among users in the Segura Basin between 1999 and 2005. The *Mancomunidad de Canales del Taibilla*, the major urban water supplier in the Segura Basin, signed an agreement in 2006 with farmers in the Upper Tagus Basin (*Comunidad de Regantes del Canal de las Aves*) to buy up to 40 hm^3 at a price of 0.28 €/m^3. In 2007, 36.9 hm^3 were bought at a price of 0.23 €/m^3. The price in 2006 was greater because when the agreement was reached the selling farmers had already incurred in some cultivation costs (Calatrava & Gómez-Ramos, 2009). The contract between the *Canal de Estremera* irrigation district and the *Sindicato Central de Regantes del Acueducto Tajo-Segura (*SCRATS*)* has been active during 4 years. SCRATS paid 6 million €/year for 31 hm^3/year. The price was 0.19 €/m^3 in 2006 and increased up to 0.22 €/m^3 in 2008 (Calatrava & Gómez-Ramos, 2009).

In 2007 and 2008, due to the prolonged drought in the Tagus Basin almost no water could be transferred to the Almanzora Valley through the Tagus- Segura aqueduct, farmers in Almanzora looked for alternative resources (25 hm^3 each year) and established two type of agreements: 1) They acquired 1,400 ha of irrigated land in the Marshes of Guadalquivir; and 2) established formal lease contracts with different irrigation districts in the Middle Guadalquivir (*Bembézar* and *Guadalmellato* irrigation districts) and the Genil (Corominas, 2011). This author calculates the profit obtained by the sellers in the Guadalquivir entering the latter mentioned lease contracts as the difference between the income losses due to lower use of water and the received compensation. This profit was 220 €/ha (Guadalquivir) and 280 €/ha (Genil). Corominas (2011) stated that for prices of 0.15 €/m^3, both buyers and sellers could obtain gains from the exchanges in the Guadalquivir River Basin (in practice, the price was 0.18 €/m^3).

The exchanging system in the former case, which enabled transfers of water from the Upper Guadalquivir to the Andalusian Mediterranean River Basins, involved water purchasers in the recipient basin (the company *Aguas del Almanzora, S.A.*) purchasing or leasing irrigated land with appurtenant water rights in the lower Guadalquivir, and transferring the water rights to irrigate more land in the Andalusian Mediterranean Basins. Note that there are three geographical sites involved in the arrangement: (1) water-rights linked to land in the lower Guadalquivir basin were transferred to the, (2) Andalusian Mediterranean Basins using the (3) Aqueduct Negratín-Almanzora, whose abstraction point is in the Upper Guadalquivir. However, there was only one agent, i.e. company *Aguas del Almanzora*, which is buyer and seller at the same time. Since this aqueduct's abstraction point is in the Upper Guadalquivir Basin, the transfer effectively involved water taken 350 km upstream the location it would have been used under normal conditions. To reduce the environmental and third-party impacts of the reduced flows from the Aqueduct's headwaters to the lower Guadalquivir, a volumetric tax of 50% was enacted (the contractor was given permission to transfer only 50% of the water rights attached to the purchased land). Since the exchange involved only one partner, there was no price or economic compensation. The average price paid for land purchase was 24,000 €/ha and approximately 40 hm^3 of water were transferred using the Negratín-Almanzora transfer (Garrido & Calatrava, 2009).

Aguas del Almanzora has also established five-year water lease agreements with farmers in the Middle Almanzora Valley (*Comunidad de Regantes del Pago de la Vega del Serón*) with concessions from the Negratín reservoir (Guadalquivir Basin) at prices in the range of 0.15-0.18 €/m^3.

A common element in both across-basins exchanges is the fact that the MARM (Spanish Ministry of Environment) decided to exempt the exchanging parties from paying the fees[7] applicable to all regular aqueduct's beneficiaries, on the grounds that there was an extreme drought situation in which these trading took place.

3.2.4. The Canary Islands

A very emblematic case of Spanish water markets can be found in the Canary Islands. Some of hese markets have been active for a very long time, mainly for groundwater resources, and it is seen as an example of efficiency. Despite this, Canaries' water trading system has some problems and abuses: water is concentrated in a few hands (which determine the price and the conditions of the exchanges); there is a lack of transparency and information; water quality is not guaranteed by pipe owners and the owners are not responsible for water losses (Aguilera-Klink & Sánchez-García, 2005; Custodio & Cabrera, 2012).

Some buyers prefer to purchase public water rather than private water, even when the price is higher than the price of private water in the market, mainly because it is more reliable, water quality is higher, and there are no charges for conveyance losses (Custodio, 2011). Prices paid for irrigation water during high-demand periods can reach or exceed the price of desalination; so only very competitive water users can afford to purchase it (Custodio & Cabrera, 2012). However, the water market plays an important role for some agricultural areas and cities when there is no other available water source and it encourages economic and social development in the islands (Custodio, 2011).

[7] In the case of the Tagus-Segura Aqueduct the fees range from 0.09 €/m^3 for irrigators to 0.12 €/m^3 for water agencies supplying municipalities in the recipient region.

3.2.5. Informal water exchanges

The combination of water scarcity, intensive agricultural production and urban expansion has provided the ideal context for “informal” water exchanges. Hernández-Mora & De Stefano (2013, p. 377) define informal water markets as “exchanges that take place apart from the legislation and, in some cases, beyond the control and overseeing of the Administration”.

Before and after 1999, informal water exchanges at the local level have taken place frequently in many Spanish basins, primarily in East and Southeast Mediterranean areas (Segura, Júcar and Mediterranean Andalusian Basins; see Figure 2). Transactions normally occur when water scarcity problems arise and water users need a rapid solution in order to obtain enough water to irrigate tree crops or to supply other critical water uses. Water volumes exchanged in these informal markets usually comes from groundwater sources and mostly from private groundwater rights.

Price is quite high compared to formal lease contracts and public purchases, and it is often of a speculative nature. The prices also vary by location, water quality, alternative supply sources and, to a larger extent, the scarcity level. Prices have been documented to reach 0.7 €/m^3, although in general there will always be a ceiling marked by the charges for desalinized water, plus the transportation costs (0.33 €/m^3 in coastal areas, and 0.39 €/m^3 in inland areas, with a total of 0.45-0.47 €/m^3 at the point of use), in those coastal areas where those resources are available. Quality graded waters fetch different market prices with growers combining different sources to raise water quality to levels crops can tolerate. In addition, in some areas farmers or water companies desalinize deep saline groundwater, which is sometimes traded[8]. In some cases, water sold comes from illegal pumping.

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[8] A distinction has to be made between desalination of brackish waters and desalination of sea water. In some coastal areas of Southeast Spain, individual farmers (commonly larger ones) use small desalination of deep brackish water, about which hardly any reliable documentation can

It has been documented that even municipalities have participated in informal exchanges with farmers, mainly to meet the water demand derived from the tourist activity. That was the case of Benidorm (Alicante), with a seasonal population of 400,000 inhabitants and a regular one of 70,000. The resulting agreement was to swap fresh sources originally owned by horticulturalists for treated urban waste water (Martí, 2005). In some cases, informal exchanges eventually become legalized or exchanged rights adjudicated by the Water Agency.

3.3. Economic issues

Regarding the economics of Spanish water markets, three aspects are analyzed in the following pages: price of water exchanges, the price setting mechanism, and the economic efficiency of the exchanges.

In general, water prices in the markets have been closer to the willingness to pay (WTP) of the buyer than to the opportunity cost of the seller, especially in inter-basin transfers (Garrido et al., 2013). Exchange prices have been advantageous for the involved parties, and they have shown that the water scarcity value in Spain is 0.18-0.30 €/m^3 in moderate drought situations, net of costs (lost, transportation and distribution costs) and in a very wide area (Tagus Basin and all the river basins in South Spain). Water buyers consider that they are paying high prices for water in the market, as the selling part is in a dominant situation and it takes advantage of it.

No author has set out to evaluate the actual impact of water markets in Spain, although a number of studies obtained hypothetical evaluations of welfare gains under various market scenarios (Arriaza et al., 2002; Calatrava &

be found. Eventually, in drought periods, some of these volumes are sold in informal markets, mostly to smaller farmers that have shalower wells and no desalinization facilities. There are also water companies that sell desalinized/brackish water. We only know of one irrigation district desalinizing brackish water, as districts in Southeast areas more commonly rely on desalinized sea water, when available, of which some information exists about cost, contracts, and used volumes.

Garrido, 2005a; Albiac et al., 2006; Gómez-Limón & Martínez, 2006; Pujol et al., 2006; Blanco et al., 2010; Blanco & Viladrich, 2013). As mentioned earlier, the bulk of traded volumes involved inter-basin transfers. Therefore, the net benefit of an exchanged cubic meter would result from deducting from its use value the transportation cost and the opportunity, resource and environmental costs in the area-of-origin.

Due to the heterogeneity of water productivity values, the different environmental status of water bodies, the different parties involved in water exchanges (inter-sectoral or intra-sectoral; inter-basin or intra-basin), and the need for conveyance infrastructures, it is difficult to obtain a single assessment of the economic value of Spanish water markets. What follows is a discussion about the most important trading activity in the country, and the factors that should be considered to obtain a solid conclusion about the impact of water markets on the areas involved.

In inter-basin water exchanges, the impacts may be larger than those derived from intra-basin exchanges. Corominas (2011) analyses the inter-basin trading activity through the Negratín-Almanzora Transfer (Andalusia). Buyers were farmers (growing citrus and horticultural crops) in the Almanzora Basin. Sellers were farmers in the Guadalquivir Basin growing annual crops including rice. The considerable difference in average water productivity of these two regions (0.25 €/m^3 in the selling area, 1.6 €/m^3 in the buying area) facilitated the agreement. In 2007 and 2008, 25 hm^3 were transferred at a price of 0.18 €/m^3. According to Corominas (2011), the water price range that would afford benefits for both water buyers and sellers in the Andalusian region would be, approximately, 0.15-0.35 €/m^3. However, in some cases, 0.15 €/m^3 may not be enough to compensate sellers for their income losses derived from the water exchange. For a complete assessment of the impact of such water exchanges, some other factors should be taken into account, such as the environmental cost due to the transfer of water to another basin (0.005-0.0244 €/m^3 based on previous studies in different Spanish regions (Elorrieta et al., 2003; Ramajo-Hernández & del Saz-Salazar, 2012)). In some cases the multiplier effect of any displaced agricultural activity in the area-of-origin of the water should also be included.

The other important inter-basin water exchanges in Spain took place through the Tagus-Segura Aqueduct during the drought period 2005-2009. The agreed prices for the exchanges were 0.19-0.22 €/m^3 for irrigators. The marginal value of irrigation water in the Segura Basin was 0.52 €/m^3 (Calatrava & Martínez-Granados, 2012), whereas in the Tagus Basin it was around 0.07 €/m^3. So, there is enough room for increasing the price paid by sellers in order to compensate for any negative effects in the Tagus Basin (area-of-origin of the water): environmental effects related to the transfer of water (see the above estimates), foregone value of unused and transferred water and hydropower opportunity costs (0.09 €/m^3 according to Hardy & Garrido (2010)).

In the case of the water exchange centers in the Júcar, Segura and Guadiana, the buyer was the River Basin Authority. The prices vary across basins, depending on the water productivity in each region (see Table 4). Although the environmental flow value estimations are relatively low, the Administration is willing to pay the irrigators' willingness to accept with the aim of reaching a good ecological status for reservoirs and guaranteeing minimum environmental flows.

For bilateral agreements between water users within the same basin, such as the lease contracts that took place in the Tagus Basin and in the Guadalquivir Basin, the differences in the value of water are smaller than between different basins. Those gains from trade are expected to be smaller, which explains the relatively reduced market activity within most basins. Still, transportation costs and environmental impacts are also expected to be smaller but will depend on the location of sellers and buyers in each basin.

Another important economic benefit from water trading, especially between users in different basins, relates to the potential improvement in supply reliability. For example, in the Guadalquivir Basin, several studies show that farmers are interested in increasing their water supply reliability. According to Mesa-Jurado et al. (2012) olive trees irrigators in the Guadalbullon sub-basin (Guadalquivir Basin) are willing to increase by 10-20% the community annual payment and also to reduce average water supply by 30% of the water concession to increase their water supply guarantee. Their study shows a WTP for improving water supply reliability of 0.034-0.074 €/m^3. The opportunity costs related to the reduction of water allocation from 1,500 to 1,000 m^3/ha is 0.39 €/m^3. Besides, water users in this basin are willing to pay 0.01-0.015 €/m^3 for improving water quality (Martín-Ortega et al., 2009). In the Segura Basin, Rigby et al. (2010) estimates the WTP of horticultural farmers in the coastal *Campo de Cartagena* irrigation district for an increase in the water supply reliability to range from 0.22 to 0.5 €/m^3.

The results derived from all these studies show that potential buyers are willing to pay considerable amounts of money to increase their water availability and to improve water supply reliability, but not that much to improve the water quality of the rivers. The government, in contrast, is willing to devote public funds to recover resources for the environment (or at least was before the current economic crisis). Through the water market, buyers can achieve the desired water supply reliability, sellers can be well-compensated for transferring their water, and the environmental status of the water bodies can be improved thanks to water exchange centers.

3.4. Reasons behind the limited success of water markets in Spain

Several reasons can explain the limited development of water markets in Spain. First, there are a number of restrictions and pre-requisites before a water exchange is approved that certainly add transaction costs and red tape (Garrido & Calatrava, 2009). These restrictions are meant to avoid speculation and water rights hoarding, and to protect third-parties from negative effects, but result in low market activity.

There are a number of regulatory elements, identified by Ariño & Sastre (2009, pp. 100–101), that can restrict the functioning of water markets, including: i) rights to consumptive uses cannot be sold to holders of non-consumptive use rights (hydropower) and vice versa; ii) restrictions on potential water buyers, such as rights can only be leased out to other rights holders of an equivalent or higher category in the order of preference. It was decided that the market should only be available for pre-existing and fully legally supported users; iii) limits to the spatial extent of trading: licenses for the use of public infrastructure connecting different river basin areas may only be authorized if they come under the National Hydrological Plan or other specific laws; iv) limits on prices; regulations may determine maximum prices for water licenses. Competitive pricing can be superseded by administrative intervention. Unlike the Australian differentiation of entitlements and use rights, in Spain only a formal right, in the sense of entitlement, is defined.

Second, environmental limits are those enforced by public agencies responsible for the stewardship of the ecological quality of rivers and water bodies. In general, these limits, such as minimum environmental river flows, are based on modeling evidence, and are seldom contested. Occasionally, an "environmental tax" is imposed as a proportion of the volume/flow to which the traded right is entitled and which should be left in the natural source.

Third, most water in Spain is currently allocated through public water concessions, rather than private water rights, which still exist because their holders had rights before 1985. Water markets do not always work efficiently because concessions were not designed for market transactions. Law specialists differ in interpreting whether the rights definition necessarily hamper the market (Ariño & Sastre, 2009) or simply enforce the very Water Act tenets

(Embid, 2010). Consider the situation of a drought. One would expect that shortages would trigger more market activity, but in fact water authorities effectively reduce the volumes accessible to the right-holders in areas facing scarcity, thereby reducing any incentive to purchase a water right. In a sense, the RBA still has a major role in allocating water under scarcity conditions. But decisions are agreed upon by all represented stakeholders, in meetings of formal committees with executive power. So the market is not deeply ingrained in Spanish water culture, and more collective responses to drought are common and widely accepted. This is not the case in Australia, Western US or in Chile. Moreover, there is also a problem of poorly defined water rights in some areas. It is not a coincidence that most of water trading in Spain has been inter-basin trading because scarcity situations have been different across basins and buyers and sellers have been able to trade different percentages of the volume or flow established in their formal right.

Fourth, with some exceptions, the potential for water trading between users in the same basin are limited, as differences in WTP/WTA are usually not significant. In addition, inter-basin water trading has only been allowed in drought periods as an emergency relief tool. The largest exchanges of water in the 2005-2008-drought period took place among users in different basins.

Fifth, a significant proportion of agricultural users are grouped in Water Users Associations (WUAs) that in Spain usually take the form of communal entities. If their users agree, the WUA can become the right-holder of all the resources assigned to them individually, but this implies the termination of the individual water rights. Under this case, WUAs rather than individual farmers are the ones participating in water trading, and they are less likely to participate as sellers in a water market. Furthermore, decisions to buy or sell are taken in Assembly or Commissions, rather than individually. According to Giannocaro et al. (2013), managers of WUA are interested in selling water, but seasonally.

Sixth, inter-sectoral barriers occur when representatives of one sector fights collectively exchanges that go against its political standing within the hierarchy of water rights and political priorities. This is generally the case of irrigators. A huge literature (see Easter et al., 1998) exists that show farmers being initially reluctant to sell water out of the sector. As a recent example, irrigators in the Ebro Basin made their water rights available to the city of Barcelona during the severe water supply crisis during the 2005-2008 drought, but they would not accept any monetary payment for transferring their resources. There are long-term strategic reasons for combating out-of-sector water sales; chief among them the fear that the economic forces go against them and eventually their tradable rights will be questioned and perhaps irrigators will be deprived of them (Howitt, 1994; Albiac et al., 2006).

Finally, in spite of the functioning of formal water markets for more than a decade in Spain, there are still uncertainties. Criteria for approving or denying applications for water exchanges are not clear. Consequently market participants rely more on previous experience than on a clear public definition of the circumstances under which trading is allowed (origin of water, area of destination, tradable volumes, fees to be paid, environmental restrictions, etc.). Similarly, the potential for inter-basin markets was hampered by the uncertainty about whether or not the Spanish Government will allow exchanges. The tedious administrative process and the needed time to obtain an answer from the Administration discourage water users to participate in water markets. Access to water rights, existing infrastructure, and legal and administrative aspects are important factors influencing the acceptability of water trading in Southern Spain (Giannocaro et al., 2013).

These and other barriers to trade result in other markets taking the role of water markets. The market for agricultural land (lease or purchase) and informal water markets substitute, to some extent, for formal water trading with a significantly higher cost. Consider the real case of a thermo-solar power plant, which needs water for cooling and replenishing vapor losses. If its owners do not hold water rights, the only way he can obtain water is by purchasing irrigated land and its attached water rights, and then request a change of use from the water authority. Furthermore, technologies and management practices, both on-farm, on site and at the district levels, have had a significant impact on reducing water application rates in Spain and deterring consumption. The energy cost component in many areas with abundant surface water supplies, on top of the financial and operating costs of recently modernized districts, have increased irrigation cost by 400% (Hardy et al., 2012).

As Qureshi et al. (2009) assessed for the Australian case, the costs derived from water market barriers (institutional and administrative constraints, financial disincentives and spatial restrictions) are considerably high.

3.5. Present and future: Possible reforms

There are a number of shortcomings in Spanish water markets as well as in other countries: high transaction costs, slow administrative procedures, difficulties in finding buyers/sellers, high prices, rigid legislation, etc. (Garrido et al., 2012b). However, markets in Australia, US and Chile are much more active and deeper. As mentioned before, traded volumes in the Spanish water market have never represented more than 1% of all annual consumptive uses. Furthermore water markets are mainly used during drought periods, except for a few water banks. Table 5 contains some insights and ideas that would improve the functioning of water markets in Spain.

Table 5. Potential improvements for Spanish water markets

Potential improvements	Description
Option contracts	This type of trading mechanism has several advantages that have been presented and discussed in section 2.3.
Water saving certificates	To promote water use efficiency. The most efficient water users who do not have easy access to other water sources would pay the less efficient ones to reduce their water losses. For that, they would get extra water corresponding to the water volume saved.
Water market legislation	i) Remove the hierarchy of use priorities; ii) allow water exchanges only of the volume irretrievably lost from a given use, not of the total volume diverted; iii) adopt regulations for inter-basin and inter-regional trading, with the objective of reducing the political interference and arbitrariness; iv) allow non-right holders to purchase water resources.
Water management improvements	To define and approve the major allocations for all water basins, to implement cost-recovery levels in full compliance with the WFD; to establish a pre-registration and screening procedure for users interested in becoming market participants
Dissociation of water rights attributes	Formal and effective separation of water rights and allocations, as the Australian case.
Implementation of a decision system for the approval of water exchanges.	See Table 6
Price regulation	More information and transparency about prices in water exchanges.

Source: Adapted from Rey et al. (2014).

Table 6. Criteria and risk valuation for evaluating a water exchange

Criteria	Categories	Risk level*
Exchanged volume	Less than 50.000 m^3	1
	50.000 m^3 and 500.000 m^3	2
	>500.000 m^3	3
Knowledge about the seller's water consumption	Direct measurement	1
	Estimated measurement	3
Distance between buyer and seller	<5km	1
	5-20 km	2
	>20 km	3
Seller is downstream from the buyer	No	1
	Yes	3
Inter-basin transfer	No	1
	Yes	3
Water use change	To urban uses	1
	To industrial or energy uses	2
	To irrigation	3
Likely impacts on water flow returns	No	1
	Yes	3
Groundwater exchange	No	1
	Yes	3
A new use essentially different from the seller	No	1
	Yes	3

* 1: low risk; 2: medium risk; 3: high risk.

Source: own elaboration.

Among all these possible reforms, this work is focused on water option contracts. In the following chapters, option contracts are analyzed from different points of view in order to assess the potential benefits derived from the implementation of this mechanism in the Spanish water market.

4. AN INNOVATIVE OPTION CONTRACT FOR ALLOCATING WATER IN INTER-BASIN TRANSFERS: THE CASE OF THE TAGUS-SEGURA TRANSFER IN SPAIN

Abstract

Users in the Mediterranean region face significant water supply risks. Water markets can provide flexibility to water systems run in tight situations. The largest water infrastructure in the Iberian Peninsula connects the Tagus and Segura Basins. Water volumes are annually transferred to the Segura Basin to alleviate water scarcity problems in this region. The need to increase the statutory minimum environmental flow in the middle Tagus and to meet new urban demands has lead to the revision of the Transfer's management rules, which will cause a reduction of transferable volumes to the Segura Basin. We evaluate the consequences of this change in the whole Tagus-Segura system, regarding the available water volume for irrigators in the Segura Basin, the resulting impact on environmental flows in the Tagus Basin, and the economic impacts on both basins. To minimise the consequences of such change on irrigators in the Segura Basin who depend on the transferred volumes, we propose a water option contract between both basins that represents an institutional innovation with respect to previous inter-basin spot market experiences. Based on the draft of the new Tagus Basin Plan, we propose both a modification of the Transfer's management rule and an innovative two-tranche option contract. The main goal is to define this contract and evaluate it with respect to spot and non-market scenarios. Our results show that the proposed option contract would reduce the impact of a change in the transfer's management rule and the supply risks in the recipient area.ç

4.1. Introduction

Water users' reliability is subject to the variability of precipitation, deep infiltration and runoff. One of the main objectives of water management is to offer the required levels of supply reliability and mitigate the social, economic and environmental consequences of droughts and floods. Water infrastructure and allocation rules mitigate climatic cycles but do not completely eliminate supply risks. Spot water markets facilitate the efficient allocation of this resource and have some supply risk reduction properties, but do not provide efficient risk allocation mechanisms per se, which exploit differences in risk tolerance and exposure (Calatrava & Garrido, 2006).

Formal water markets in Spain have been functioning since 2006, although the legal basis was approved in 1999. Trading experiences have been limited and the existing market system presents important problems that demand several reforms and innovative mechanisms in order to reduce water users' risks due to the low reliability of water supply from year to year (Garrido et al., 2012b; Hernández-Mora & De Stefano, 2013). Thus, in this chapter a novel water option contract between water users in the Tagus and the Segura Basins is proposed and evaluated with respect to previous spot market experiences.

As water will become scarcer in the future and Mediterranean rain-fed regimes will become more unstable, option contracts between different water users associations or river basins could add flexibility and security to their operations. A fundamental prerequisite for these exchanges to be successful is a situation with considerably high water productivity difference between the buying and the selling areas, a circumstance that is commonly found in areas connected through inter-basin aqueducts.

Climate change projections over the next decades show an important decrease in runoff and recharge in all Spanish River basins, mainly in the southeast of the Iberian Peninsula. In the Tagus Basin, for the period 2010-2040 this reduction of runoff is projected to be between 8% and 11%, under A2 and B2 emission scenarios (CEDEX, 2011). According to Maestre-Valero et al. (2013), water availability in the Segura Basin could be reduced by up to 40 %, with an economic impact in the 32–36 % range.

Because water scarcity in the Tagus Basin is becoming a serious concern, a change in the Tagus-Segura Transfer management rule has already been agreed upon (CHT, 2013), in the sense of making it more restrictive in the provision of water resources to the Segura Basin during dry periods. Ensuring greater minimum environmental flows downstream the city of Madrid would reduce the resources available for the Tagus-Segura system.

The proposed option contract aims to: a) minimise the negative impact that the change in the management rules governing the Transfer would have on water availability for irrigators in the Segura Basin; and b) reduce risk, increase stability and security in inter-basin water exchanges for both buyers and sellers with respect to past spot trading experiences. Based on the draft of the Tagus Basin Plan[9], we propose an amendment transfer management rule. Also, an innovative two-tranche option contract seeks to provide an improved market regime.

In the Spanish water market, option contracts are not a common type of exchange but there has been one experience of a multi-annual contract that resembles an option contract. In Spain, option mechanisms have been suggested by Gómez-Ramos & Garrido (2004) and Cubillo (2010). Also, in several meetings with Spanish water market stakeholders and experts, they have shown interest in the implementation of this kind of trading mechanisms in this country.

After recent legislation changes in 2013, inter-basin water trading is going to be allowed in every circumstance, and not only during drought

[9] http://www.chtajo.es/Informacion%20Ciudadano/PlanificacionHidrologica/Planif_2009-2015/Paginas/PropProyPHC_2009-2015.aspx [Available since March 2013].

periods and with the permission of the Ministry of Environment. This change is going to have important consequences for inter-basin water trading activity due to the huge potential of these exchanges.

The chapter is organised as follows: first, we describe the main characteristics of the Tagus-Segura Transfer, and present the water supply reliability problems in the recipient area. Second, we define the main features of the proposed option contract and present the other considered scenarios (spot market and no market). The third section describes the modelling framework and data used to perform the analyses. Fourth, the results showing the impact of different exchange scenarios on the water availability to irrigators in the Segura Basin and on environmental flows in the middle Tagus Basin are presented, together with an economic analysis of the different exchange mechanisms. Lastly, conclusions are drawn based on the preceding analyses.

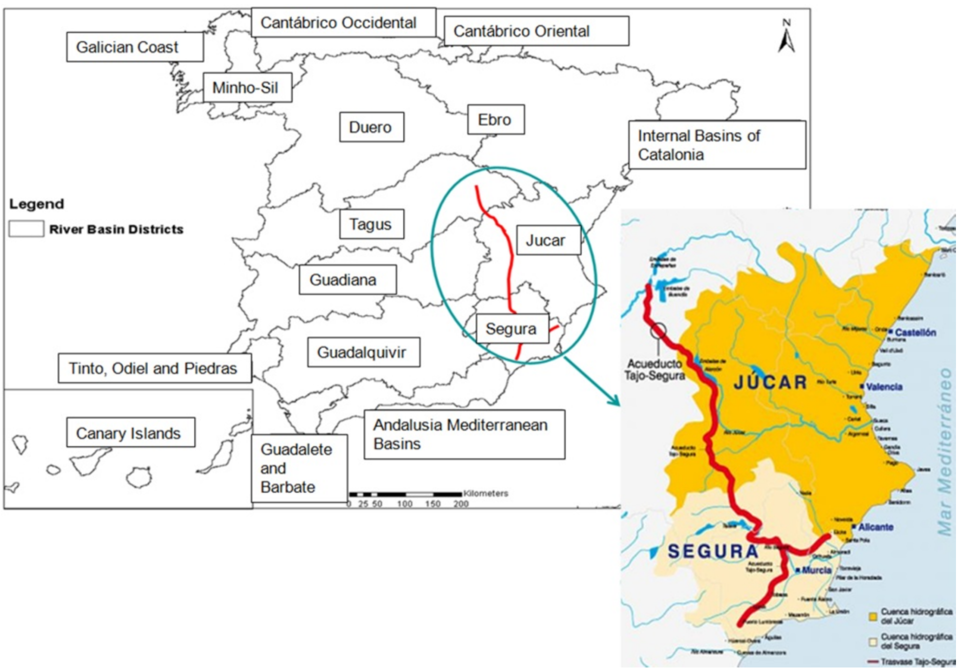
4.1.1. Case study: The Segura Basin and the Tagus-Segura Transfer

4.1.1.1. Tagus-Segura Transfer

The Segura Basin is the most water scarce basin in Spain with a structural water deficit of 370 million m^3/year (CHS, 2007). Usually, this is covered by non-renewable groundwater pumping and deficit water application to crops, which in many cases are subject to water stress conditions, increasing water supply costs (Calatrava & Martínez-Granados, 2012). In the 1970s, the Tagus-Segura Transfer (TST) was projected with the aim of reducing this water deficit by transferring water resources from the Upper Tagus Basin to irrigation districts and urban water suppliers in the Segura Basin (Figure 4). In order to avoid misunderstandings throughout the chapter, it is important to clarify that the Tagus-Segura Transfer was approved by law in 1979 to enable water transfers from the Tagus to the Segura Basin, but it is not a water market.

Since the beginning, representatives from the area-of-origin of the water have contested the TST operations. The argument was that there is no water surplus in the Tagus Basin, so water should remain in the basin for the different economic activities, to meet urban demands and to maintain a good ecological status of the Tagus River. Opposition to transfers grows stronger during drought periods when the Tagus River flow becomes significantly reduced.

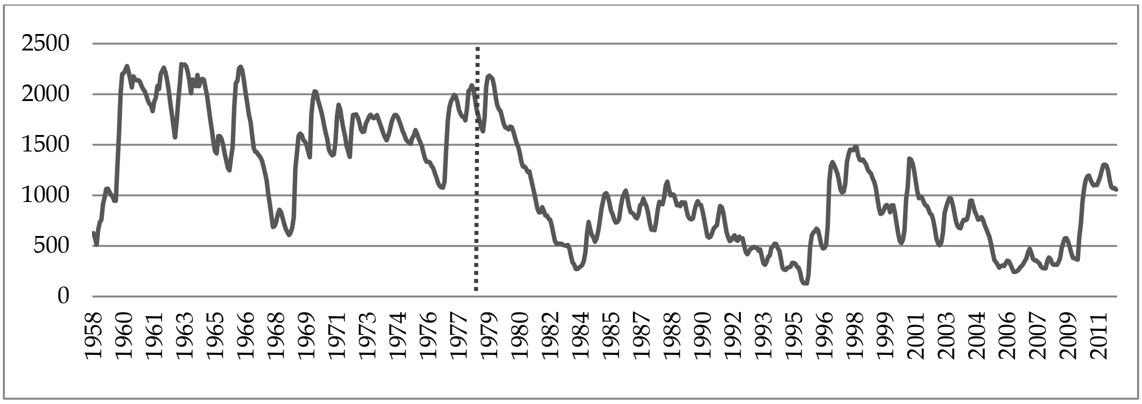
Figure 4. Tagus and Segura Basins' location in the Iberian Peninsula and the Tagus-Segura Aqueduct



Source: Adapted from www.iagua.es.

The annual transferred volume to the Segura Basin depends on the water stock jointly stored in the interconnected *Entrepeñas* and *Buendía* reservoirs (E-B) in the Upper Tagus Basin, which have a total storage capacity of 2,443 million m^3. The stored water in the E-B reservoirs has exhibited a downward trend since 1980. Prior to 1980 (when the TST was projected), the stock was above 1,500 million m^3 for 70% of the months of the year (CHT, 2011). After 1980, the stored volume has experienced a sharp drop and the total volume hardly ever surpassed 1,500 million m^3 (See Figure 5). The two last severe drought episodes (starting in 1992 and 2005, respectively) are easily identifiable, when stored volumes fell below 500 million m³.

Figure 5. Monthly stored volume (million m³) in Entrepeñas-Buendía



Vertical line marks the beginning of the inter-basin transfer operation

Source: (CHT, 2011).

Fluctuations in the stored volume cause great uncertainty, which translates to uncertainty in the water volume that will be transferred each year to the recipients in the Segura Basin. Water from the Tagus Basin is delivered to users in the Segura Basin based on certain transfer management rules. These rules require that the Tagus Basin's demands should always be met without limitation. Twice a year, the Ministry of Environment announces the maximum volume that can be transferred to the Segura Basin during the following semester. This decision is based on the total volume stored in the E-B reservoirs (Table 7). Then, water will be delivered based on the fortnightly water demand of the Tagus-Segura Transfer's beneficiaries. In any case, the maximum annual transferable volume is 600 million m³, an amount that has rarely been reached since the Aqueduct was built, with a capacity of 1000 million m³and covering a distance of more than 300 km.

Table 7. Tagus-Segura Transfer's statutory management rules

LEVEL	RESERVOIR STATUS	MONTHLY MAXIMUM TRANSFERABLE VOLUME (million m^3)
Level 1	Accumulated water inflows during the last 12 months higher than 1000 million m^3, or total stored volume above 1500 million m^3.	68
Level 2	Accumulated inflows during the last 12 months smaller than 1000 million m^3, or total stored volume below 1500 million m^3.	38
Level 3 (Exceptional hydrological situation)	Total stored water volume lower than the volumes in Table 8	23
Level 4[a] (No water surplus)	Total stored volume below 240 million m^3.	0

[a] The new Tagus-Segura management rule is more restrictive. It considers there is no water surplus in the Tagus Basin (Level 4) when the total stored volume is below 400 million m^3, rather than 240.

Source: CHT (2008).

When the total water stock in E-B is below the minimum monthly volumes shown in Table 8, the decision over the water volume that could be transferred to the Segura Basin is made by the Council of Ministers, instead of by the Tagus's Basin Agency. This means that there is some discretionary political power presiding over the inter-basin operations.

Table 8. Minimum stored volumes in the Entrepeñas-Buendía reservoirs below which the decisions for transfer correspond to the Council of Ministers (hm^3)

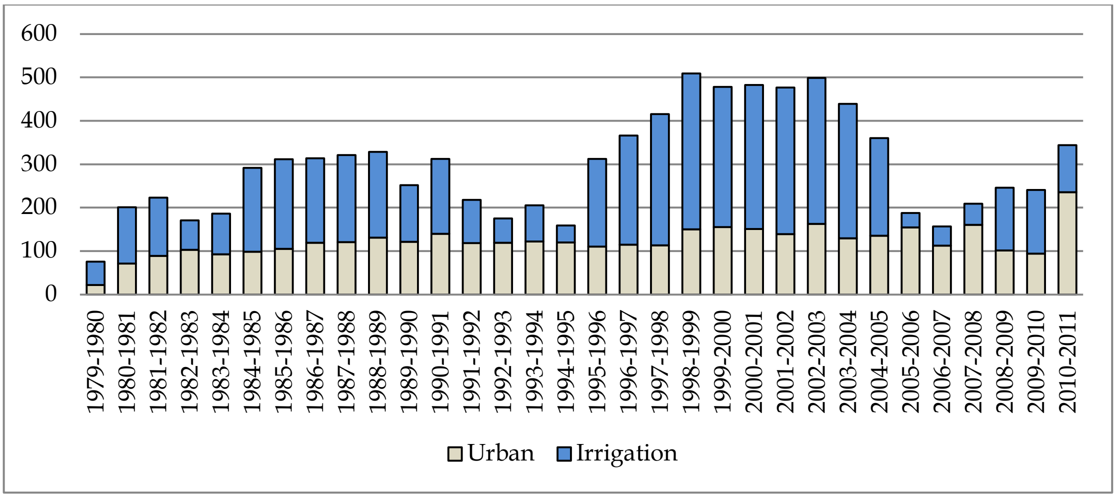
OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
456	467	476	493	495	496	504	541	564	554	514	472

Source: CHT (2003).

4.1.1.2. Water availability risk in the Segura Basin

Irrigation districts in the Segura Basin, which receive water from the Tagus Basin, face important risks regarding the planning of crops due to water supply variability. In addition, when this transferred volume is low, urban uses have priority over irrigation, and therefore irrigators' water volumes are the most affected (see Figure 6). In the last 10 years, the maximum volume transferred from the Tagus Basin to irrigators in the Segura Basin was 337.57 million m^3 and the minimum was 33.10 million m^3 in 2005-2006, which was a year of drought.

Figure 6. Transferred water volume (million m^3) for irrigators and urban suppliers through the Tagus-Segura Transfer, 1979-2011



Source: San Martín (2011).

4.1.1.3. Previous water trading activity between users in the Tagus and the Segura Basins through the inter-basin transfer[10]

In the case of inter-basin market exchanges, where the scope for water trading is greatest and the largest lease contracts have been signed, the approval of the Ministry of Environment was required, which constituted a relevant restriction

[10] For a complete description of Spanish water markets, see chapter 3.

to this type of agreements. Some spot water purchases have been arranged during drought periods to buy water from the Tagus Basin for agricultural and urban users in the Segura Basin using the Tagus-Segura Aqueduct.

After 1999, due to the reductions in the transferred water volumes from the Tagus Basin during drought periods, water users in the Segura Basin resorted to the water market to obtain the needed water volume for their activity. Since 2005, there have been several market exchanges between irrigation districts in the Tagus Basin (sellers) and irrigation districts or urban water suppliers in the Segura Basin (buyers, all of them beneficiaries of the TST) (Garrido et al., 2012b). In all cases, the stock level in E-B was below the threshold that determines that the decision of the transferred volume should be taken by the Council of Ministers.

Table 9. Water transaction experiences between users in the Segura (buyer) and the Tagus (seller) basins

SEASON	BUYER[11] (Segura Basin)	SELLER (Tagus Basin)	VOLUME (million m^3)	STOCK[12]
2005/2006	SCRATS	Canal de Estremera	31.05	320.4
2006/2007	MCT	Canal de Las Aves	46.5	349.9
	SCRATS	Canal de Estremera	31.05	349.9
2007/2008	SCRATS	Canal de Estremera	31.05	332.3
	MCT	Canal Las Aves	36.9	393.3
2008/2009	SCRATS	Canal de Estremera	31.05	553.9

Source: Own elaboration.

[11] SCRATS (Central Association of the Irrigators' of the Tagus-Segura Aqueduct, *Sindicato Central de Regantes del Acueducto Tajo-Segura,*); Canal de Estremera (irrigation district in the Tagus Basin); MCT (Taibilla's Canals Commonwealth, *Mancomunidad de Canales del Taibilla*); Canal de las Aves (irrigation district in the Tagus Basin).

[12] Stock in the *Entrepeñas-Buendía* reservoirs at the moment of the transaction (million m^3).

Counting on the Ministry's approval, the volume of water purchased in 2006 by users in the Segura Basin from irrigation districts of the Tagus Basin largely surpassed those of all the intra-basin exchanges approved among users in the Segura Basin between 1999 and 2005 (Garrido et al., 2012b). The MCT (Taibilla's Canals Commonwealth, *Mancomunidad de Canales del Taibilla)*, the major urban water supplier in the Segura Basin, signed an agreement in 2006 with farmers in the *Canal de las Aves* irrigation district at a price of 0.28 €/m^3. In 2007, the negotiated price was 0.23 €/m^3. The price in 2006 was greater because when the agreement was reached the selling farmers had already incurred some cultivation costs (Calatrava & Gómez-Ramos, 2009).

The contract between the *Canal de Estremera* irrigation district and SCRATS (Central Association of the Irrigators' of the Tagus-Segura Aqueduct, *Sindicato Central de Regantes del Acueducto Tajo-Segura*) was annually renewed during four years. SCRATS paid 6 € million/year to irrigators in the Tagus Basin for 31.05 million m^3/year. The price was 0.19 €/m^3 in 2006 and increased to 0.22 €/m^3 in 2008 (Calatrava & Gómez-Ramos, 2009).

As these parties had already arranged some water exchanges in consecutive years, we conjecture that they might be interested in signing a water option contract due to the stability it provides for both buyers and sellers. The above mentioned spot market activity took place during a drought period, when water users in the Segura Basin were in an emergency situation. Under these conditions, it may be difficult for buyers to easily find potential sellers and get the water in a short period of time to irrigate the crops. A more stable and reliable system could reduce water supply uncertainty for Segura's water users, and could provide stability to the area-of-origin water sellers as well.

Water markets have allowed agricultural water users in Southeast Spain to cope with periods of severe water scarcity and to avoid significant economic losses in their intensive export-oriented horticulture. Despite this, these types of contracts have been limited in duration and exchanged volumes, and still present significant uncertainties for the buyers.

4.1.1.4. Water productivity values for the considered river basins

For a water market to exist there is a need for considerable differences between water productivity in the selling and the buying areas. The difference should be large enough to cover the transaction, transportation and environmental costs. Water productivity is very different in the two considered regions in this work. For instance, in Madrid (Tagus Basin) the irrigation water apparent productivity is 0.6 €/m^3. In Murcia (Segura Basin) the productivity is 3.4 €/m^3 according to Gil et al. (2009). The high water productivity in irrigated areas receiving water from the Tagus Basin is, in part, due to the concentration of horticultural crops and greenhouses, and also to the modernization of the irrigation systems (Calatrava & Martínez-Granados, 2012). This difference favours the arrangements of water exchanges between users in these Spanish basins. Table 10 shows some relevant economic data of water productivity values in each area, and of the water exchanges that took place between water users in both basins.

According to PricewaterhouseCoopers (2013), the agricultural sector in the Segura Basin that depends on the transferred volumes from the Tagus Basin generates 1268 € million to the GDP of the region. The cancellation of the water transfers to the Segura Basin would lead to a reduction of the GDP of the Murcia region close to 7.1% (Sancho, 2008).

Table 10. Average values for irrigation in the Tagus Basin and the Segura Basin (areas served from the Tagus-Segura Aqueduct) (€/m^3)

	Tagus Basin	Segura Basin
Marginal Value of water (net of water price)	0.06	0.69
Average value of water (net of water price)	0.29	0.95
Average water price paid by farmers served from the Transfer	--	0.19
Price (water market)[a]	--	0.18-0.28

Economic values measured at average levels of water supply availability.

[a] Prices paid by irrigators in the Segura Basin for water from irrigators in the Tagus Basin during the drought period 2005-2008.

Source: Own elaboration based on Calatrava (2007) and Calatrava & Martínez-Granados (2012).

4.2. Description of scenarios

The aim of this work is to evaluate the impacts derived from a change in the Tagus-Segura management rules, and the potential of inter-basin trading as a mechanism to reduce these impacts on the Segura Basin, in terms of water availability and economic risks.

Our main objective is to define an option contract that would be potentially interesting for both parties (Segura and Tagus Basins). For both buyers and sellers, a multi-annual option contract would create an institutionally stable and secure means to trade water resources, according to rules with strong legal support and lesser political/administrative discretionary power. It could be a multiannual agreement but the decision to acquire the water should be annual if the predefined conditions prevail. The decision date is set at the end of May, as this is the beginning of the dry season in the Iberian Peninsula and the period of highest demand for crops.

Our proposal includes the following elements: an alternative Transfer's management rule, which has been formulated based on the draft of the new Tagus Basin Plan[13]; the parametric definition of the option contract; and the economic analysis of the different scenarios.

Table 11. Scenarios

Scenario	Transfer management rule	Water market
1a	Current rule	No market
2a	New rule	No market
2b	New rule	Spot purchases in drought periods
2c	New rule	Option contract (different parameterizations)

Source: Own elaboration.

4.2.1. Tagus-Segura Transfer management rules

Based on the records of the Tagus-Segura water transfer, we can elicit the current management rule, denoted by $f(.)$, conceptually defined by:

$$V_{t_1} = f(\tilde{S}_t) \quad (1)$$

where V_{t_1}(measured in million m^3) is the transferred volume to the Segura Basin in one year and $\tilde{S}_t$ is a stochastic function of the water storage on January 1st in E-B. Function $f(.)$ is statistically fitted with actual records of the previous three decades of transfer operations.

We also define an alternative management rule, $V_{t_2} = g(\tilde{S}_t)$, which is similarly shaped to $f(.)$ but with different parameters that result in different probability density functions for $V_{t_1}$and V_{t_2}. This change of the management rule has implications for both the recipient basin (Segura irrigators) and the

[13] For this analysis, we assume here that the transferred volume to the cities in the Segura Basin will remain unchanged, as they have priority over irrigation uses. So, all the burden of the change in the transfer management rule would have to be borne by Segura Basin's irrigators.

area-of-origin (Tagus environmental flows), and is a mathematical representation of the agreement reached in 2013.

4.2.2. Water market scenarios: spot market and option contract

We define two different water exchange scenarios: a spot market, similar to the inter-basin trading activity that took place between 2005 and 2008 (Table 9); and the water option contract. The exchanged water volume through the spot market is modelled as follows:

$$\tilde{V}_{spot} = \tilde{p}\, V_s \tag{2}$$

where $\tilde{V}_{spot}$ is the stochastic purchased volume in the spot market if the hydrological conditions prevailing during the 2005-2008 drought period are met[14], which occurs with probability p; $\tilde{p}$ is a binomial distribution (0,1) and V_s is equivalent to 31.05 million m^3 (as this was the annual purchased volume by irrigators in the Segura Basin from irrigation districts in the Tagus Basin during the 2005-2008 drought period). Although there is not sufficient data and observations to fit a binomial distribution, we make the assumption that if spot market sales were under some circumstances in the past they will also occur in the future under the same conditions.

The other market scenario considered is the water option contract, which represents an innovation with respect to previous exchanges in the spot market. It is modelled as follows:

$$\tilde{V}_{option} = \tilde{q}\ 31.05 + (1 - \tilde{q}) H\ (\Delta \tilde{I}_{J-M}) \tag{3}$$

where $\tilde{V}_{option}$ is the obtained volume through the option contract; $\tilde{q}$ is a binomial variable (0,1); $\Delta \tilde{I}_{J-M}$ is the stochastic accumulated inflows during the first five months of the year in the E-B reservoir; and $H(.)$ is a function that yields the proportion of this increase that can be purchased under this scheme.

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[14] Water stock in the E-B reservoir < 550 million m^3.

The proposed option contract has two different components with different purposes. The first tranche is intended to protect Segura's irrigators in those years when the stock level in E-B is very low and thus the probability of receiving water through the TST based on the institutional management rule is low. The second tranche of the scheme would allow irrigators in the Segura Basin to have access to a higher water volume in those years when the stock level in the reservoir is high, as a compensation for the change in the Transfer's management rules.

The first one (when $\tilde{q}$ is 1) represents a contract between an irrigation district in the Segura Basin (buyer) and an irrigation district in the Tagus Basin (seller). The trigger for obtaining the associated water volume to this part of the option contract would be a minimum stock level in the E-B reservoirs. Therefore, when the stock level in E-B is below this limit, the irrigators in the Segura Basin can purchase the corresponding water volume just as it happened in years 2006, 2007 and 2008. The water resources subject to this part of the option contract would be the allocated volume to an irrigation district in the Tagus Basin. Based on previous spot market exchanges between these parties, it has been established that the maximum volume that they would have access to with this part of the agreement is 31.05 million m^3. The buyer will pay a premium at the beginning of the year to the seller as compensation. This part of the option contract intends to integrate past spot market experiences between these two agents in a more reliable and secure system.

The second part (when $\tilde{q} = 0$) represents an agreement between irrigators in the Segura Basin (buyer) and the Tagus Basin Agency (seller). This part of the option contract could only be accessed when the water stock in E-B is higher than the established minimum, allowing the buyer to purchase a proportion H of the accumulated water inflows in the reservoir between January and May.

4.3. Empirical analysis

Three different issues have been analyzed for the considered scenarios: i) water availability for irrigators in the Segura Basin; ii) remaining stock in the E-B reservoir (Tagus Basin); and iii) economic impacts in the whole Tagus-Segura system.

Monte-Carlo simulations were performed in order to obtain the probability distribution functions (PDFs), for each scenario, of water availability both for irrigators in the Segura Basin (referring only to water resources from the Tagus Basin) and for the Tagus' headwaters reserves. We also obtained simulation results of the net benefit of the inter-basin operations. By comparing these PDFs, we can compare the impacts of different water trading mechanisms and transfer management rules on irrigators' water availability and on the economic performance of the whole system.

4.3.1. Water availability for irrigators in the Segura Basin

4.3.1.1. Water availability under the current management rule (1) and alternative management rule (2)

For the definition of water availability under the current rule (previously introduced in section 4.2.1), a regression model describing the annual transferred volume (V_{t_1}) has been fitted. This variable cannot be treated as stochastic, due to the existence of the TST's management rule. Because of this rule (described in Table 7), the transferred volume depends on the water stock in E-B and the accumulated inflows in this reservoir. A regression has been performed following this expression:

$$V_{t_1} = f(S_t) = k + a\,S_t + bD + c\,Y + dY^2 + \varepsilon_t \qquad (4)$$

V_{t_1}: Annual transferred volume to the Segura Basin under the current management rule (million m^3).

S_t: Water stock at the beginning of the year in E-B reservoir (million m^3).

D: Dummy variable that takes the value 0 when the stock in January is below 1000 million m^3 and 1 otherwise.

Y: Number of the year in the database (1,...,20).

ε: Error term ($\varepsilon \sim N\ (0, \sigma_\varepsilon)$).

We have added a time variable (Y) in both linear and quadratic terms because in previous and simpler specifications of the fitted model we observed that the error terms followed a quadratic pattern over time.

Table 12. Estimated regression model for the variable "annual transferred volume to irrigators" ($\mathbf{V_{t_1}}$)

	Coefficient	Standard error	t value	p value
$\hat{k}$ (intercept)	-150.414	60.9494	-2.47	0.025
$\hat{a}$ (Stock)	0.549	0.0592	9.27	0.000
$\hat{b}$ D (Stock > 1000)	-245.014	46.7163	-5.24	0.000
$\hat{c}$ (Year)	26.729	10.5895	2.52	0.023
$\hat{d}$ (Year^2)	-0.919	0.3766	-2.44	0.027
Number of obs.	20	(1991-2010)		
F (4,16)	40.08			
Prob > F	0.000			
R^2	0.909			
Adj. R^2	0.887			

Source: Own elaboration.

Currently, the minimum environmental flow in *Talavera de la Reina* (downstream of Madrid) is set by law at 6 m^3/s. The proposed Tagus Authority figure was set at 10 m^3/s (CHT, 2013). To achieve this, a higher stock level ('remaining stock') in E-B would be required. We model such an increased environmental flow scenario by simulating a change from management rule (1),

$f(.)$, to management rule (2), $g(.)$; a change that would allow maintaining of a higher water stock in the E-B reservoirs. Once we have the values of the coefficients from the function $f(.)$ representing the current management rule (Table 12), another function with different curvature and parameters $g(.)$ is proposed, which is more restrictive in terms of the stock level needed in the E-B reservoirs to transfer a certain amount of water.

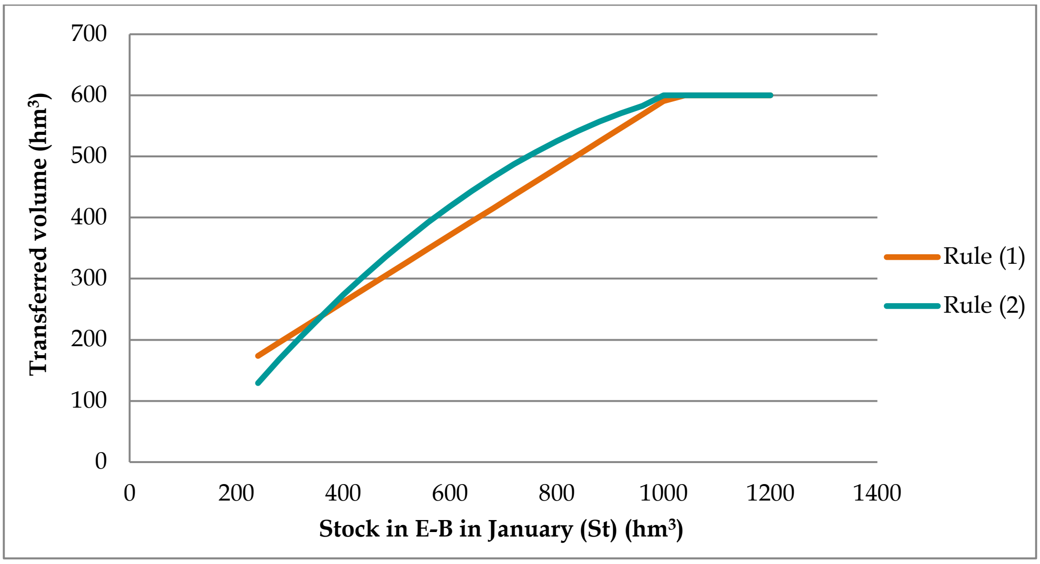
Tentatively, management rule (2) is proposed as follows:

$$V_{t_2} = g(S_t) = -462 + 0.000483\, S_t^2 + 1.210\, S_t - 1.661\, Y^2 + 47.131\, Y + \varepsilon \quad (5)$$

In Figure 7, the "Rule (1)" curve represents the current management rule and the "Rule (2)" curve represents the new management rule ($g(S_t)$). Neither the new nor the current rules permit transferred volumes greater than 600 million m^3 (400 million m^3 for irrigation, 140 million m^3 for urban uses. The remaining 60 million m^3 are conveyance losses). Figure 7 shows that for the same stock level in the reservoir in January (S_t) (X axis), the transferred volume with the new management rule would be lower than with the current rule for stock levels below 400 million m^3. As defined in this work, for water storage levels in E-B in January between 400 and 1000 million m^3, the new rule permits greater volumes to be transferred. In short, this new rule would deliver more water to the Segura Basin when the status of the E-B storage is high and would reserve larger volumes when the stock levels are low[15].

[15] This is only an alternative of what could be the new Tagus-Segura Transfer management rule, proposed by the authors.

Figure 7. Different management rules for the Tagus-Segura Transfer



Source: Own elaboration.

For farmers in the Segura Basin, this scenario (without water market activity) implies the following available volume:

$$\tilde{V}_{1a} = min\left[\, f(\tilde{S}_t), 400 \,\right] \quad \text{or} \quad \tilde{V}_{2a} = min\left[\, g(\tilde{S}_t), 400 \,\right] \qquad (6)$$

depending on whether the current or the proposed alternative management rule prevails. $\tilde{V}_{1a}$ and $\tilde{V}_{2a}$ cannot be higher than 400 million m^3, as this is the maximum established volume that could be transferred to the Segura Basin for irrigation purposes.

4.3.1.2. Water availability with spot purchases

The pattern of annual spot purchases during 2005 and 2008 has also been included in the analysis. This is based on the water trading activity in the previous drought period between water users in the Segura Basin and irrigation districts in the Tagus Basin (see section 4.1.1.3). The results of this scenario in terms of probability distribution functions will be compared with the other two (no market, option contract).

$$\tilde{V}_{2b} = \; min\left[\, (V_{t_2} + \tilde{p}\, V_s), 400 \,\right] \qquad (7)$$

where $\tilde{V}_{2b}$ represents the total water availability for irrigators in the Segura Basin in this case (taking into account only water resources from the Tagus Basin); V_{t_2} is the water transferred through the Tagus-Segura Transfer under the new management rule; $\tilde{p}$ is a binomial variable that takes the value 0 when the stock in E-B is higher than 550 million m^3 and 1 otherwise. V_s is the purchased volume (always 31.05 million m^3).

4.3.1.3. *Water availability with the option contract*

With this option contract, irrigators in the Segura Basin would have the chance to obtain extra water volumes from the Tagus Basin:

$$\tilde{V}_{2c} = min[\, V_{t_2} + \tilde{q}31.05 + (1 - \tilde{q})\, H\left(\Delta\, \tilde{I}_{J-M}\right)), 400\,] \qquad (8)$$

where V_{t_2} is the transferred volume that irrigators would receive every year based on the new Transfer management rule (described above); $\tilde{q}$ is a binomial variable that takes the value 1 when the stock level in the reservoir is below 550 million m^3, so that the buyer would be able to purchase 31.05 million m^3 from an irrigation district in the Tagus Basin; and zero otherwise. $H(.)$ is the transformation function that defines the proportion of the increase of water inflows in the E-B reservoirs ($\Delta\, \tilde{I}_{J-M}$) between January and May[16], which will be the volume that the buyer has access to, only when the stock in E-B is higher than 550 million m^3. $\tilde{V}_{2c}$ is the total water volume from the Tagus Basin in this case.

The reason for dividing the option contract into these two parts is the following: This scheme is defined with the aim of protecting irrigators' water availability in the Segura Basin from the impacts of a change in the Tagus-Segura Transfer management rules. As this change in the Transfer's management rules would attempt to improve the ecological status of the Tagus River, the option contract should not reduce the available water for the

[16] The inflows during these months are taken into account for the option contract model as the buyer has to decide whether to purchase the water or not at the end of May.

environment in the reservoir, mainly when the water stock level in E-B is low. Therefore, when the stock level in the E-B is below 550 million m^3, the buyer only has access to the first part of the contract (31.05 million m^3). As this part of the agreement is between two irrigation districts, one in each basin, the transfer of this volume would not affect the stock level in the reservoir, as it does not add an extra consumption in the basin of origin, but a change in the final use of the water. Thus, the positive impacts of the new transfer management rule on environmental flows would not be affected by this water transaction.

When the stock level is higher than 550 million m^3, the buyer would have access to a certain volume of water through the second part of the agreement (depending on function $H(.)$). This volume is a proportion of the accumulated inflows in the reservoir during the first five months of the year. Therefore, if irrigators in the Segura Basin buy that water volume, the final stock in E-B will be reduced, as it is an extra consumption of water. However, with the change in the management rule, environmental flows will be guaranteed.

This second part of the agreement is a compensation for the Tagus-Segura Transfer beneficiaries after the change in the Transfer management rule. Despite receiving less water when the stock level in E-B is low than under the current management rule, the proposed scheme would reduce the negative impacts of the new rule for the Segura users, and they could even have access to more water when storage in E-B is larger.

$H(.)$ can take different values depending on the total stored volume in E-B at the beginning of the year and on those water inflows between January and May. This volume is a proportion of the accumulated inflows during the first five months of the year ($H(\Delta\tilde{I}_{J-M})$). The proportion would be higher when the water stock level in January is high and the rainfall from January to May has been abundant. Mathematically, ($H(\Delta\tilde{I}_{J-M})$) is parameterised as follows:

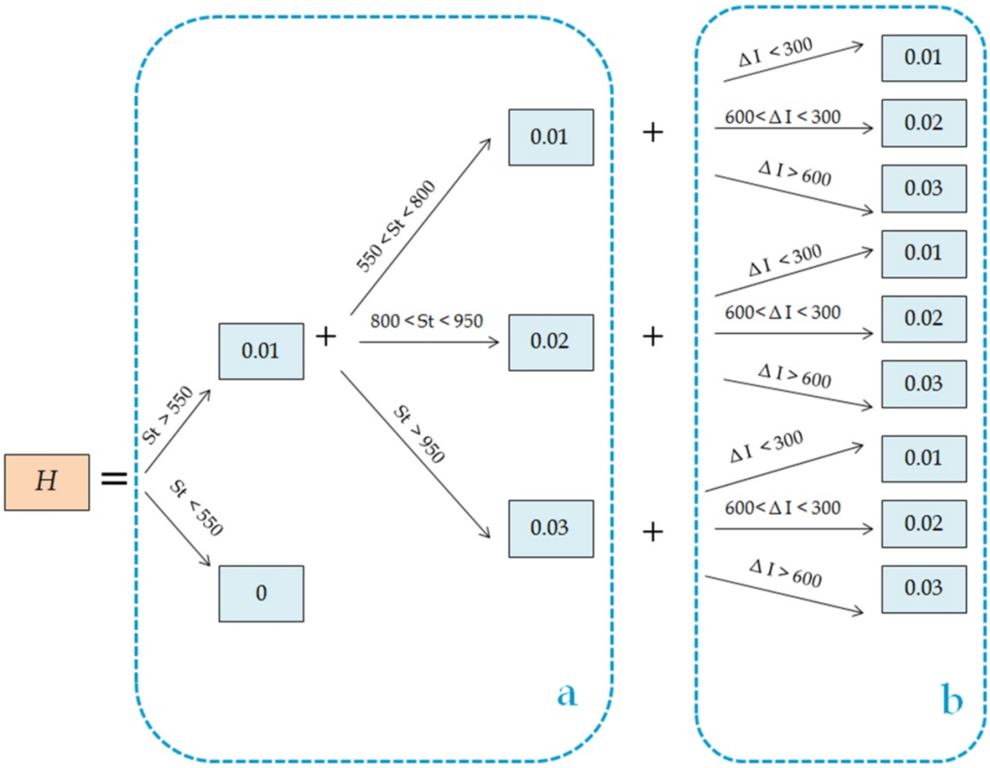
$$(H(\Delta\tilde{I}_{J-M})) = (a + b) \times \Delta\tilde{I}_{J-M} \quad (9)$$

With a and b being defined as follows:

$$a = \begin{cases} 0 \;\; if \; S_t \leq 550 \\ 0.02 \;\; if \;\; 550 < S_t \leq 800 \\ 0.03 \;\; if \;\; 800 < S_t \leq 900 \\ 0.04 \;\; if \;\; S_t > 900 \end{cases} \quad \text{and} \quad b = \begin{cases} 0 \;\; if \; S_t \leq 550 \\ 0.01 \;\; if \;\; \Delta\tilde{I}_{J-M} < 300 \\ 0.02 \;\; if \;\; 300 < \Delta\tilde{I}_{J-M} \leq 600 \\ 0.03 \;\; if \;\; \Delta\tilde{I}_{J-M} > 600 \end{cases}$$

In the following figure, the values of this coefficient H are shown.

Figure 8. Suggested values of the coefficient H



Source: Own elaboration.

The values of the parameters a and b have been chosen by the authors in order to obtain some numerical results. In the model simulations, $H(.)$ could be redefined, considering different versions of this option contract. Some will be more restrictive in the proportion of the water inflows that the buyer could purchase depending on the level of stock and the total inflows in the reservoir. Different types of this scheme could be proposed and analysed simply by changing these proportions. Higher proportions would benefit the recipient of the transferred volumes, but would reduce storage levels and could be harmful for the environment in critical areas of the Tagus River.

To assess the impact of the option contract on irrigators' water supply risk in the Segura Basin, we have formulated a model of Monte-Carlo simulations. The results show how the level of risk faced by Segura water users will change with a modification of the transfer management rule and with the different market scenarios. In parallel, we have also evaluated the resulting probability distribution function of the water stock available for meeting the Tagus' environmental needs.

4.3.2. Resulting water availability in the Tagus Basin

Stored volumes in E-B are released to ensure that water demands and environmental flows in the middle Tagus are met. The remaining stock in the E-B reservoirs, after delivering the statutorily defined volumes by the Transfer's management rule function ($f(.)$ or $g(.)$) to the Segura Basin, is also a determinant factor of the current and proposed schemes. The following expression could help us understand the effect of each scenario on the stock level in the reservoir and therefore, the water volume that would determine the water flow in the middle Tagus.

$$\tilde{S}_e = \tilde{S}_t + \Delta\tilde{I}_{J-D} - \tilde{V}_x - \tilde{U}_t - M \quad (10)$$

$\tilde{S}_e$ is the stock in the reservoir on December 31st; $\tilde{S}_t$ is the stock at the beginning of the year[17]; $\Delta\tilde{I}_{J-D}$ represents the total water inflows during the year[18]; V_{tx} is the transferred volume for irrigators in the Segura Basin for each case (subscript x could be (a) referring to the case 'no market'; (b) 'with spot water purchases' and (c) 'with the option contract'); $\widetilde{U}_t$ is the annual transferred

[17] $\tilde{S}_t$: Discrete function fitted using historical data (1991-2010).

[18] $\Delta\,\tilde{I}_{J-D}$: Follows an Inverse Gauss pdf (p value: 0.6444). Distribution function fitted using historical data (1991-2010)

volume to urban suppliers in the Segura Basin (based on the management rule)[19]; and M is the minimum stock level that should always remain in the E-B reservoirs (240 million m^3). The remaining stock ($\tilde{S}_e$) is meant to meet all water demands in the Tagus Basin, including environmental flows. The larger the remaining volume is, the larger the environmental flows that can be granted will be.

4.3.3. Economic valuation

Apart from evaluating the different scenarios between the Tagus and the Segura Basins from the hydrological point of view, it is important to assess the economic impacts that the different scenarios have on each basin. We have estimated the economic value of the transferred/sold water under each considered scenarios and some conclusions regarding the whole Tagus-Segura system have been derived from the analysis.

For the Tagus Basin, the positive and negative economic factors derived from each scenario have been defined (Table 13). The values of these factors have been obtained from the existing literature for different river basins in Spain (MMA, 2000; Elorrieta et al., 2003; Hardy & Garrido, 2010; Garrido et al., 2012b; Calatrava & Martínez-Granados, 2012).

The Tagus Basin is going to receive the transfer fees (net of transportation costs) paid by irrigators in the Segura Basin for the transferred water under the Transfer management rule for all the considered scenarios. For transferring or selling water to irrigators in the Segura Basin, the Tagus Basin would incur in several opportunity costs related to that transferred (or sold) water volume that should be included in the analysis: energy costs (the water volume could have been used to produce hydroelectric power), environmental costs (the water volume could have been used for environmental purposes in

[19] $\tilde{U}_t$: Follows an extreme value pdf (p value: 0.7358). Distribution function fitted using historical data (1987-2010).

the Tagus Basin), and economic costs (when the sold water comes from the water allotment of irrigators in the Tagus Basin, this volume could have been used for irrigation in the basin). This last cost, which results from a reduction of agricultural production in the Tagus Basin, has an associated multiplier effect that should be also taken into account. It is important to highlight that only those transferred water volumes that come from an irrigation district water allotment (as it is the case of the spot purchases and the first tranche of the option contract) result in an economic loss for the Tagus Basin, as this transferred water would have been used for irrigation in the area-of-origin of the water.

Table 13. Positive and negative factors affecting the Tagus Basin for each scenario

Scenario	Positive factor	Negative factor
1. Current transfer rule (no market)	• Transfer fees	• Opportunity costs (hydropower) • Opportunity costs (environment)
2. New transfer rule (no market)	• Transfer fees	• Opportunity costs (hydropower) • Opportunity costs (environment)
3. New transfer rule (spot market in dry periods)	• Transfer fees • Spot price	• Opportunity costs (hydropower) • Opportunity costs (environment) • Opportunity costs (economic) • Multiplier effect
4. New transfer rule (option contract)	• Transfer fees • Option premium • Exercised price	• Opportunity costs (hydropower) • Opportunity costs (environment) • Opportunity costs (economic) • Multiplier effect

Source: Own elaboration.

In the recipient area, the transferred water volume would allow Segura's farmers to secure their activity and maintain their agricultural production, having a positive impact on this basin, including a multiplier effect on its economy. But for receiving this water, they have to pay the agreed price for each water source.

For the Tagus Basin, the economic opportunity cost for each scenario has been calculated using water value curves obtained from a non-linear mathematical programming model, developed by Calatrava for the Tagus Basin River Authority (Calatrava, 2007), that simulates the economic use of irrigation water in the Tagus Basin. The economic value that the received water volume from the Tagus Basin has in the Segura Basin under the different scenarios is computed using a non-linear mathematical programming model that simulates the economic use of water in the irrigated agriculture of the Segura Basin. For detailed descriptions of the model used see Martínez-Granados et al. (2011) and Calatrava & Martínez-Granados (2012).

For each scenario, the net benefit derived from the transferred water volumes in the whole Tagus-Segura system is obtained, taking into account all the above mentioned positive and negative factors in each basin.

$$NB(\tilde{V}_i) = B(\tilde{V}_i) - C(\tilde{V}_i) \tag{11}$$

being B the benefits derived from the transferred volume, C the total costs, $\tilde{V}_i$ is the transferred/sold water volume from the Tagus Basin to irrigators in the Segura Basin under the scenario i. Obviously, a transfer of water to another basin has a negative impact on the area-of-origin of the water. However, if the positive impact of this water transfer on the recipient area is higher than that negative impact, the overall welfare will be improved.

4.4. Data sources

For the analysis of irrigators' water availability in the Segura Basin (taking into account only water resources from the Tagus Basin), the following data have been collected: monthly water inflows and stored volumes in E-B reservoirs (1958-2011, in million m^3), monthly transferred volume from the Tagus to the Segura Basin (1987-2011) and monthly water consumption from the TST by irrigators and municipalities (2000-2010).

For the economic assessment of the different scenarios in the Tagus Basin, some economic data found in the literature from previous studies for the Iberian Peninsula has been collected (Table 14).

Table 14. Considered values of the economic factors affecting each basin.

Basin	Concept	Value	Source
Tagus	Transfer fees	0.030 €/m³	(Calatrava & Martinez-Granados, 2012)
	Spot price	0.090 €/m³	(Garrido et al., 2012b)
	Option contract fee	0.060 €/m³	--
	Economic multiplier effect	0.315 €/€ of product	(MMA, 2000)
	Environmental opportunity cost	0.0244 €/m³	(Elorrieta et al., 2003)
	Energy opportunity cost	0.0930 €/ m³	(Hardy & Garrido, 2010)
Segura[a]	Transfer fees	0.1250 €/ m³	(Garrido et al., 2012b)
	Spot price	0.2100 €/ m³	(Garrido et al., 2012b)
	Option contract fee	0.2100 €/ m³	--
	Economic multiplier effect	1.206 €/€ of product	(PwC, 2013)

[a] The difference between the price that irrigators in the Segura basin pay for the water that comes from the Tagus Basin and the money that the Tagus Basin receives represents the conveyance costs of the Tagus-Segura Aqueduct

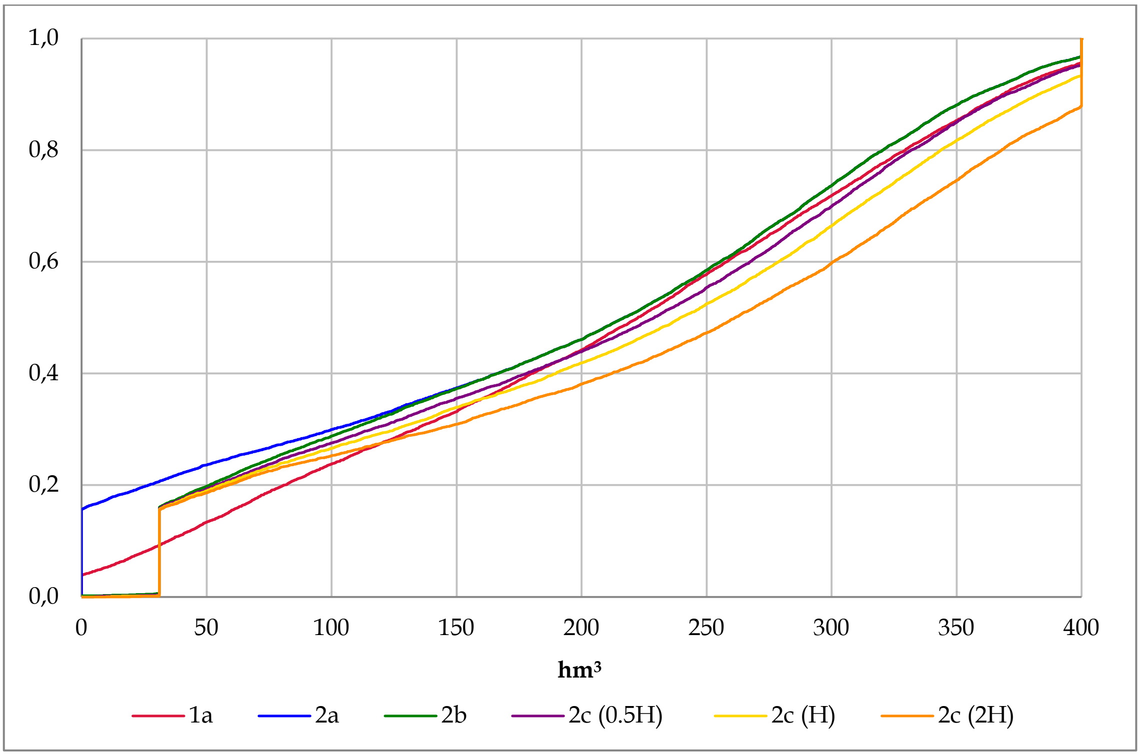
Source: Own elaboration.

4.5. Results and discussion

4.5.1. Comparison of water availability under the different scenarios

If the new TST management rule is implemented ($g(S_t)$, with parameters shown in Eq.5), the assigned water volume for irrigators in the Segura Basin would be reduced, especially when the stock in E-B is low (see Figure 9). The proposed option contract would represent a mechanism for offsetting this negative impact on water availability for irrigators.

Figure 9. Cumulative probability curves representing the water availability (million m^3) for irrigators in the Segura Basin.



1: current management rule; 2: new management rule; a: no market; b: with water purchases; c: with the option contract.

Source: Own elaboration.

Figure 9 shows the reduction in the water supply from the Tagus Basin for irrigators in the Segura Basin if the management rule changes to a more restrictive one (from the red line, 1a; to the blue line, 2a). With the first part of the scheme, which entitles them to 31.05 million m^3 when the stock in E-B is low, this reduction is compensated. With the second part, based on $H(\Delta\tilde{I}_{J-M})$, there are further gains as E-B stock grows. Depending on the proportion of the accumulated inflows that irrigators in the Segura Basin have access to (H, 0.5H, 2H), the impact of the change of the TST management rule would be reduced in a different proportion. The scenario $2H$ would represent an improvement with respect to the water availability under the current rule, increasing the probability of obtaining 400 million m^3 from the Tagus Basin from 4% to 12%. Both H and $2H$ represent an improvement in the mean volume of transferred water to the Segura Basin (Table 15).

Table 15. Percentiles' value of the water availability (million m^3) for the different scenarios

	P1	P5	P10	P25	P50	P65	P75	P95
1a	0.00	7.49	35.12	105.32	222.44	275.67	311.21	393.05
2a	0.00	0.00	0.00	59.90	217.76	273.86	305.63	387.61
2c (0.5H)	31.05*	31.05*	31.05*	83.64	225.59	285.00	316.45	398.54
2c (H)	31.05*	31.05*	31.05*	88.92	237.23	297.31	328.60	400.00
2c (2H)	31.05*	31.05*	31.05*	98.18	259.25	319.95	351.65	400.00

1a: current rule (no market); 2a: new rule (no maket); 2b: new rule (spot purchases); 2c: new rule (option contract).

* These volumes are obtained from the first tranche of the proposed option contract.

Source: Own elaboration.

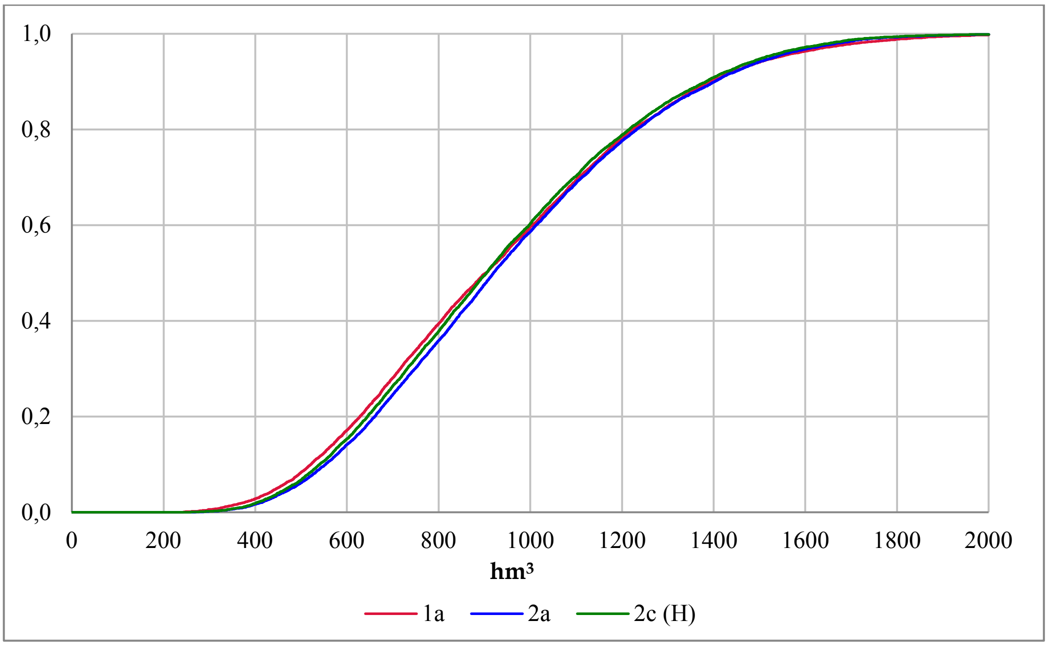
The probability of not receiving any water from the Tagus Basin would be higher under the new management rule, as more stock in E-B is required to transfer a certain amount of water. Therefore, with this new rule, irrigators in the Segura Basin would receive less water when the stock level in E-B is low, allowing for a better and faster recovery of the water stock in the Upper Tagus Basin. In these years, they could have access to the first part of the option contract and obtain a certain water volume from an irrigation district in the Tagus Basin, thereby not causing any extra consumption from the reservoir because the first part is obtained from resources already allocated to irrigators in the Tagus Basin.

When the stock in E-B is low, the irrigators in the Segura Basin would have access to the same water volume (31.05 million m^3) both with water purchases and with the option contract, which is why the values of p5 and p10 are similar for both cases.

4.5.2. Remaining water stock in E-B reservoir

Another important aspect of the proposed contract is its effect on the remaining water stock in E-B, which is shown in Figure 10, and consequently on the environmental flows in the Tagus River. These curves represent the remaining water stock in the reservoir (defined in Eq. 10) after meeting the Segura Basin's demands and subtracting the minimum established water stock that should be stored in the reservoir. With the new management rule, as the transferred water volumes to the Segura Basin would be lower, the available stock in E-B would be higher, allowing the maintenance of higher environmental flows in the middle Tagus. Note, however, that the three cases do not differ significantly.

Figure 10. Cumulative ascending curves of the PDFs of the remaining stock (S_t) in E-B



Current management rule (1a); and under a new management rule with (2c) and without (2a) an option contract

Source: Own elaboration.

Table 16 shows that the remaining stock in dry years (lower percentiles' values) is higher under the new rule with the option contract (even with $2H$) than under the current management rule. For higher percentiles (wet years), the stock differences are very small in relative terms.

Table 16. Percentiles' value of the remaining stock in the E-B reservoir (million m^3) for the different scenarios.

	P1	P5	P10	P25	P50	P65	P75	P95
1a	330.91	448.58	518.56	670.57	900.40	1054.27	1166.84	1534.51
2a	374.33	480.68	554.90	705.33	919.83	1062.20	1166.00	1522.09
2c (0.5H)	372.22	475.02	548.85	696.04	911.32	1054.91	1156.06	1510.97
2c (H)	368.76	469.79	542.27	689.34	901.97	1045.17	1147.57	1501.64
2c (2H)	355.32	458.47	528.86	675.25	884.11	1028.43	1134.77	1487.90

1a: current rule (no market); 2a: new rule (no market); 2b: new rule (spot purchases); 2c: new rule (option contract).

Source: Own elaboration.

This option contract is a means to allow transfer beneficiaries in the Segura Basin to take advantage of a high water level in the reservoir in good years at the expense of reductions in drought conditions caused by the change in the TST management rules. With a new management rule and the option contract, the left tail of the PDF of the stock in E-B is higher (40 million m^3 more in percentile 1%), improving the hydrological status of the reservoir in critical years and allowing the maintenance of environmental flows in those years. However, with the proposed scheme, in years when the stock in E-B is high, the holder could benefit from this situation, having access to a greater water volume.

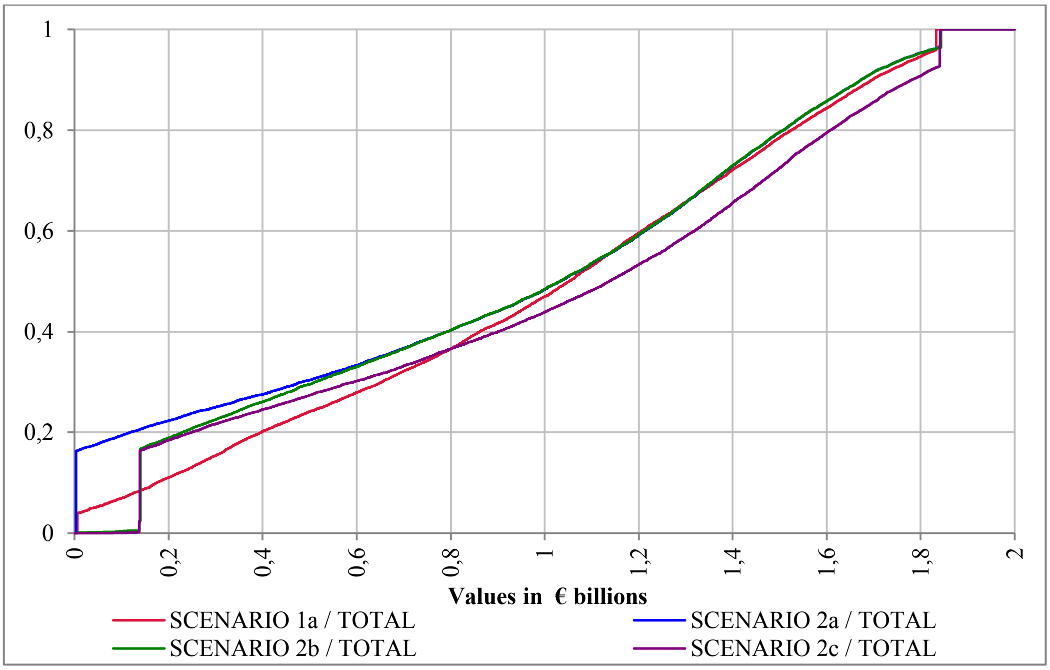
4.5.3. Economic analysis

In addition to presenting the differences in water availability in the Segura Basin and in the remaining stock in the Tagus Basin among the considered scenarios, it is important to address the economic aspects of the proposed option contract.

After identifying potential economic factors of the water transfer affecting each basin under the considered scenarios (see section 4.3.3), the economic value of these impacts has been obtained for the Tagus-Segura whole system.

Taken into account the transferred water volumes to irrigators in the Segura Basin under each considered scenario, the economic value of the water deliveries from the Tagus to the Segura Basin has been obtained (only water for irrigation in the Segura Basin is considered). The following figure shows the PDFs of the economic value (in billion €) for the whole system (considering both basins).

Figure 11. Cumulative ascending curves of PDFs of the net benefit derived from the Tagus-Segura water transfers



1a: current rule (no market); 2a: new rule (no market); 2b: new rule (spot purchases); 2c: new rule (option contract).

Source: Own elaboration.

As shown in Figure 11, the Tagus-Segura Transfer has a very important net economic benefit. This is mainly due to high-productive agriculture of the recipient area (Segura Basin). A change in the transfer management rules will lead to a negative impact in this Tagus-Segura system, which has been estimated on average at nearly 75 € million. Both the spot purchases scenario and the option contract scenario reduce this negative impact. Moreover, results clearly show that the proposed option contract would be more beneficial for the Tagus-Segura system than a spot water market such as the currently existing one (see Table 17).

Comparing the spot purchases scenario and the option contract scenario, results clearly show that the proposed option contract would be more beneficial for the Tagus-Segura system than a spot water market such as the currently existing one (see Table 17).

Table 17. Percentiles' value of the net benefit derived from the transferred water volume (€ million).

	P1	P5	P10	P25	P50	P65	P75	P95
1a	6.00	47.41	179.40	531.54	1053.17	1290.89	1445.31	1799.61
2a	3.00	3.00	3.00	299.74	1034.21	1290.57	1431.19	1787.81
2b	138.27	140.15	140.15	365.43	1033.09	1289.28	1430.26	1788.72
2c	137.12	139.01	139.01	413.92	1138.91	1395.76	1533.26	1840.85

1a: current rule (no market); 2a: new rule (no market); 2b: new rule (spot purchases); 2c: new rule (option contract).

Source: Own elaboration.

For P50 and higher percentiles, the net benefit values derived from the option contract under the new management rule are the highest in comparison with the rest of the considered scenarios.

4.6. Conclusions

Water users in Mediterranean regions suffer considerable water supply risks. The Spanish Tagus-Segura Transfer has alleviated water scarcity in the Segura Basin, but its water deliveries have economic and environmental effects in both the recipient basin and the area-of-origin. It operates under a management rule that depends on stochastic hydrological variables, but also under some political discretionary rule.

Either because of the need to increase the minimum environmental flows in the Middle Tagus or because of reduced run-off caused by climate change, or both, a redefinition of the management rules governing the Tagus-Segura, the largest water transfer operating in Spain, is going to be implemented. A change in the TST management rule, such as the one simulated in this chapter, would imply a reduction in the transferable volumes, especially in dry periods.

However, a water option contract similar to the one proposed here would reduce the negative impacts of a change in the management rule on both the water availability and the risk exposure of the transfer's beneficiaries. When the stock level in E-B is high, the scheme would allow irrigators in the Segura Basin to benefit from this situation, having access to even more water than with the current rule.

Under the new transfer management rule, in those years when the transferred volume to the Segura Basin is very low, users in the Segura could rely on the first tranche of the option contract and on other more costly but also more secure water sources, such as desalination. In fact, a serious breakdown in one section of the Tagus-Segura Transfer tunnel in July 2012, which interrupted the service for several months, has been partially made up by desalination plants.

A change in the management rule would increase the currently low environmental flows in the Tagus Basin and meet the increasing demands of local and regional representatives and environmental groups. With the proposed option contract both objectives could be met, striking a more balanced equilibrium between environmental and irrigators' interests. Parameters in function $H(.)$, that determine the proportion of the water inflows that the buyer has access to, should be carefully chosen in order to meet these goals. They should allow the beneficiaries to obtain more water when the stock in E-B is high and the rest of uses (including the environmental ones) are fully met. In this paper, we have modelled three different levels somewhat arbitrarily set to meet the general option contract requirement: acceptability by both sellers and buyers and by the Tagus Basin's stakeholders.

According to a recent report by PricewaterhouseCoopers (2013), a 10% reduction in the released water volume to the Segura Basin could cause an impact on the Segura's agricultural production of 1% in the short term, and 4% in the long term. The Tagus-Segura Transfer has an enormous importance for the economy in the recipient area, one of the most agricultural productive regions in Spain. As our results show, a change in the transfer management rule would have considerable consequences for the Tagus-Segura system, causing an important impact on the benefits derived from this water transfer. This economic information should be taken into account when deciding the future of the most important water transfer in the Iberian Peninsula.

As urban uses have priority over irrigation, the risk that urban suppliers in the Segura Basin have to face is smaller. However, as they also depend on the resources from the Tagus Basin, they are affected when the transferred water is not sufficient to cover the cities' demands. Therefore, a water option contract similar to the one proposed here could be useful for them.

Traditionally, spot markets have been the used mechanisms for water exchanges between users in the Tagus (sellers) and in the Segura (buyers) basins. The restriction of inter-basin trading activity only in times of drought did not encourage the development of more stable and sophisticated trading mechanisms. Under the new legislation, in which the inter-basin market is allowed in all circumstances, option contracts could provide stability to both parties.

5. COMPARISON OF DIFFERENT WATER SUPPLY RISK MANAGEMENT TOOLS FOR IRRIGATORS: OPTION CONTRACTS AND INSURANCE

Abstract

Irrigators must cope with the risk of not having enough water to meet crops' demands. There are different tools to manage this risk, including water markets and insurance. Given the choice, a farmer will use any of them when the expected utility change derived from the tool is positive. This chapter presents a theoretical assessment of a farmer's expected utility for two different water option contracts and a drought insurance policy. The conditions that determine farmer's preference for these instruments are analyzed and a numerical application to a water-stressed Spanish region is performed. Results show that farmer's willingness to pay for the considered risk management tools are greater than the preliminarily estimated costs of the instruments. This suggests that option contracts and insurance may help farmers manage water supply availability risks.

5.1. Introduction

Irrigators face the risk of not having enough water to meet crops' demands. There are a number of strategies to cope with this risk. Farmers can apply on-farm strategies to reduce vulnerability, share the risk with an external agent (Cummins & Thompson, 2002; FAO, 2003; Hardaker et al., 2004; Sivakumar & Motha, 2007; Garrido & Gómez-Ramos, 2009b), or find combination of internal and external instruments. Among all the existing tools that could help irrigators manage this risk, this chapter focuses on water supply option contracts and drought insurance.

The possibility of trading water rights may lead to a reduction in the water availability risk faced by farmers (Calatrava & Garrido, 2005a, 2005b; Bjornlund, 2006; Lefebvre, 2011). Option contracts are one type of derivative contract that gives the holder the right (not the obligation) to buy or sell the underlying asset (Williamson et al., 2008; Cui & Schreider, 2009; Cheng et al., 2011). Water option contracts help the option holder to protect himself from the risk of not having enough water for his activity (irrigating in the case of farmers).

Insurance provides compensation for losses that occur with relatively low frequency and whose probability and actual damage can be evaluated (Garrido et al., 2012c). Index insurance has been proposed to deal with water scarcity in several contexts, including Mexico (Zeuli & Skeest, 2005; Leiva & Skees, 2008) and New South Wales (Australia) (Brown & Carriquiry, 2007). In this chapter, the proposed insurance will provide a monetary compensation when the volume of irrigation water to which a farmer is entitled is reduced and falls short to meet the crops' average water demand. Unlike option contracts, an insurance policy transfers the water supply risk outside the water and agricultural markets.

While both instruments (water option contracts and drought insurance) aim at protecting irrigators from water supply availability risks, they have different features and prerequisites. Among the available alternatives, farmers will choose the risk management tools that are perceived to improve their utility. The literature on agricultural water supply risks has not theoretically analyzed different mechanisms and compared them to one another. This is one of the main objectives of this work.

I develop a theoretical framework to evaluate farmers' willingness to pay (WTP) for different water supply risk management instruments, and to obtain agents' hypothetical ordered preferences for them. Using the expected utility theory approach, drought insurance and option contracts are compared to draw some conclusions about the designing parameters that may make one mechanism more attractive than the other. Three different situations are considered: no water supply risk management tool, a water option contract (two different types), and a drought insurance; and provide preliminary evaluations of the instruments' costs and farmers' potential willingness to pay for them.

Both drought insurance and option contracts are being considered or have been actually designed and structured, though not yet used in Spain. The developed theoretical framework is applied to an irrigation district in Southeast Spain to obtain some numerical results that show farmer's potential WTP for the proposed instruments. These results are compared to others obtained in previous works on different water supply risk management tools also applied to Spain (Tobarra, 2008; Rigby et al., 2010; Mesa-Jurado et al., 2012; Pérez-Blanco & Gómez 2012, 2013).

The chapter is organized as follows: section 5.2 presents the theoretical framework, where the farmer's expected utility, the risk premium and the cost of each instrument are calculated; section 5.3 includes an analysis of the farmers' preferences for the proposed instruments; section 5.4 presents the application of the theoretical model to irrigators in one of the most arid and most efficient agricultural areas in Spain; in section 5.5 a discussion of the obtained results is provided; and finally, in section 5.6 some conclusions from this analysis are presented, highlighting the importance of these risk management tools for agriculture. Most of the mathematical derivations are presented in Appendix 1 at the end of the document with the aim of facilitating the reading of this chapter.

5.2. Theoretical framework

According to the Expected Utility Theory a decision maker chooses between risky or uncertain prospects by comparing their expected utility values

(Mongin, 1997). Between different alternatives, an agent will choose the one with higher expected utility.

We assume that the Expected Utility (EU) of a farmer depends on his uncertain profit ($\tilde{\pi}$). As an irrigator, his profit is going to be a function of his seasonal water availability ($\tilde{w}$), which follows a probability distribution function, $f(w)$.

$$EU(\tilde{\pi}) = \int U(\pi(w))f(w)dw \quad (1)$$

A farmer would choose to use one instrument, i, if his expected utility is higher than the one without this instrument ($EU_0(\tilde{\pi})$):

$$EU_i(\tilde{\pi}) - EU_0(\tilde{\pi}) > 0 \quad (2)$$

Even acknowledging that the expected utility framework has been consistently discredited by empirical work (Kahneman & Tversky, 1979; Just & Peterson, 2010), it still provides a valid approach for discriminating among risk management instruments whose outcomes are not extremely different both in their second and third moments, such as the ones considered in this chapter.

Some assumptions are made to ease the mathematical complexity of the theoretical analysis and to facilitate the comparison between the considered risk management tools. First, although several studies have shown that farmers mainly exhibit Decreasing Absolute Risk Aversion (DARA) (Hardaker, 2000; Gómez-Limón et al., 2002; OECD, 2009), we assume a Constant Absolute Risk Aversion (CARA), in particular an exponential utility function ($U(\pi) = 1 - e^{-r\pi}$). Assuming a DARA utility function, such as the Logarithmic or the Power function, leads to integrals that have no analytical solution for the most common asymmetric probability density functions suitable to model $f(w)$ (Gamma, Lognormal, Beta, Weibull), except for the Exponential function. However, this last function has very rigid properties (mean, variance, kurtosis) that are not adequate for this analysis. For the purpose of comparing different risk management instruments, we ponder the analytical convenience of using a

CARA utility function, taking into account that the range of outcomes of $\tilde{\pi}$ considered is not very wide (see Calatrava & Garrido, 2005b; Garrido, 2007), and that farmers' wealth (land and capital values) is invariant to the choice of instrument. Several authors have used the same assumption before (Cerdá & Quiroga, 2008; Garrido & Zilberman, 2008; Quiroga et al., 2011). In the numerical section of the paper we performed a comparison of results obtained with DARA and CARA.

Second, we assume a linear restricted profit function (dependent on $\widetilde{w}$). This assumption is acceptable in cases where water is used in Leontief production functions, each activity has fixed proportion of inputs, and farmers in the short run change activities (crops) instead of searching for new production methods. Actually, that is the case in many irrigated areas, where water rather than irrigable land is the limiting input, water applications to crops are finely controlled, and changes of water availability result in changes in crop patterns and irrigated area instead of changes in water applications.

Lastly, we shall assume that farmer's water availability follows a gamma distribution function. This function has a simple Moment Generating Function[20] (MGF) that facilitates calculation and together with the previous assumptions provides a convenient analytical approach (Collender & Zilberman, 1985; Garrido & Zilberman, 2008). The gamma is bounded on the left, but unbounded on the right. We assume a truncation on the right tail (at $\overline{w}$), leaving out this tail of the distribution for representing unlimited and unneeded water availability levels.

Based on these assumptions and applying the expected utility theory, we have obtained the mathematical expressions of farmers' expected utility and risk premium for the different cases.

[20] A MGF of a random variable is a specification of its probability distribution, which gives us a convenient way of collecting together all the moments of a random variable into a single power series.

5.2.1. Expected utility function without a water supply risk management tool

In this case, farmer's total water availability would be his water allotment ($\tilde{w}$). A very simplified farmer's linear restricted profit function is used ($\tilde{\pi}_0(w)$). We are not taking into account the costs associated with the farming activity neither the income[21].

$$\tilde{\pi}_0(w) = a + b\tilde{w} \tag{3}$$

where a is the net benefit of agriculture, independent of water availability; b is the marginal value or marginal profit of water (net of price)[22]. The CARA exponential utility function for this case is:

$$U(\tilde{\pi}_0) = 1 - e^{-r\tilde{\pi}_0} = 1 - e^{-r(a+b\tilde{w})} \tag{4}$$

r is farmer's absolute risk aversion coefficient. The farmer's expected utility can be expressed as (see Appendix 1, section A for the entire calculation):

$$EU_0(\tilde{\pi}) = \int_0^{\overline{w}} U(\tilde{\pi})f(w)dw = \int_0^{\overline{w}} \left[1 - e^{-r(a+bw)}\right] f(w)dw = 1 - e^{-ra} MGF_w(-rb) \tag{5}$$

$\overline{w}$ is the maximum water availability for the farmer, being zero the minimum. $MGF_w(-rb)$ is the Moment Generating Function of the variable $\tilde{w}$ of order $(-rb)$. As explained before, we assume that variable $\tilde{w}$ follows a gamma distribution, which has a considerably simple MGF:

$$MGF_w(-rb) = \left(1 + \frac{rb}{\lambda}\right)^{-\alpha} \tag{6}$$

λ and α are parameters of the Gamma function; with mean α/λ and variance α/λ^2. From equation (5) it is clear that $MGF_w(-rb)$ is the disutility resulting from

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[21] Our assessment only takes into account the changes in the farmer's expected utility caused by different water availability (due to an option contract or an insurance).

[22] $b = c - P_w$; c is the marginal profit of water use and P_w the water tariff.

unstable profit ($\tilde{\pi}$). It decreases with the marginal productivity of water ($\frac{\partial MGF_w(-rb)}{\partial b} < 0$) and increases with water supply variance keeping average water supply constant ($\frac{\partial MGF_w(-rb)}{\partial \sigma_w^2})\Big|_{w^e} > 0$).

5.2.2. Expected utility function with a water supply risk management tool

In this work, three different water supply risk management tools for irrigators are considered (two different option contracts and drought insurance). To ease the presentation, only the theoretical model for an option contract is presented in detail. Based on this mathematical calculation, the risk premium for the other two considered tools is briefly presented. In Appendix 1 (sections B through E), the entire mathematical analyses for these instruments are presented.

5.2.2.1. Option contract (a)

This option contract allows the farmer (option holder), when his yearly water allotment ($\tilde{w}$) is below a given threshold or guaranteed level (w_g) and when an external condition (trigger) is also met, to exercise the option and obtain the remaining water volume to reach the guaranteed level ($w_g - \tilde{w}$), paying the exercise price to the seller.

A farmer that decides to sign an option contract has to pay a premium (P) to the seller for having the right to purchase the optioned water volume at the maturity date if needed. The premium represents the value of the flexibility gained by the buyer from postponing the decision to purchase water (Hansen et al., 2006); and it must compensate the seller for giving away a part of his water allotment.

The farmer would only be able to exercise the option and acquire the optioned volume when two different trigger conditions are met: his water availability is lower than w_g and the water stock (S) in the reservoir which stores the seller's water allotment is higher than a pre-established limit k[23]. As both conditions are related to water availability, we assume they are stochastically dependent. Thus, the probability of exercising the option can be modeled as a joint probability distribution. For the rest of the chapter, this probability is going to be denoted by Z. When one of these two conditions is not met, the option contract cannot be exercised ($prob = 1 - Z$).

The farmer's profit function in this case depends on whether the conditions related to the option contract are met:

$$\tilde{\pi}_{opt_a}(w) = a + b\tilde{w} - P_{opt_a} \qquad if \quad \tilde{w} \geq w_g$$

$$\tilde{\pi}_{opt_a}(w) = \tilde{\varphi}\left(a + b\mathrm{w}_g - P_{opt_a} - P_e\left(w_g - \tilde{w}\right)\right) + (1 - \tilde{\varphi})\left(a + b\tilde{w} - P_{opt_a}\right) \qquad if \quad \tilde{w} < w_g \tag{7}$$

P_{opt_a} is the option premium. φ is a binomial variable (0,1), with a probability Z of being 1, so the option is exercised. P_e is the exercise price or strike price[24].

The farmer's expected utility function with this option contract is (see Appendix 1, section B.1):

$$EU_{opt_a}(\tilde{\pi}) = 1 - e^{-r(a - P_{opt_a})}MGF_w(-rb) - Ze^{-r(a + bw_g - P_{opt_a} - P_e w_g)}LIMGF_w(-rP_e)$$
$$+ Ze^{-r(a - P_{opt_a})}LIMGF_w(-rb) \tag{8}$$

[23] This is the case of farmers relying on inter-basin transfers where, because of area-of-origin preferences, no volume is transferred unless minimum water volumes are stored in the region where the transfer is derived from. Any other condition can be established as a trigger for the option contract instead of the proposed one.

[24] A farmer exercising the water supply option contract will pay P_w plus P_e for the optioned volume. P_e is defined as a price additionally paid, besides the price paid for the normal source of water supply (P_w). If the exercise price agreed in the option contract were lower that the price paid for the normal source of water supply, P_e would then be negative. This situation is not very common, but it can occur when the contract is established between water users who have very different water productivities. In order to simplify the presentation of this approach, only positive P_e values are considered in the analysis, unless stated otherwise. In section 5.5, an example of an inter-basin exchange with a lower exercise price than P_w that took place in the Spanish water market is presented.

where LIMGF is the Lower Incomplete Moment Generating Function[25] of $\tilde{w}$.

The maximum premium value that makes the contract attractive for the farmer (i.e., the risk premium, R_{opt_a}) results from making equal farmer's expected utility with and without the option contract (see Appendix 1, section B.2 for the entire mathematical derivation).

$$EU_0(\tilde{\pi}) = EU_{opt_a}(\tilde{\pi})$$

$$R_{opt_a} = \frac{1}{r}\, ln\left(\frac{MGF_w(-rb)}{(1-Z)MGF_w(-rb)+\mathrm{Z}\left[e^{-r(b-P_e)w_g}LIMGF_w(-rP_e)+UIMGF_w(-rb)\right]}\right) \quad (9)$$

UIMGF is the Upper Incomplete Moment Generating Function of order $(-rb)$ (see footnote 6). The risk premium depends on several parameters, including farmer's absolute risk aversion coefficient (r), the marginal water value (b), the exercise price (P_e), the guaranteed water volume (w_g), and the parameters of the gamma function that represents farmer's water availability (α and λ). Changes in these parameters have a quite complex impact on the risk premium value. In section 5.4, the application of the theoretical model to a real case will illustrate the relationship between the value of the risk premium and some of these parameters.

Expression (9) is best interpreted inspecting the bracketed term within the logarithm. If the bracketed term is greater than 1, then $R_{opt_a} > 0$; and this holds if $e^{-r(b-P_e)w_g}LIMGF_w(-rP_e) < LIMGF_w(-r\mathrm{b})$, which holds if $b > P_e$. The intuition is as follows: if the disutility of the left tail of the distribution covered by the option (for $w < w_g$) – which is captured by $LIMGF_w(-rP_e)$ – is lower than

[25] $\mathrm{MGF_w(-rb) = UIMGF_w(-rb) + LIMGF_w(-rb)}$

The UIMGF and the LIMGF are calculated in the same way, the only thing that changes is the value of the integral's limits (In appendix 1, section C, the expression of $\mathrm{UIMGF_w(-rb)}$ is obtained).

$$\mathrm{LIMGF_w(-rb) = MGF_w(-rb)\left[-Q\left(\alpha, (\lambda + rb)w_g\right) + 1\right]}$$

$\mathrm{Q}\,(.)$ is a regularized gamma function.

the disutility of water supply risk (for $w < w_g$) without the option ($LIMGF_w(-r\text{b})$), then there will be a positive willingness to pay for the instrument ($R_{opt_a} > 0$).

Apart from this option contract, two other risk management tools are assessed in this work for different exercise conditions: an option contract (b) with Z=1; and a drought insurance policy.

5.2.2.2. *Option contract (b)*

Option contract (b) allows the holder to exercise the option whenever his water allotment is below a pre-established guaranteed level (w_g). The difference with option contract (a) is that in this case there is no additional trigger ($Z = 1$) (additional condition for exercising the option). Thus, under option contract (b), the option holder is going to have, at least, a water volume equivalent to w_g every season, paying the exercise price (P_e) to the seller.

The mathematical expression of the risk premium (R_{opt_a}) for this instrument is (see Appendix 1, section D):

$$R_{opt_b} = \frac{1}{r} \, ln\left(\frac{MGF_w(-rb)}{e^{-r(b-P_e)w_g} LIMGF_w(-rP_e) + UIMGF_w(-rb)}\right) \tag{10}$$

The risk premium for the option contract (b) is greater than that of option contract (a). The interpretation of equation (10) is simpler than that of equation (9), because there is no risk associated with the execution of the contract. Therefore, $R_{opt_b} > 0$ holds if and only if $b > P_e$ and $LIMGF_w(-rP_e) < LIMGF_w(-r\text{b})$, i.e. if the disutility of paying the premium is lower than the disutility of not having the optioned water volume available.

While contract (b) is just a particular case of the contract (a), with Z=1, it is more directly comparable to the insurance policy, because both guarantee some compensation (either in water volume or in revenue) in case of shortage. Also, contract (b) is easier to evaluate in economic costs.

5.2.2.3. *Insurance*

The proposed insurance contract would have similar risk reduction effects as option contract (b). It offers a financial compensation for the lost profit if the received water volume by the farmer is below the guaranteed volume ($w < w_g$).

Applying the same methodology as the two previous cases, the risk premium is (see Appendix 1, section E):

$$R_{ins} = \frac{1}{r}\, ln\left(\frac{MGF_w(-rb)}{\gamma e^{-rbw_g} + UIMGF_w(-rb)}\right) \tag{11}$$

γ is the probability of the farmer's water availability ($\tilde{w}$) being lower than w_g; i.e., the probability of receiving the insurance indemnity.

5.2.3. Analysis of the supply side of the instruments

It is important to make a distinction between the risk premium (R) and the premium actually paid by the farmer. The risk premium represents the farmer's willingness to pay for using a given instrument. The premium actually paid is the amount of money that the farmer pays to the seller/insurance company to have access to the optioned water volume/indemnity if needed. Obviously, the farmer is not going to pay a premium higher than his WTP for contracting the option/insurance.

As important as analyzing farmer's WTP for different water supply management tools, it is the evaluation of the supply side of these instruments. The market price is going to determine the final decision to purchase one instrument or the other. Each risk management tool (insurance and option contract) has its own pricing mechanism.

For an insurance policy, the basic premium is equivalent to the expected indemnity. Different costs (administrative costs, re-insurance costs, …) are added to this basic premium to obtain the final value of the premium that the farmer should pay to purchase the insurance policy. Thus, the commercial premium is:

$$P_{ins} = E[max(b(w_g - \widetilde{w}), 0)] \times (1 + C) \tag{12}$$

P_{ins} is the pure premium; $E[max(b(w_g - \widetilde{w}), 0)]$ is the expected compensation and C represents all the associated costs.

For option contracts, the Black-Scholes-Merton model (Black & Scholes, 1973; Merton, 1973) is commonly used. The model is defined as follows:

$$P_{opt} = S_0 N(d_1) - X e^{-rT} N(d_2) \tag{13}$$

with

$$d_1 = \frac{\ln\left(\frac{S_0}{X}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \tag{14}$$

$$d_2 = d_1 - \sigma\sqrt{T} \tag{15}$$

P_{opt} is the value of the option (contract premium); S_0 is the spot price for water; N is the cumulative distribution function of a normal function; X is the exercise price of the option ($P_e + P_w$ in our case); r is the interest rate (in %); T is the time to maturity date in years; σ is the volatility (in %) of the underlying asset (water). The option contract premium plus the exercise price represents the total price of the option.

5.3. Comparison between instruments

In the following sections we compare the risk premium of option contracts (a) and (b), with the insurance policy.

5.3.1. Comparison between option contract (b) and insurance

The risk premium for both cases (R_{opt_b} and R_{ins}) has been obtained in the previous section (equations (10) and (11)), and they differ only on the denominator of the logarithm. In order to compare the risk premium value for these cases, we compare the value of their denominators. Insurance is preferred to option contract (b) $(R_{ins} > R_{opt_b})$ if:

$$e^{-r(b-P_e)w_g} LIMGF_w(-rP_e) + UIMGF_w(-rb) > \gamma e^{-rbw_g} + UIMGF_w(-rb)$$

$$LIMGF_w(-rP_e) > \gamma e^{-rP_e w_g} \tag{16}$$

Expression (16) compares the utility of the risk associated to the left tail of the distribution ($w < w_g$) of the option contract with the certainty equivalent of the tail guaranteed by the insurance[26]. Further algebra with (16) allows us to conclude that, if $P_e > 0$, R_{ins} is always going to be greater than R_{opt_b}, and thus the insurance will be preferred to option contract (b).

$$e^{rP_e w_g} LIMGF_w(-rP_e) - \gamma > 0$$

$$e^{rP_e w_g} \int_0^{w_g} e^{-rP_e w} f(w)dw - \int_0^{w_g} f(w)\, dw > 0$$

$$\int_0^{w_g} (e^{-rP_e(w-w_g)} - 1) f(w)dw > 0 \tag{17}$$

As the upper limit of the integral is w_g, w is going to be always smaller than w_g. Thus, $e^{-rP_e(w-w_g)} > 1$; and this expression would be positive for $P_e > 0$.

Both instruments offer similar protection level for farmers. However, in the case of the option contract farmers must also pay an exercise price for getting the optioned volume. That is why the insurance risk premium is higher when the exercise price of the option contract is positive. The farmer would have to pay all the costs of the insurance (the insurance premium) at the beginning of the year. In the case of the option contract, the interaction between buyer and seller takes place in two steps. First, all the contract terms are established: the premium, the exercise price and the optioned volume. Water availability is uncertain at this point, but the farmer has to decide whether to

[26] $LIMGF_w(-rP_e) = \int_0^{w_g} e^{-rP_e w} f(w)dw$. As $P_e = 0$; then $\int_0^{w_g} e^0 f(w)dw = \int_0^{w_g} f(w)\, dw = \gamma$.

sign the option contract and pay the premium to the seller. In the second period, when such uncertainty disappears, the buyer has to decide whether to exercise the option, paying the exercise price for the optioned volume (Tomkins & Weber, 2010).

If the price of the water acquired through the option contract were lower than the usual source of water ($P_e < 0$), then the option contract might be preferred to the insurance policy[27]. This scenario occurred in inter-basin water markets in Spain (see Garrido et al., 2012b), which operated during the 2006-2008 drought years (see section 5.5).

The decision to purchase one instrument or the other would depend on the effect that each tool has on farmer's welfare. If P_{opt_b} and P_{ins} are the premiums paid by the farmer for each instrument, he is going to purchase the one that provides him higher welfare; i.e., the difference between the risk premium and the premium paid is higher[28]. If $R_{opt_b} - P_{opt_b} > R_{ins} - P_{ins}$, the farmer would purchase the option contract.

$$R_{opt_b} = \frac{1}{r}\, ln\left(\frac{N}{D_{opt_b}}\right) \quad \text{and} \quad R_{ins} = \frac{1}{r}\, ln\left(\frac{N}{D_{ins}}\right)$$

$$R_{opt_b} - P_{opt_b} > R_{ins} - P_{ins}$$

$$P_{opt_b} - P_{ins} < \frac{1}{r}\, ln\left(\frac{D_{ins}}{D_{opt_b}}\right) \tag{18}$$

where N is the numerator of the risk premium (which is the same for both the option contract (b) and the insurance); D_{opt_b} is the denominator of the option

[27] Expression (17) can be rewritten as $\int_0^{w_g}(1 - e^{-rP_e(w-w_g)})f(w)dw < 0$.

$\int_0^{w_g}(1 - e^{-rP_e(w-w_g)})f(w)dw$ is the expected utility of $(-P_e(w - w_g))$, i.e., the expected utility of the increase in the cost of water due to obtaining it through the option contract instead of the usual water source. If $P_e < 0$, such expected utility would be positive and thus $R_{ins} < R_{opt_b}$.

[28] Obviously, irrigators will only sign the option contract if their WTP (risk premium, R) is higher than the price that they have to pay for it (P); $R > P$.

contract's risk premium (see Eq. 9); and D_{ins} the denominator of the risk premium of the insurance (see Eq. 10).

Therefore, if $P_{opt_b} < P_{ins} + \frac{1}{r}\, ln\left(\frac{D_{ins}}{D_{opt_b}}\right)$, the farmer would prefer the option contract. The value of the premium paid that makes the farmer indifferent between both alternatives is: $P_{opt_b} = P_{ins} + \frac{1}{r} ln\left(\frac{D_{ins}}{D_{opt_b}}\right)$.

For a risk-averse farmer and $P_e > 0$, D_{opt_b} is greater than D_{ins} (and R_{ins} greater than R_{opt_b}), and therefore $\frac{1}{r}\, ln\left(\frac{D_{ins}}{D_{opt_b}}\right) < 0$. Expression (18) would be:

$$P_{ins} - P_{opt_b} \; > \; -\frac{1}{r}\, ln\left(\frac{D_{ins}}{D_{opt_b}}\right) > 0 \qquad (19)$$

This result implies that the farmer will choose the insurance even if the premium to be paid for it is greater than the one to be paid for the option contract, as long as the former does not overpass the latter in more than $\frac{1}{r}\, ln\left(\frac{D_{ins}}{D_{opt_b}}\right)$.

On the other hand, if $P_e < 0$ (the optioned water is cheaper than the price the farmer pays for his regular water allotment), D_{ins} is greater than D_{opt_b} (and R_{opt_b} greater than R_{ins}), and therefore $\frac{1}{r}\, ln\left(\frac{D_{ins}}{D_{opt_b}}\right) > 0$. Expression (18) would then be:

$$P_{opt_b} - \; P_{ins} \; < \; \frac{1}{r}\, ln\left(\frac{D_{ins}}{D_{opt_b}}\right) > 0 \qquad (20)$$

In this case, the farmer will purchase the option contract as long as this premium does not overpass the premium to be paid for the insurance in more than $\frac{1}{r}\, ln\left(\frac{D_{ins}}{D_{opt_b}}\right)$. Below, we discuss why $P_e < 0$ would hold probably in certain contexts.

5.3.2. Comparison between option contract (a) and insurance

A similar comparison is made between option contract (a) and the insurance. The probability of getting the compensation through the insurance is higher than the probability of getting the optioned volume through this option contract. For risk averse growers, $R_{ins} > R_{opt_a}$ always holds for $P_e > 0$ (proof available for request). If $P_e < 0$, only for very low exercise prices, the WTP for this option contract could be slightly higher than R_{ins} . Similarly to the previous comparison, the farmer will choose the insurance even if P_{ins} is greater than the premium to be paid for this option contract, as long as the former does not exceed the latter in more than $\frac{1}{r}\, ln\left(\frac{D_{ins}}{D_{opt_a}}\right)$.

In sum, when comparing two of these risk management tools (i and j), the decision rule that determines which instrument is going to be purchased by a risk-averse farmer is:

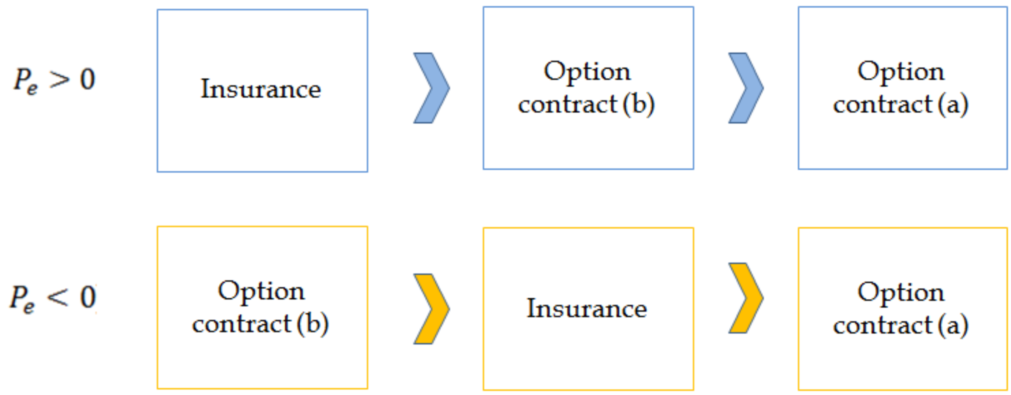
$$P_i \; < \; P_j + \frac{1}{r}\, ln\left(\frac{D_j}{D_i}\right) \;\rightarrow\; i$$

$$P_i \; > \; P_j + \frac{1}{r}\, ln\left(\frac{D_j}{D_i}\right) \;\rightarrow\; j$$

From all the possible pair-wise comparisons of the analyzed instruments[29], we obtain the order of preferences for them, considering a risk-averse farmer, which is shown in Figure 12.

[29] See appendix G, where the remaining comparisons between the proposed tools are shown.

Figure 12. Farmer's ordered preferences for the risk management tools (according to the obtained risk premium for each case)



Source: Own elaboration.

Clearly, the parameters of each instrument will influence the farmer's WTP for a risk management tool, pointing out which factors are more determinant when designing this type of tools[30]. As expected, a higher guarantee level (w_g) will increase the WTP for all the instruments. Higher values of the gamma parameter α, increase the value of the guaranteed volume (which would increase the risk premium), whereas higher values of λ have the opposite effect. A low exercise price in comparison to the price normally paid for the water allotment or for alternative sources can change farmer's preferences for the different risk management tools considered in this study.

5.4. Application to an irrigation district in Spain

Currently, water trading mechanisms help reduce the risk of Spanish farmers of not having enough water to irrigate their crops. Insurance providing coverage against water shortages is still in a developing stage in Spain (Pérez-Blanco & Gómez, 2012, 2013; Ruiz et al., 2014).

[30] A comparative statics analysis has been carried out in order to determine the influence of the main parameters on the value of the risk premium for each instrument. This material can be provided by the authors upon request.

Since 1999, the Spanish National Water Law permits agreements between water users to exchange water rights (temporary or permanent), under several conditions and restrictions (Garrido et al., 2012b). During drought periods, irrigators in less water-endowed areas resort to spot water markets to increase their water availability. However, in these situations it is very difficult to find a water seller and prices may be extremely high because of the dominant position of the seller. Gómez-Ramos and Garrido (2004), Cubillo (2010) and Gómez-Ramos (2013), among others, discuss the advantages of water option contracts over spot water markets for the Spanish case.

Regarding insurance, while the Spanish crop insurance system is one of the most developed worldwide (Antón & Kimura, 2011), insurance covering water shortages is still under development. Several studies show the potential of drought insurance for Spanish agriculture. Quiroga et al. (2011) highlight the importance of reliable drought information to help farmers to avoid the negative impacts of droughts and to develop effective hydrological risk insurance schemes. Pérez-Blanco & Gómez (2012, 2013) focus on the potential of drought insurance to reduce aquifers' overexploitation during water scarcity periods.

Average water productivity for irrigation in Spain vary among regions, ranging from 0.3 to 3.4 €/m^3 (Gil et al., 2009), due to the existence of wide differences in climatic and soil conditions, and water supply costs. The price that irrigators have to pay for water also differs widely, even within the same basin (Garrido & Calatrava, 2009). But, in general, irrigation water price in Spain is considerably low, covering only the operation and management costs and a small share of investment costs. This heterogeneity in water productivity and prices could lead to differences in farmers' preferences for different water supply risk management mechanisms, such as the ones proposed in this chapter. In addition, this heterogeneity favors water exchanges between users with different productivity levels, especially if they are in different basins.

The theoretical framework presented in previous sections is applied to irrigators in the *Campo de Cartagena* irrigation district in the Segura Basin (Southeast Spain). This irrigation district (ID) is the largest in the basin, and one of the largest in the country, with 41,065 hectares. Open-air intensive horticulture is the predominant land use, covering 59% of the total district's irrigable area. The rest of the area is dedicated to citrus crops (30%), greenhouses (7%) and fruit crops (4%).

Farmers in this ID have to deal with high variability and uncertainty of their water supplies. However, the district has developed several adaptive strategies to get water under water supply constraint situations (Martínez-Álvarez et al., 2014). From its total annual water quota (141 hm^3), 122 hm^3 should come from the Tagus Basin through the Tagus-Segura inter-basin Aqueduct; 4.2 hm^3 from the Segura Basin, 2.2 hm^3 from a desalination plant and 13.2 hm^3 from a wastewater treatment plant[31]. However, resources from the Tagus-Segura are dependent on the hydrologic cycles in the area-of-origin, the Upper Tagus Basin, and annual allotments rarely reach the 122 hm^3 quota.

The initial database contains the annual water allotment data for this ID (1979-2012). To use this database, some preliminary modifications were required: first, the two first years of the database were removed, because during those two years the Tagus-Segura Transfer was not working at full capacity; second, the water volumes that come from the desalination plant (since 2001), from the wastewater treatment plant (since 2008) and from the spot market (2007-2010) were removed as well. The reason for doing this is that those volumes were available for the ID only in some years of the period under study. And third, the resulting water allotment data series for this irrigation district was detrended, because runoff in upstream Tagus Basin has clearly gone down (Lorenzo-Lacruz et al., 2010). After these recalculations were made,

[31] http://www.crcc.es/informacion-general/informacion-c-r-c-c/

the water volume that this irrigation district currently receives from the desalination plant (2.2 hm^3) and from the wastewater treatment plant (13.2 hm^3) were added to the annual water volume datum. At the end, we obtain a detrended data series of the annual water allotment of this ID for the period 1981-2012, taking into account all the available water sources that irrigators in this district have currently access to.

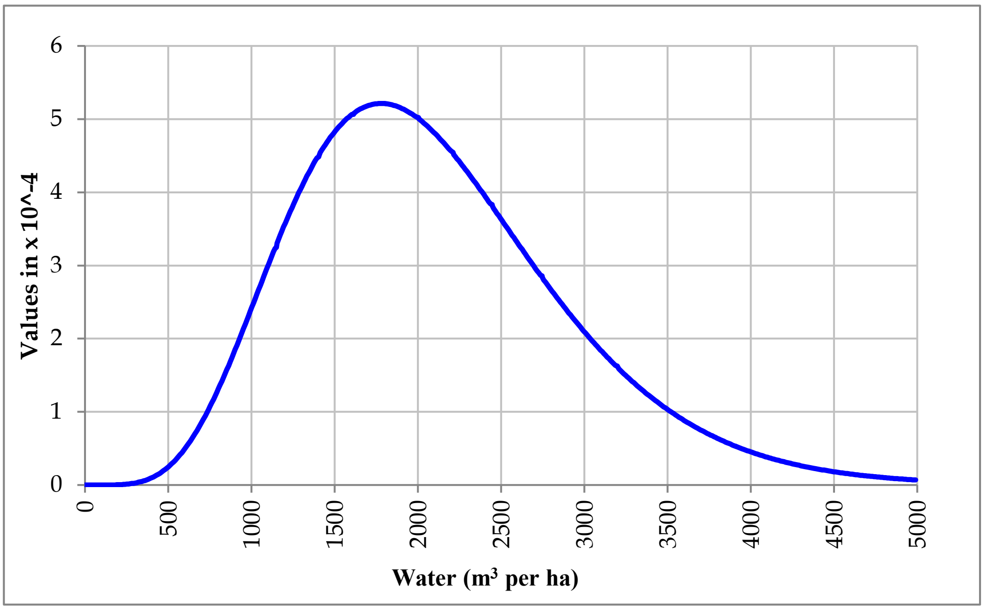
The probability distribution function (PDF) of the annual water allotment for this ID was obtained (a gamma distribution function has been fitted to these data; $Chi^2 = 1.375$; p value = 0.927)[32]. From this PDF, we obtained another PDF representing the mean water allotment per hectare, which is the one used in our analysis (see Figure 13).

5.4.1. Willingness to pay for the different instruments

Knowing the water availability PDF ($\tilde{w}$), and applying the theoretical framework, we obtain the risk premium values for each instrument. By changing the value of different parameters affecting the risk premium, we derive some conclusions about the influence of these parameters on farmer's WTP for these risk management tools.

[32] As the p-value approaches one, we have no basis to reject the hypothesis that the fitted distribution actually generated our data set (Source: @Risk Manual).

Figure 13. PDF of farmer's water availability (m^3) per hectare in the Campo de Cartagena irrigation district[33].

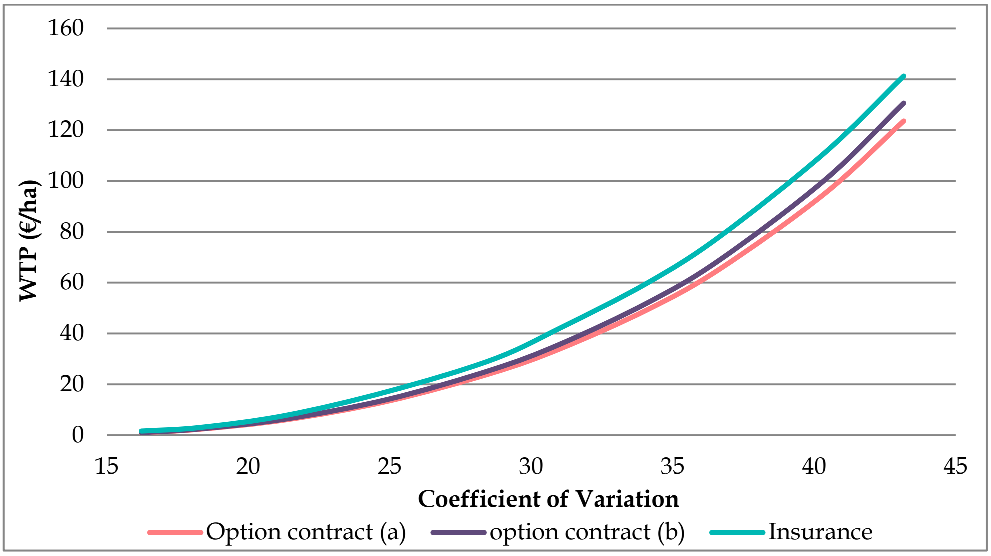


Source: Own elaboration.

The water supply risk faced by a farmer is related to the coefficient of variation (CV) of his water availability. With higher CV values, the farmer's risk of not having enough water for irrigating his crops increases. Figure 14 shows farmer's WTP (expressed in euro per ha) for the studied instruments under different water availability CV values. The WTP is equivalent to the risk premium for each instrument (R_i) obtained in the theoretical models. The maximum WTP for the option contract (a) is €123 per ha, but for the insurance the maximum WTP is close to €142 per ha. The WTP for the insurance can vary in approximately €140 per ha for the considered CV range.

33 The value of the gamma function's coefficients are: α = 6.6292; λ = 0.003146.

Figure 14. Farmers' willingness to pay for each instrument, by water availability variation coefficient values[34].



Source: Own elaboration.

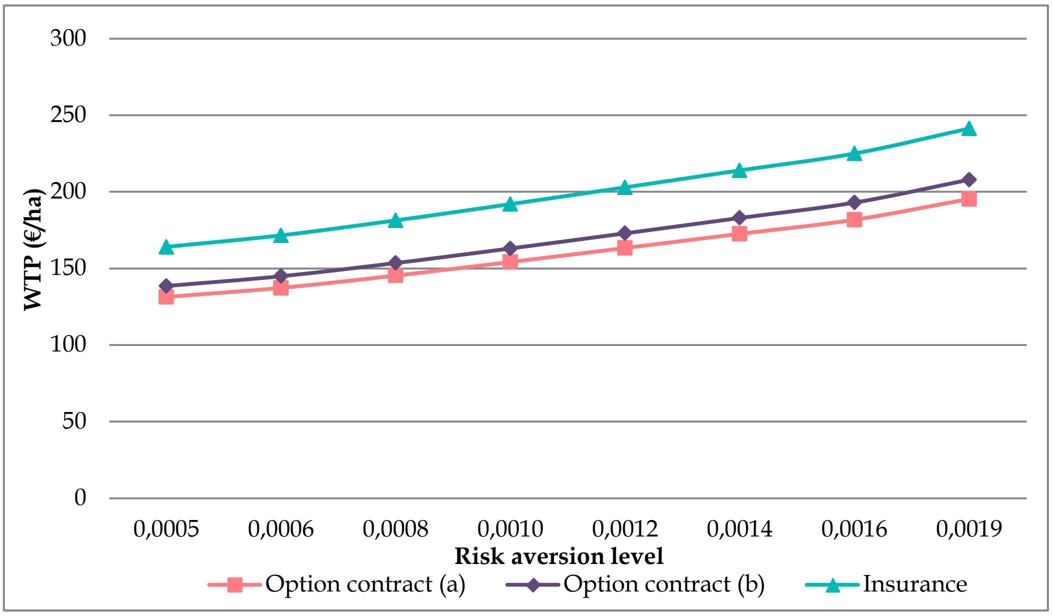
Farmer's risk preference is another factor that is going to affect the farmer's WTP for a given instrument. Figure 15 shows the WTP of farmers for these tools, taking into account different risk aversion levels. The values of the Arrow-Pratt absolute risk aversion coefficient have been obtained taking into account farmer's wealth in the area[35], and the relative risk aversion values normally applied to the agricultural sector. For the case study area, farmer's absolute risk aversion ranks from 0.00046 to 0.00185, being the relative risk aversion 5-20. These high values of relative risk aversion are explained by the definition of the farmer's profit function, which only depends on his water

[34] Parameters' values for this figure: Absolute risk aversion=0.0012; marginal value of water, b = 0.7 €/m^3; parameter affecting the probability of exercise the option (a), Z=0.95; guarantee level, w_g= 1406 m^3 (probability γ =0.2); exercise price, P_e = 0.12 €/m^3. The chosen value for *b* is the average marginal water value in the area according to Calatrava & Martínez-Granados (2012).

[35] Wealth data obtained from the Spanish Farm Accountancy Data Network (RECAN), published by the Spanish Ministry of Agriculture, Food and Environment, MAGRAMA, http://www.magrama.gob.es/es/estadistica/temas/estadisticas-agrarias/economia/red-contable-recan/

availability (a very realistic assumption in the area of study where water is the limiting production factor and rain fed crop production is not profitable). Similar values can be found in the literature (Kandel & Stambaugh, 1991; Gómez-Limón et al., 2003).

Figure 15. Farmers' willingness to pay for these instruments under different risk aversion levels[36]



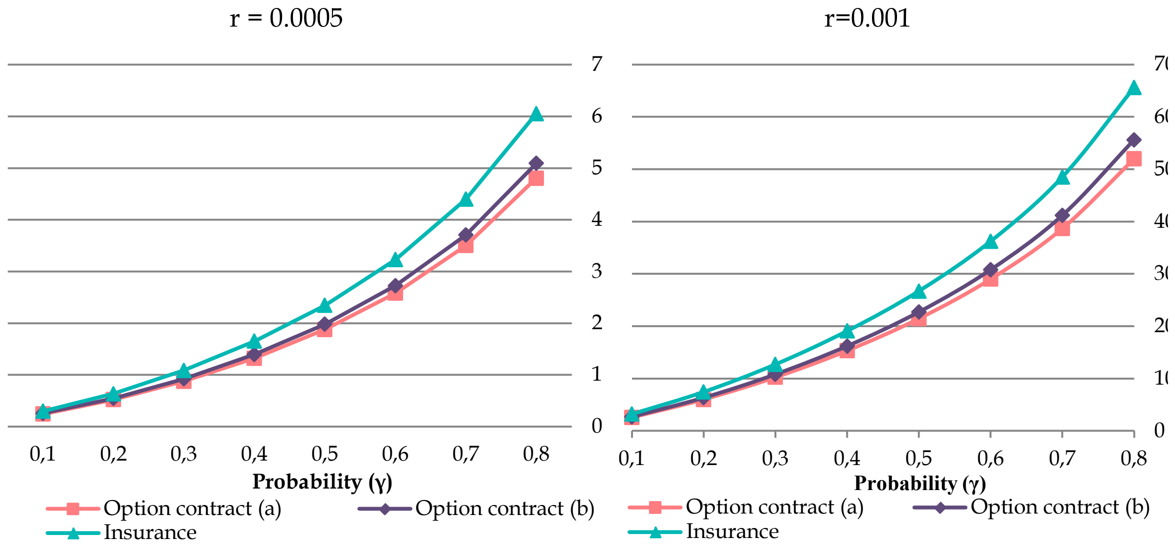
Source: Own elaboration.

For less risk-averse farmers, WTP for these instruments ranges from €131 to €164 per ha (Figure 15). For higher risk aversion levels, the differences among the WTP for these tools increase. As expected, farmer's WTP for these instruments increases with risk aversion, reaching €241 per ha for the insurance, €208 for option contract (b) and €195 for option contract (a) when the risk aversion level is the highest. The WTP for option contract (a) is lower than for (b) because option contract (a) does not offer complete protection as there is

[36] Parameters' values for this figure: Marginal value of water, b = 0.7 €/m^3; parameter affecting the probability of exercise the option (a), Z=0.95; guarantee level, w_g= 1808 m^3 (probability γ =0.4); exercise price, P_e = 0.12 €/m^3.

a probability of not being able to exercise the option due to the parameter Z (see section 5.2.2).

Figure 16. Farmer's willingness to pay (€/ha) for each instrument considering different probabilities of exercising the option/getting the indemnity (**γ**)[37]. Absolute risk aversion level = 0.0005 and 0.001

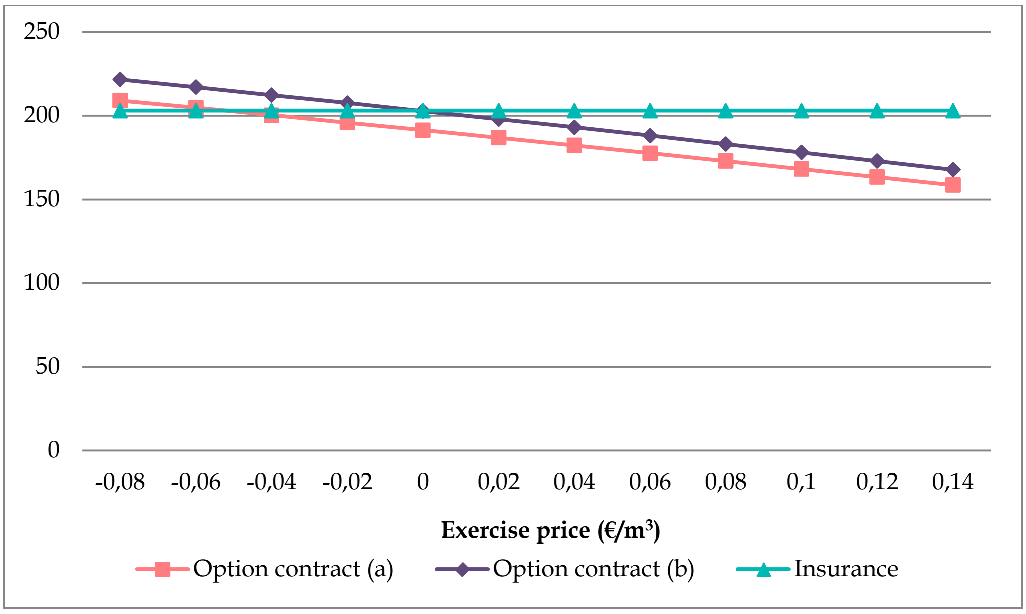


Source: Own elaboration.

As expected, Figure 16 shows that the WTP for a risk management tool increases with the probability of receiving the compensation. Since γ is the probability of farmer's water availability being lower than w_g, a higher γ leads to a higher guaranteed level. Note that WTP increases exponentially with γ and has a positive second-derivative. The value of this kind of instruments depends on the supply reliability they deliver. For a risk aversion level of 0.001, the WTP for insurance decreases from nearly €650 when the probability of exercising the option is 80% to €27 when this probability is only 10%. For a less risk-averse farmer (r = 0.0005), the WTP for these instruments are lower than for the previous case for all tools.

[37] Parameters' values for this figure: Absolute risk aversion level = 0.0004 and 0.001; marginal value of water, b = 0.7 €/m^3; parameter affecting the probability of exercise the option (a), Z=0.95; exercise price, P_e = 0.12 €/m^3.

Figure 17. Farmer's willingness to pay for each instrument considering different exercise prices[38]



Source: Own elaboration.

Figure 17 shows the impact of a change in the option's exercise price on the farmer's WTP for the option contracts. Obviously, the WTP for signing an option contract decreases with its exercise price. For instance, the WTP for the option contract (b) decreases from €222 to €168 per ha for the considered exercise price range. When the price paid for the optioned water volume is lower than the price of the regular water allotment ($P_e < 0$), the order of preferences for these tools changes (see Figure 12). In this case, the farmer would be willing to pay a higher premium for the option contract (b) than for the insurance. It could be the case that the WTP for the option contract (a) would be slightly higher than the WTP for the insurance when the exercise price is excessively low.

[38] Parameters' values for this figure: Absolute risk aversion level=0.0012; marginal value of water, b = 0.7 €/m³; parameter affecting the probability of exercise the option (a), Z=0.95; guarantee level, w_g= 1808 m³ (probability γ =0.4)

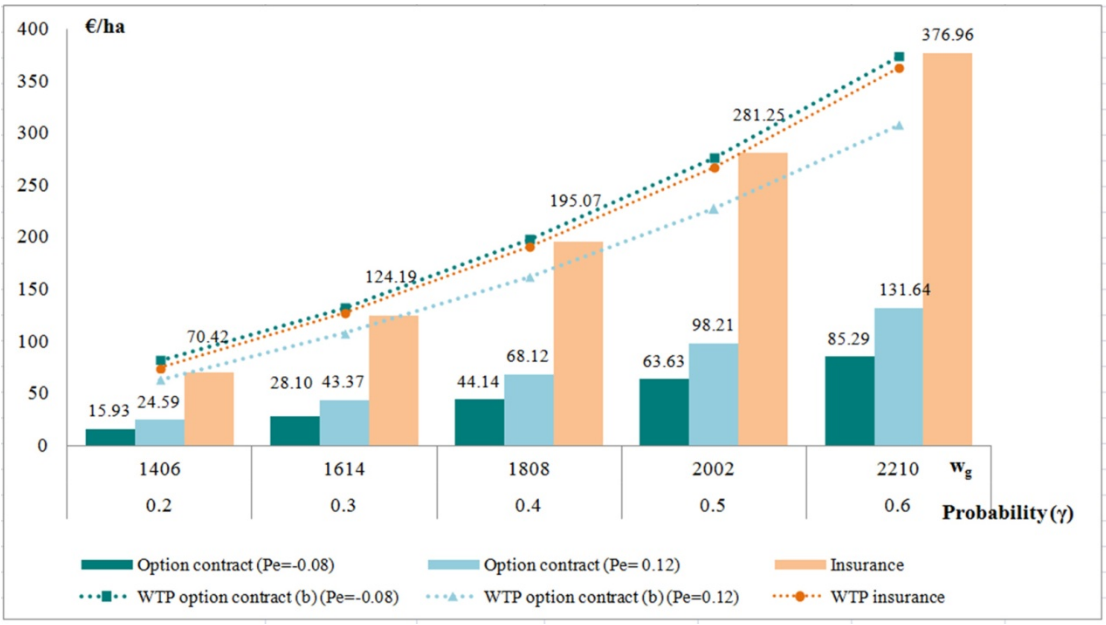
The previous results have been obtained under the assumption of constant absolute risk aversion (CARA). However, farmers are usually less risk averse when their wealth augments, exhibiting decreasing absolute risk aversion (DARA). To check that our CARA assumption does not change the farmer's preferences for the proposed risk management tools in our case study, we have compared the above presented results with those obtained assuming a DARA utility function instead. We have used Monte Carlo simulation to obtain the PDF of the farmer's utility function for the different cases assuming both CARA and DARA utility functions, because with DARA preferences and asymmetric $\tilde{w}$ equation 5 does not have an analytic solution. Results show that farmers' ordered preferences for these instruments do not change from CARA to DARA (proof available upon request).

5.4.2. Option contract and drought insurance prices

To calculate the price of the drought insurance for farmers in the *Campo de Cartagena* irrigation district we have used equation (12). From the PDF of farmer's water availability in this district, and for different guarantee levels (w_g), the expected compensation is calculated. This is the pure or basic premium. All the costs that should be added to the basic premium to obtain the final price of an insurance policy are clearly defined by the Spanish crop insurance system: 9.24% of the basic premium for administrative costs, 5% for legal reserves; 20.66% for commercial mark-up, and 5,60% for reinsurance costs (Varela, 2008).

Our results show that the final price of the proposed insurance would be from 70 €/ha to 377 €/ha for the considered range of guarantee levels (Figure 18). This price would be very close to the farmer's WTP for the drought insurance policy.

Figure 18. Prices (€/ha) for option contract and drought insurance, and WTP for these instruments for different guarantee levels (w_g)[39]



Source: Own elaboration.

Figure 18 shows the tentative prices of a water option contract for two different exercise prices. The price of the option contract has been calculated applying the Black-Scholes-Merton formula (Eq.13). The final price of the option is the sum of the option premium plus the exercise costs (exercise price for each purchased cubic meter), transaction costs (nearly 1% based on previous water trading experiences in the area) and a payment for compensating third-party effects (near 5%, as applied in the option contracts between the Metropolitan Water District of Southern California and several Sacramento irrigation districts, reported by Hansen et al. (2013)). Although the total cost of the option contract (premium + exercise costs) considering P_e=-0.08 €/m^3 is lower than the option with an exercise price of 0.12 €/m^3 (Figure 18), the premium of the former would be higher. This is because an option contract with such a low exercise price would be more valuable for an irrigator.

[39] Parameters' values for the WTP curves: Absolute risk aversion level=0.001; marginal value of water, b = 0.7 €/m^3; parameter affecting the probability of exercise the option (a), Z=0.95.

A single price for the option contract is obtained, although two different option contracts (a and b) are being considered. It would be expected that the price of option contract (b) would be higher than option contract (a) because the probability of being able to exercise the option is higher with option contract (b). Some authors have argued that this formula tends to sub-estimate option prices (Fleming et al., 2013). Thus, the actual prices of the proposed option contracts might be higher than the ones reported here.

Although the price of the drought insurance would be higher than the one for option contract, the final decision would depend on the potential for increasing famer's welfare. If the difference between the WTP for the insurance and its price is higher than the different between the WTP for the option contract and its final price, farmer would choose to contract the insurance policy. As it can be seen in Figure 18, the difference between the WTP and the price of the insurance is considerably lower than for the option contract. However, as mentioned before, higher prices of the option contract could be expected.

5.5. Discussion

The application of the theoretical framework to an irrigation district in Spain allows us to rank the considered instruments under different situations. As it can be seen from the results, the insurance policy is the most preferred instrument. In this case, the received compensation could be used to overcome the financial loss caused by the drought situation, or could be used to buy water from another water source, including desalinized water. This risk management tool has the advantage that farmers would gain in revenue stability, transferring to the insurance market the risk of water shortage. One disadvantage is that farm labor and both the processing and input supply sectors would suffer the indirect consequences of reduced agricultural activity resulting from water shortages. However, in a real setting the cost of insurance is greater than the cost of an option contract, as our results show.

Option contract (b) is the next most valued tool after the insurance. The final decision to purchase one instrument or the other would be based on: (i) the premium actually paid for each instrument (as previously explained in section 5.3); (ii) the specific designing elements of the instrument (maturity date, process to get the indemnity/optioned water, transaction costs); (iii) farmer's trust on the other agent involved in the contract (the water seller in the case of the option contract, and the insurance company when he purchases the insurance policy); and (iv), the exercise price of the option. If it is considerably lower than the price that the farmer has to pay for his water allotment from the regular supply source, the WTP for option contract (b) could increase and become significantly higher than the WTP for the insurance (see Figure 17).

However, as mentioned before, there could be some cases where the exercise price is lower than the normal water tariff (P_w) paid by the buyer. In these cases, the farmer's ordered preferences for these risk management tools change (see Figure 12). During the 2005-2008 drought period, the Spanish Government permitted inter-basin market exchanges to alleviate the conditions of the most affected river basins (Garrido et al., 2012b). It was materialized in an agreement between the irrigation district *Canal de Estremera* (Tagus Basin) and the SCRATS (Central Association of the Irrigators' of the Tagus-Segura Aqueduct, *Sindicato Central de Regantes del Acueducto Tajo-Segura,* Segura Basin). The price paid by farmers in the Segura Basin was 0.18 €/m^3 (they were exempted from paying additional 0.12 €/m^3, which is the Tagus-Segura Transfer tariff). In fact, marginal value of irrigation water in the Tagus is lower than the average price paid by water users in the Segura basin, so there is scope for the latter water being cheaper than their usual sources of supply[40]. This

[40] The authors are aware of agreements between water users in the Tagus (sellers) and Segura basins (buyers) to sell water at a price of 0.06 €/m^3. If there is a drought period and they are exempt of paying the Aqueduct tariff, the final price of this water would be lower than the usual water price.

process resulted from a bilateral negotiation between farmers in the area-of-origin (Tagus Basin) and farmers in the recipient basin (Segura Basin), and was accepted by the Spanish Ministry of the Environment during three consecutive years. It was beneficial for both parties, but downstream users in the Tagus contested it (Garrido et al., 2012b). In October 2013, a memorandum[41] of understanding between the Ministry and the involved regional governments was signed to reformulate the inter-basin managing tools, increasing the prerequisites in the Tagus Basin to allow for exchanges, although leaving the possibility of inter-basin market exchanges between parties. Considering the differences of water productivity across regions (Garrido et al., 2010), market exchanges would likely continue if the Ministry permits them again. The potential transaction costs (transfer fees, environmental costs, etc.) would determine the exercise price and whether the insurance policy would be more attractive than an option contract or not.

Based on the current development of agricultural and drought insurance (for rainfed crops, only), we would expect that the insurance premium would not cost more than 20-30% more than our calculated risk premium for several reasons. First, there is wide experience and expertise in the agro-insurance sector in Spain, accumulated during 35 years (Antón & Kimura, 2011); secondly, there is broad risk dispersion across 26 lines of crop insurance and 15 lines of livestock insurance, covering almost all insurable risks; and thirdly, there are two independently executed projects looking at the implementation details of this type of insurance that seem to suggest their feasibility (Pérez-Blanco & Gómez, 2013; Ruiz et al., 2014).

Despite this, our results show that the insurance premium would be higher than the total price of the option contract. In fact, many authors highlight the need to subsidize insurance premium to make them affordable for

[41] http://www.scrats.es/wp-content/uploads/2013/10/131014-ENMIENDAS-ATS-_TEXTO-DEFINITIVO_.pdf

farmers (Bielza et al., 2008; Garrido & Zilberman, 2008; Pérez-Blanco & Gómez, 2013).

The farmer's WTP obtained for the different water supply risk management tools analyzed are consistent with those from previous studies in this Spanish region (Tobarra, 2008; Rigby et al., 2010; Pérez-Blanco & Gómez, 2012). These authors evaluate the farmers' willingness to pay for reducing uncertainty with different water supply guarantee levels. It is thus difficult to make a direct comparison among them, but they give us an idea of farmer's interest in these instruments in the region under study. Tobarra (2008) assessed the farmers' WTP for a reduction in their water supply uncertainty, guaranteeing the average water allotment every year. According to his results, for the Segura Basin (where the *Campo de Cartagena* irrigation district is located), farmers' mean WTP is €112-163 per hectare, but may reach considerably higher values in the most productive areas of the basin, as it is the case of the considered irrigation district in our study. Rigby et al. (2010) claimed that farmers in this irrigation district are willing to pay a considerable high premium to increase their water supply reliability. Their results show that the average WTP of farmers for an increase of 25% in the certainty of getting the average water supply is €330. Pérez-Blanco & Gómez (2012) obtained basic risk premium values for specific crops in this area, expressed as a percentage of the expected production value in a normal hydrological year. For citrus crops, the WTP for a drought insurance is the highest in the district (3.66-9.13% of the expected production), ranging from €199 to €234. It is important to note that our proposed instruments have different objectives, as they are meant to guarantee a minimum water volume in dry years.

Similar works have been carried out in other Spanish River basins, highlighting the importance of water supply risk management tools for Spanish agriculture. As an example, Mesa-Jurado et al. (2012) performed a contingent valuation to assess farmers' WTP for a guaranteed water supply under scarcity conditions in the Guadalbullon river sub-basin (Guadalquivir

Basin, Spain). They obtained a mean WTP in irrigated olive farms of €42.5 and €80.6 per ha, to ensure 2/3 of the average water application in 5 out of 10 years or in 9 out of 10 years respectively. However, it must be taken into account that farming in the Guadalquivir basin is less profitable than in the Segura Basin.

As Figure 18 shows, in general, that farmer's WTP for these instruments would be higher than their prices. Thus, a risk averse farmer would be interested in purchasing these water supply risk management tools.

5.6. Conclusions

Water supply uncertainty is one of the main risks faced by irrigators. New and innovative risk management tools can help them manage this important risk factor, guaranteeing a minimum water volume each season to cover, at least, their basic water needs, or else a financial compensation. We have analyzed irrigators' preferences and willingness to pay for different water supply risk management tools, and the tentative prices of these instruments. In Spain, at least, work is being done to develop this kind of instruments from a supply perspective, and may be available commercially in short.

Our results show that farmer's decisions to use a water option contract or a drought insurance policy depend on his risk aversion, profit function, risk premium for each instrument and the administrative additional costs and fees, and the trustworthy of the instrument.

Knowing the farmer's WTP for the different risk management instruments helps us understand the potential demand of these tools, and to design the most appropriate mechanism for a certain region or agent. The comparisons presented in this work can be applied to more general contexts, giving values to the different parameters, providing the best option for a farmer based on his risk preferences. We conclude that a menu of options might better fit the irrigated agricultural sector, especially if it regularly has to cope with various uncertain water supply sources.

The potential of this type of mechanisms for the Spanish agriculture, and some others similarly subject to water supply risks, is very high, as drought episodes in this country are a recurrent phenomenon and may grows in the future as a result of climate change. Differences in water productivity among different water users facilitate the arrangement of this type of contracts between them. Though in this study we are considering the case of a farmer as a water option holder or as an insured agent, this same mechanism can be used by cities as well, increasing cities' water supply reliability during drought periods; or by regional governments to enhance environmental flows. For the implementation of these risk management tools in Spain, some legislative and management changes are need.

6. OPTIMIZATION OF WATER PROCUREMENT DECISIONS IN AN IRRIGATION DISTRICT: THE ROLE OF OPTION CONTRACTS

Abstract

Water supply instability is one of the main risks faced by irrigation districts. The optimization of the water procurement decisions is essential to increase supply reliability and reduce costs. The resource to temporary water markets, such as spot purchases or water supply option contracts can provide flexibility to this decision process. In this chapter, the potential interest of an option contract for an irrigation district in Southeast Spain that has access to different sources of water is analyzed. An stochastic recursive mathematical programming model is applied to simulate the water procurement decisions of a district in a context of water supply uncertainty and analyze the role that different option contracts may play to secure its water supply. Results indicate that the irrigation district would be willing to sign the proposed option contract in most cases, under realistic values of the option contract economic conditions. The contract's premium and optioned volume are the variables that have a greater impact on irrigation district's decisions.

6.1. Introduction

Water supply uncertainty results from climatic variations that affect water resources availability and reduce agricultural production. In water-scarce areas, hydroclimatic uncertainty is also costly in terms of irrigation decisions efficiency (Griffith et al., 2009). During low water availability periods, farmers must cope with water shortages, but very often they must also take crop and management decisions without knowing how much water they will have available in the season (Calatrava & Garrido, 2005b; Iglesias et al., 2007).

Water supply reliability is an important attribute of a district's service for farmers. For example, Mesa-Jurado et al. (2012) found that farmers in South Spain would be willing to increase by 10-20% their annual payment to the irrigators' community they belong to, as well as to accept a reduction of their average water supply by 30% of their water concession, to increase water supply guarantee. Irrigation districts' boards in water-scarce areas do not only aim to efficiently distribute water to their members, but also to manage the water supply risks faced by them, for example, by trying to secure alternative sources of water for dry periods.

A well-defined water planning strategy can help irrigators to reduce both water delivery risks, and water procurement costs. Reducing these costs will be even more essential in the coming decades as water tariffs are expected to increase due to an increasing water scarcity (Rey et al., 2011).

According to Kidson et al. (2013), water supply reliability increases with access to a pool of resources. Previous works have demonstrated that a water planning portfolio that considers option contracts and/or spot purchases can reduce costs and risks for an urban water supply agency (Jenkis and Lund, 2000; Gómez-Ramos & Garrido, 2004; Characklis et al., 2006; Kirsch et al., 2009), for environmental purchases (Hollinshead & Lund, 2006), and for irrigation districts (Calatrava & Garrido, 2005a).

Voluntary water exchanges among users reduce risk exposure (Easter et al., 1998), providing flexibility and water supply reliability under hydrological uncertainties (Calatrava & Garrido, 2005a, 2005b; Bjornlund, 2006; Cheng et al., 2011). In Spain, agricultural water right holders have relied on water markets as another source of water for scarcity situations. Here, although we consider other strategic sources of water for dry periods, such as spot markets or emergency wells, we focused on the role of water supply option contracts as an alternative for irrigation districts.

Water supply option contracts give the holder the right (not the obligation) to buy or sell the underlying asset (Williamson et al., 2008; Cui & Schreider, 2009; Cheng et al., 2011). They have a high risk-reduction potential in comparison with spot purchases, lowering the supply and price uncertainty risks for both buyers and sellers of water (Howitt, 1998; Brown & Carriquiry, 2007; Ranjan, 2010). Besides, the option contract allows the holder to delay water purchase decisions until more information is available (Characklis et al., 2006; Kaspzryk et al., 2009) and offers protection against spot prices volatility (Hollinshead & Lund, 2006). Although water option contracts do not currently exist in Spain, they have been previously evaluated for urban supply by Gómez-Ramos & Garrido (2004) and Cubillo (2010), among others.

The aim of this work is to analyze the potential of an option contract to secure water supply for an irrigation district (ID) that has access to different sources of water but is subject to a high degree of uncertainty. An original stochastic recursive mathematical programming model that determines the optimal water procurement program of an ID in a context of water supply uncertainty is presented. The analysis is focused on the decisions regarding the signing and exercising of the option contract, which interacts with other supply alternatives. The model is applied to a large ID in Southeast Spain.

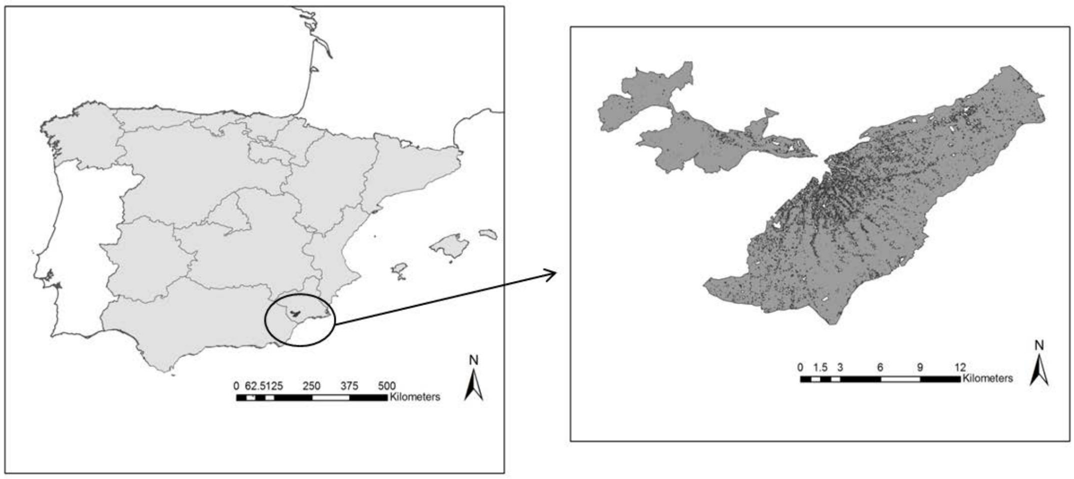
The chapter is organized as follows: in section 6.2, the case study is presented. Section 6.3 contains a description of the proposed option contract. In section 6.4 all the specifications of the developed optimization model are presented. Section 6.5 contains the model results. In section 6.6 the main conclusions derived from this work are given.

6.2. Case study and data collection: The Lorca irrigation district

The optimization model is applied to the Lorca ID in the Segura Basin (southeastern Spain, see Figure 19), one of the most water-stressed basins in Europe (EEA, 2009; Maestre-Valero et al., 2013). This ID is located in the

Guadalentín River Valley, a major tributary of the Segura River. It comprises an area of 12,116 hectares, and has 8,300 farmers, most of them with a relatively small farm size. It stands as one of the largest and most productive IDs in Spain. Farmers grow primarily high-valued horticultural crops, like lettuce, artichoke and broccoli.

Figure 19. Location of the Lorca irrigation district



Source: own elaboration.

Traditionally, irrigation in the Lorca area was supplied with scarce and highly variable surface resources. Water allocations to farmers were based on auctions. With the massive development of groundwater use and the Tagus-Segura Transfer (TST), the irrigated area enlarged, new distribution infrastructures were built and water allocation changed to use the proportional rule. The TST serves a large share of the district's water supply but is subject to a high degree of inter-annual variability, whereas groundwater resources are increasingly scarce, what has driven the district's management board to search for additional sources to secure water supply for farmers.

Currently, the Lorca ID has access to a range of nine different water sources, including an inter-basin spot market that only functions during drought periods (Table 18). The portfolio of delivery sources has been widening as new water supply sources became operational. The most recent ones are desalinized water, intermittent use of groundwater (the so-called 'drought wells[42]'), treated wastewater, and spot inter-basin water purchases from the Tagus Basin.

For the characterization of water availability we rely upon data provided by the district's management office. The initial database contains the annual ID's water availability from each water source for the period 1994-2012. In this period, two different drought episodes are included (1994-1995, 2005-2008). Our water sources database has been processed to build data series that represent the current situation on water availability for the district (Table 18).

Surface water resources come from three different sources: (a) a concession of 14 hm^3/year from the *Puentes* reservoir; (b) a concession of 29.06 hm^3/year from the TST; and (c) a concession of 4.2 hm^3/year from the Segura River Regulation System. The original data consists of a series of annual water availability from each source that have been detrended, when needed, to obtain stationary series. These three series exhibited a significant ($p<0.05$) downward trend. In practice, average values of water availability from each source are quite below the amount of water set in the concession (8, 18.25 and 1.58 hm^3/year, respectively; see Table 18).

[42] Each basin in Spain has a Drought Management Plan, which determines all the actions aimed at reducing the impacts of the drought period (Estrela and Vargas, 2012). One of the proposed means to fight drought consequences are drought wells: wells owned and managed by the RBA and that can be used during drought periods in order to meet water users' most urgent needs (e.g. emergency water applications to tree crops).

Table 18. Current water supply sources for the Lorca irrigation district

Water source	Characterization of water availability	Water available to the district (hm^3/year)				Water effectively used by the district (hm^3/year)	
		Volume set in the concession	Min.	Average	Max.	Average	Max.
Puentes Reservoir	Variable	14	3.68	6.42	9.34	6.42	9.34
Tagus-Segura Transfer	Variable	29.06	1.31	18.25	36.85	18.25	36.85
Segura Basin regulation system	Variable	4.20	0.73	2.20	5.19	2.20	5.19
District's own wells	Freely available up to a maximum value	10,4	-	-	10,4 (3†)	3‡	4.4‡
Wastewater treatment plant	Freely available up to a maximum value	2.5	0.622	2.15	2.3	2.15	2.3
Aguilas desalination plant	Freely available up to a maximum value	8	8	8	8	0§	0§
Purchase from private wells	Freely available up to a maximum value	-	-	-	8.2	7.4†	8.2
Segura River Basin Authority's "drought wells"	Only available in drought periods upon authorization	-	-	1.17	1.17	1.17	1.17
Inter-basin spot purchases	Only available in drought periods upon authorization	-	-	2.034	2.034	2.034	2.034

†According to the district, maximum availability has declined over the last 20 years and currently is 3 hm^3/year; ‡ In the past 10 years; § No historical water use record exists because these resources are available since 2013.

Source: own elaboration based on the information provided by the ID.

Groundwater resources offer an important source of water for this ID, which are jointly used with surface resources. The data for groundwater consists of a series of annual extractions from each source. The original series have also been detrended to obtain stationary series of groundwater availability (all are significantly downward, $p<0.05$). Pumped volume increases in dry years and is reduced with more surface water availability. For that reason, we have not characterized groundwater availability as stochastic but have considered instead the maximum value as the maximum amount of water that the ID can currently use from each source, according to district's own availability estimates.

Regarding non-conventional resources, the Lorca ID has a concession of 2.5 hm^3/year from the local wastewater treatment plant and, since 2013, another concession of 8 hm^3/year of desalinized water from the coastal *Aguilas* plant.

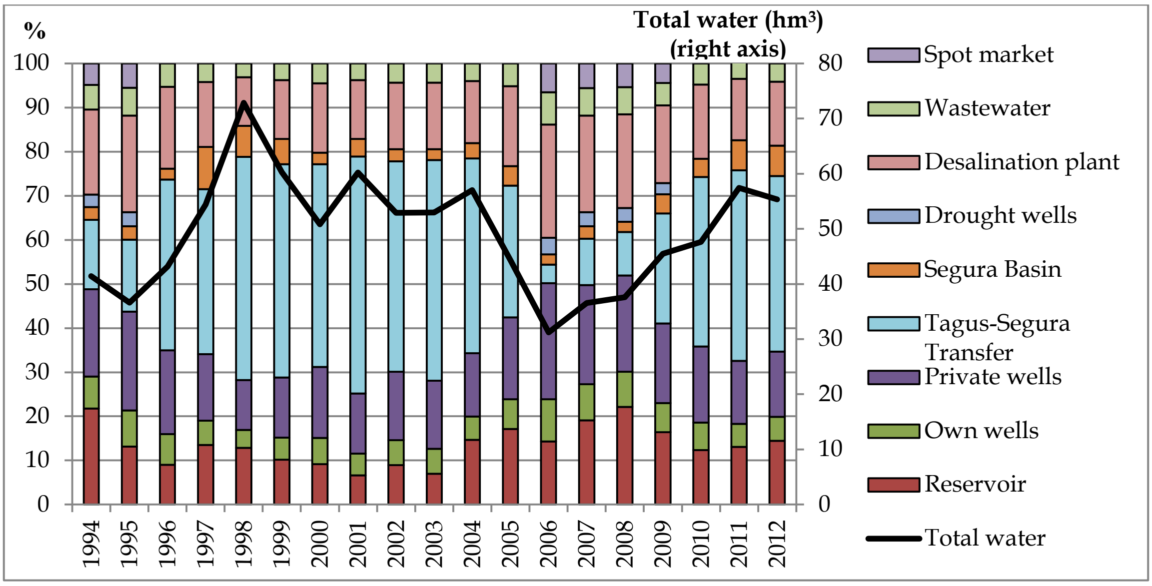
In addition, during drought periods, this ID has access to other relatively minor sources of water. First, the Segura RBA has developed a 'Strategic Set of Drought Wells' that is only used in scarcity situations to guarantee supply to small municipalities and provide some water for irrigated areas. The Lorca ID has received an average of 1.17 hm^3/year, with small variations, during the last drought period (2005-2008). Secondly, legislative changes during those years allowed for inter-basin water exchanges in drought periods through the water market (Garrido et al., 2012b). The Lorca ID participated, together with the other agricultural water users of the TST, in an inter-basin program to purchase water from water users in the Tagus Basin that was annually renewed during the four years of the aforementioned drought period. The Lorca district obtained 2.034 hm^3 in each of the four years of this agreement. Based on the redefinition of the statute of the operating rules of the TST[43] in 2013, option and spot contracts across basins can be approved. We assume in our model that

[43] One of the aims of the Memorandum of Understanding on the Tagus-Segura Transfer (2013), apart from modifying the Tagus-Segura Transfer management rules, is to provide flexibility and efficiency to the exchanges of water rights using the infrastructures of the Tagus-Segura Aqueduct. Available in Spanish at: http://www.scrats.es/wp-content/uploads/2013/10/131014-ENMIENDAS-ATS-_TEXTO-DEFINITIVO_.pdf

these two sources – drought wells and inter-basin spot purchases – are available to the district when water availability from the TST is below a certain threshold.

To characterize water supply uncertainty, we use the above description of water availability for each source and consider each of the 19 years, spanning 1994-2012, as a single state of the nature with equal probability of occurrence. The black line (Figure 20, right axis) shows total water availability under each state of nature. This ID is exposed to a high variability of available water. The minimum annual water availability is 31 hm³, being 73 hm³ the maximum. Bars represent the percentage of each water source in the total water volume in each scenario. Note that TST is the main water source in 14 out of the 19 considered states of nature, in which it ranges from 29 to 53%, but it is also the major source of variability. With reduced deliveries from the TST, the ID would rely more on desalinized water and purchases from private wells.

Figure 20. Characterization of Lorca irrigation district's current water availability from each source (hm³) under each possible state of the nature



Source: Own elaboration.

Facing this set of possible scenarios (hydrological years), the ID managers will have to decide how much water to use and from which sources, taking into account the available water from stochastic sources and the price of the different water sources (shown in Table 19), and whether to sign or not water supply option contract with different characteristics.

Table 19 reports the current water prices for each water source. These prices are quite stable over time. Desalination is, by far, the most expensive water source in the pool. Thus, the ID only uses desalinized water when other sources are unavailable. If the objective of the ID was to minimize water procurement costs, the strategy would be to purchase water from the cheapest to the most expensive water until the ID water needs are fulfilled. However, cost must be pondered against reliability.

Table 19. Current water prices for each water source paid by the irrigation district (€/m^3; distribution costs not included)

Water source	€/m^3
Puentes Reservoir	0.100
Tagus-Segura Transfer	0.127
Segura Basin regulation system	0.100
District's own wells	0.140
Purchase from private wells	0.253
Wastewater treatment plant	0.100
Aguilas desalination plant	0.450
Segura River Basin Authority's "drought wells"	0.270
Inter-basin spot purchases from the Tagus	0.205

Source: own elaboration based on the information provided by the ID.

6.3. Proposed water option contract

Several examples of water supply option contracts schemes can be found in the literature, with different features and conditions. Jenkins & Lund (2000) studied the potential of dry year option contracts, in combination with other water supply reliability strategies, for an urban water supplier to acquire water during periods of water deficit. Kirsch et al. (2009) worked on the optimization of long-term (10 years) water supply portfolios, evaluating multiyear option contracts which provide the option holder with year-to-year flexibility, while still providing the long-term contractual security avoiding the cost and inconvenience of annual renegotiation. Gómez-Ramos & Garrido (2004) evaluated 18 different 4-years option contracts, with different delivered volumes and triggering conditions, between an urban supply agency and an ID in Spain. In our work, the proposed option contract aims at reducing the risk faced by an ID in terms of water availability.

The proposed option contract is intended to provide another flexible source of water to reduce ID's supply risk. With the option contract, the ID (buyer) could have access to the optioned volume at the maturity date paying the agreed exercise price to the seller. As defined in this study, the option holder could acquire all or part of the optioned volume at the maturity date. For having the right to purchase the optioned volume, the ID would have to pay the seller an annual premium.

The option contract involves two steps: in the first one, based on the ID's risk preferences and level of water supply reliability, the ID would have to decide whether to sign the option contract to protect against the water supply uncertainty it is exposed to, assuming there is an interested counterpart. If signed, the ID would have access to the optioned volume if needed, in exchange for paying a premium for having this right. In the second step, once supply uncertainty has disappeared and if the trigger condition of the option contract is met, the ID would have to decide whether to exercise the previously signed option. The second-stage decision would be mainly determined by the water volume that the ID is going to receive from the other water sources and the price of alternative water sources.

Most examples of optioning water rights are subject to a condition or trigger. The trigger is an external condition that should be met to exercise the option. In this particular case, the trigger is related to the water volume that the ID receives from the Tagus Basin through the TST. When the volume is below the set threshold, the ID could exercise the option if needed and acquire the optioned volume. The reason to choose this trigger is that the TST is the main water source for this ID (as shown in Figure 20), so it is a good indicator of the ID potential water availability in a given year. The rationale of using a trigger, that enables the holder of a call option to exercise the option when there is less water available, is to ensure that the other party of the contract uses the water in normal or abundant conditions (Gómez-Ramos & Garrido, 2004; Hafi et al., 2005; Leroux & Crase, 2007). It thus works as a risk-transfer mechanism amongst two water users with different supply reliability needs or risk aversion levels.

6.4. Optimization model

To analyze the water procurement decisions of the Lorca ID, an optimization model has been formulated. The objective of the optimization model is to minimize the water procurement costs for the ID that meets the water requirements for irrigators, taking into account each water source availability and price. The model provides the optimal water acquisition strategy, including the possible signing of an option contract.

It is a two-stage recursive stochastic model. In the first stage, when uncertainty related to water availability exists, the ID has to decide whether to sign the option contract or not. In the second stage, when the available volumes from each source are known, the model finds the optimal water sourcing strategy, including the decision of whether to exercise or not the option (if contracted in the first stage and if the trigger condition holds) and acquires the optioned volume.

In order to assess the benefits derived from the existence of the option contract in the water source pool, we have also considered the case when the option contract for water is not available. This is the "baseline scenario" to compare the costs and the water reliability with and without an option contract in the water sources pool.

6.4.1. First-stage stochastic decision model

The decision variables are: Q, whether to sign the option contract; and $W_{i,k}$, how much water to get from each water source. The first-stage decision is modeled as follows:

$$min\ C = \sum_i \sum_k ((P_i * W_{i,k} + OP * A_{opt,k} * Q) Prob_k) \quad (1)$$

subject to:

Water needs (the target amount of water that the district has to obtain).

$$\sum_i \sum_k (W_{i,k} * Prob_k) \geq N \quad (2)$$

Water use constraint (the ID cannot use more water than it is available).

$$W_{i,k} \leq A_{i,k} \quad (3)$$

Water use constraint for the option contract (for the option holder to obtain the optioned water volume, a pre-established condition (trigger) should be met).

$$W_{opt,k} \leq A_{opt,k} * Q \qquad if\ A_{TST,k} < T$$

$$W_{opt,k} = 0 \qquad if\ A_{TST,k} \geq T \quad (4)$$

Non-negativity constraint:

$$W_{i,k} \geq 0 \quad (5)$$

C is the total water procurement cost for the irrigation district (€ million).

The decision variables are:

$W_{i,k}$: Used water by the irrigation district from each water source in each state of nature (hm^3).

Q: Decision variable. Binary variable that takes the value 0 when the irrigation district decides not to sign the option contract, 1 otherwise.

With:

i (1,...,10): Water source (reservoir, Tagus-Segura Transfer, Segura Basin, own wells, private wells, wastewater treatment plant, desalination plant, drought wells, inter-basin spot purchases, option contract). The subscript "opt" refers to the option contract; "TST" refers to the water volume that comes from the Tagus-Segura Transfer.

k (1,…,19): States of nature. Each year of the database (1994-2012) is considered a state of nature[44]. *k*=1 is the state of nature with the lowest water availability, and *k*=19 the one with the highest water availability for this ID.

And the parameters are:

P_i : Cost of each water source (€/m^3).

OP: Option contract premium (€/m^3).

$A_{i,k}$: Maximum water availability for each water source in each state of nature (hm^3).

$Prob_k$: Probability of each state of nature. All states of natures have the same probability of occurrence (1/19).

N: Irrigation district's water needs (hm^3).

T: Trigger of the option contract (hm^3).

[44] Years from the original database (1994-2012) have been reordered based on the water availability: *k*1 (2006); *k*2 (2007); *k*3 (1995); *k*4 (2008); *k*5 (1994); *k*6 (1996); *k*7 (2005); *k*8 (2009); *k*9 (2010); *k*10 (2000); *k*11 (2002); *k*12 (2003); *k*13 (1997); *k*14 (2012); *k*15 (2004); *k*16 (2011); *k*17 (2001); *k*18 (1999); *k*19 (1998).

6.4.2. Second-stage deterministic decision model

Based on the decision of the first stage (whether to sign the option contract), the second-stage model defines the optimal water procurement decisions for each state of nature, k. At this step, decisions are made without water availability uncertainty.

The decision variable Q of the first model is now introduced in this second-stage model as a parameter (R=Q). The objective function is:

$$min\ C = \sum_i \sum_k (P_i * X_{i,k} + OP * A_{opt,k} * R) \quad (6)$$

being $X_{i,k}$ the water volume obtained from each water source for each state of nature.

Subject to:

$$X_{i,k} \leq A_{i,k} \quad (7)$$

$$\sum_i X_{i,k} \geq N \quad (8)$$

$$X_{opt,k} \leq A_{opt,k} * R \qquad if\ \ A_{TST,k} < T$$

$$X_{opt,k} = 0 \qquad if\ \ A_{TST,k} \geq T \quad (9)$$

$$X_{opt,k} \geq 0 \quad (10)$$

6.4.3. Baseline model (without the option contract)

If we do not consider the option contract, the decisions are taken in a single step, and for each state of nature. There is no uncertainty related to water availability from each water source.

$$min\ C = \sum_i \sum_k (P_i * W_{i,k}) \quad (11)$$

s.t:

$$W_{i,k} \leq A_{i,k} \tag{12}$$

$$\sum_i W_{i,k} \geq N \tag{13}$$

$$W_{i,k} \geq 0 \tag{14}$$

$W_{i,k}$ is the obtained water volume from each water source i in each state of nature k.

The optimal solution has been obtained using GAMS (General Algebraic Modeling System).

6.4.4. Parameterization of the option contract

A wide range of option contract parameters (premium, exercise price, optioned volume and trigger) has been used to assess the conditions that make the option contract an attractive supply source for the district (Table 20).

The central values of the range of parameters have been obtained from records of previous trading experiences that involved irrigators in the Segura Basin (Garrido et al., 2012b). We have tried to consider a realistic set of values for the parameters, taking in to account that there are no previous water supply option contract experiences[45]. For example, water prices in the formal leases contracts that have taken place in the Segura Basin are on the range 0,03 to 0,30 €/m^3, whereas prices in inter-basin trading during the last drought period was 0,21 €/m^3. In total, we will examine 375 cases, resulting from the combination of five exercise price levels, five premium levels, five contracted volumes and three triggers (Table 20).

[45] In the Spanish water market, option contracts are not a common type of exchange but there has been one experience of a multi-annual contract between water users in the Tagus and the Segura Basin during that drought period that resembles an option contract: *Canal de Estremera* ID (Tagus Basin) and SCRATS (Central Association of the Irrigators' of the Tagus-Segura Aqueduct, *Sindicato Central de Regantes del Acueducto Tajo-Segura,* Segura Basin) signed a water trading contract for 31.05 million m^3/year that was annually renewed during four years. The average price was 0.21 €/m^3.

Table 20. Parameterization of the option contract conditions (number of cases 5x5x5x3=375)

P_{opt} (€/m^3)	OP (€/m^3)	$A_{opt,k}$ (hm^3)	T (hm^3)
0.06	0.02	3	10
0.12	0.04	6	15
0.18	0.06	9	20
0.24	0.08	12	
0.30	0.10	15	

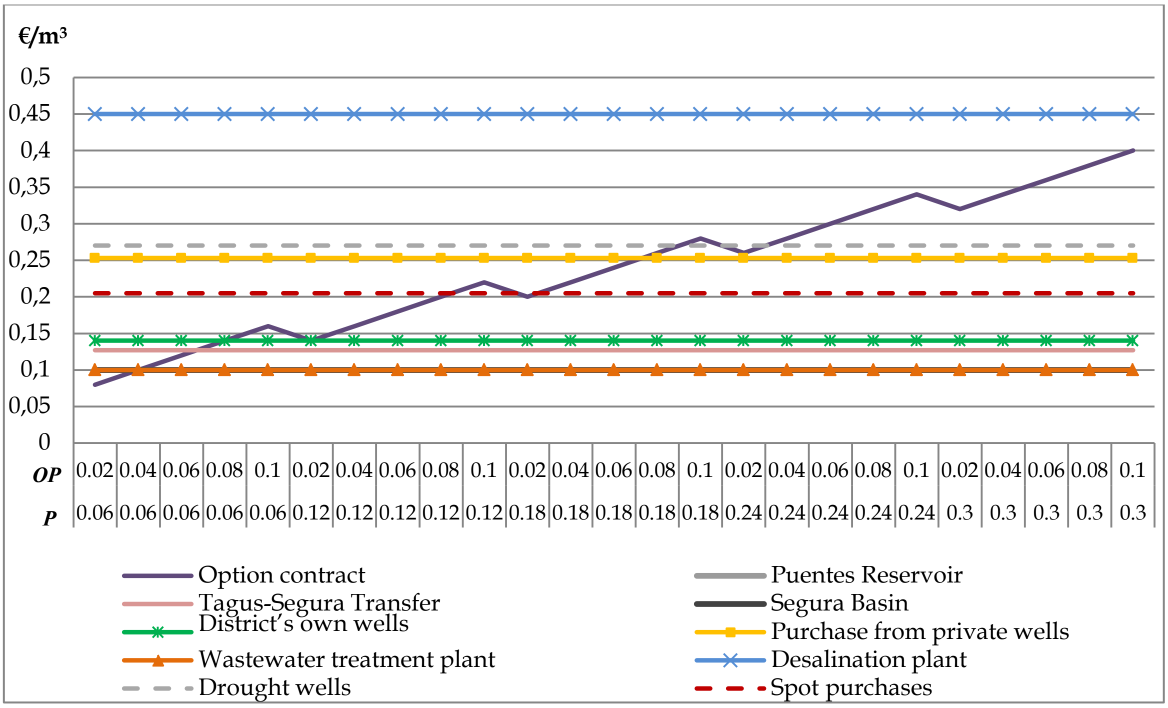
P_{opt}: exercise price; OP: premium, $A_{opt,k}$: optioned volume, T : trigger.

Source: own elaboration.

The parameterization of the option contract conditions allows us to obtain the optimal water procurement decisions of this ID in each case. As the objective of the model is to obtain the needed water volume at the minimum costs, these parameterizations are going to affect the total costs of the option contract, and so, the ID's water procurement decisions.

Figure 21 compares the option contract total price (in €/m^3, the premium plus the exercise price) with the rest of water sources prices. The range of option contract's parameters covers all the spectrum of water prices from other sources. Desalinized water is always the most expensive water source, even with the highest values of the premium and exercise price of the option contract. Thus, the ID would always prefer the option contract rather than the water that comes from the desalination plant. However, when the option contract cannot be exercised because the trigger condition is not met, or when more water is needed to meet ID water needs, desalinized water would be used.

Figure 21. Water prices for the different water sources. For the option contract, all the parameterizations (€/m³) of the premium (OP) and the exercise price (P) are taken into account



Water resources from the wastewater treatment plant, *Puentes* reservoir and Segura Basin have the same price: 0.1 €/m³. Dashed lines represent water sources that are only available during drought periods (drought wells and inter-basin spot purchases).

Source: own elaboration.

Figure 21 shows that the cost-effectiveness of the option contract with respect to other sources is totally dependent on its economic parameters, and that of course depend on the willingness to engage in such agreement of the counterpart.

6.5. Results

The analysis is focused on the decisions related to the option contract: whether the ID would sign the option contract in the first stage, whether the ID would exercise the option (if previously contracted), and the circumstances that determine both decisions.

6.5.1. First-stage decision results

In this stage, the ID has to make a decision about whether to sign the option contract (Q in the model). Depending on the values of the option contract's parameters, the ID would consider it an attractive option or not. The district will consider the probability of not meeting its target supply with its water sources and will weigh the cost of purchasing the option against the relative cost of the alternative water sources. Our results show that the ID would sign the option contract (Q=1) in 48.3% of the considered cases, taking into account all the parameterizations (see Figure 23).

Table 21 disaggregates the distribution of the optimal Q in all 375 possible cases, depending on the value of the option contract's parameters. The premium and the optioned volume are the parameters that are going to affect most the decision of signing the option contract by the ID. For high premium and optioned volume values, the ID would not sign the option contract. That is because the overall costs of the contract would be higher than other available alternatives. We can also see that there is a trade-off between the optioned volume and the contract's annual premium. Greater optioned volumes require lower annual premiums for the district to enter the option contract.

Table 21. Decision of signing the option contract, depending on the parameters' values

			Optioned volume ($A_{opt,k}$) (hm³)														
			3			6			9			12			15		
			Trigger (T) (hm³)			Trigger (T) (hm³)			Trigger (T) (hm³)			Trigger (T) (hm³)			Trigger (T) (hm³)		
		Price (P_{opt}) (€/m³)	20	15	10	20	15	10	20	15	10	20	15	10	20	15	10
Premium (OP) (€/m³)	0.02	0.06	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
		0.12	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
		0.18	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
		0.24	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
		0.3	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	0.04	0.06	■	■	■	■	■	■	■	■	■	■	■		■		
		0.12	■	■	■	■	■	■	■	■	■	■	■				
		0.18	■	■	■	■	■	■	■	■	■	■					
		0.24	■	■	■	■	■	■	■	■	■						
		0.3	■	■	■	■	■	■	■	■	■						
	0.06	0.06	■	■	■	■	■	■									
		0.12	■	■	■	■	■	■									
		0.18	■	■	■	■	■	■									
		0.24	■	■	■	■	■	■									
		0.3	■	■	■	■	■	■									
	0.08	0.06	■	■	■												
		0.12	■	■	■												
		0.18	■	■	■												
		0.24	■	■	■												
		0.3	■	■	■												
	0.1	0.06	■	■													
		0.12	■	■													
		0.18	■	■													
		0.24	■	■													
		0.3	■	■													

Grey: the ID would sign the option contract (Q = 1)

White: the ID would not sign the option contract (Q = 0)

Source: Own elaboration.

The decision of signing the option contract is analyzed through a logistic regression, using all the 375 parameterizations. The results of this regression (Table 22) show the influence of each parameter of the option (price, premium, optioned volume and trigger) on the decision to sign the option contract (binary variable; 0,1).

Table 22. Logistic regression results for the contract decision (**Q**)

Explanatory variable	Coef.	Std. Err.	z	P > |z|	Marginal effects†
P_{opt}	-4.234	3.028	-1.40	0.162	-1.02
$A_{opt,k}$	-1.682	0.344	-4.89	0.000	-0.40
OP	-278.430	53.028	-5.25	0.000	-66.76
T	0.168	0.065	2.58	0.010	0.040
Intercept	29.678	6.192	4.79	0.000	
Observations	375				
Pseudo R^2	0.81				
% of corrected classified	93.60				
% of "0" correctly predicted	94.85				
% of "1" correctly predicted	92.27				

†The marginal effect of each variable has been calculated holding all other variables in the model at their means.

P_{opt}: exercise price; OP: premium, $A_{opt,k}$: optioned volume, T : trigger.

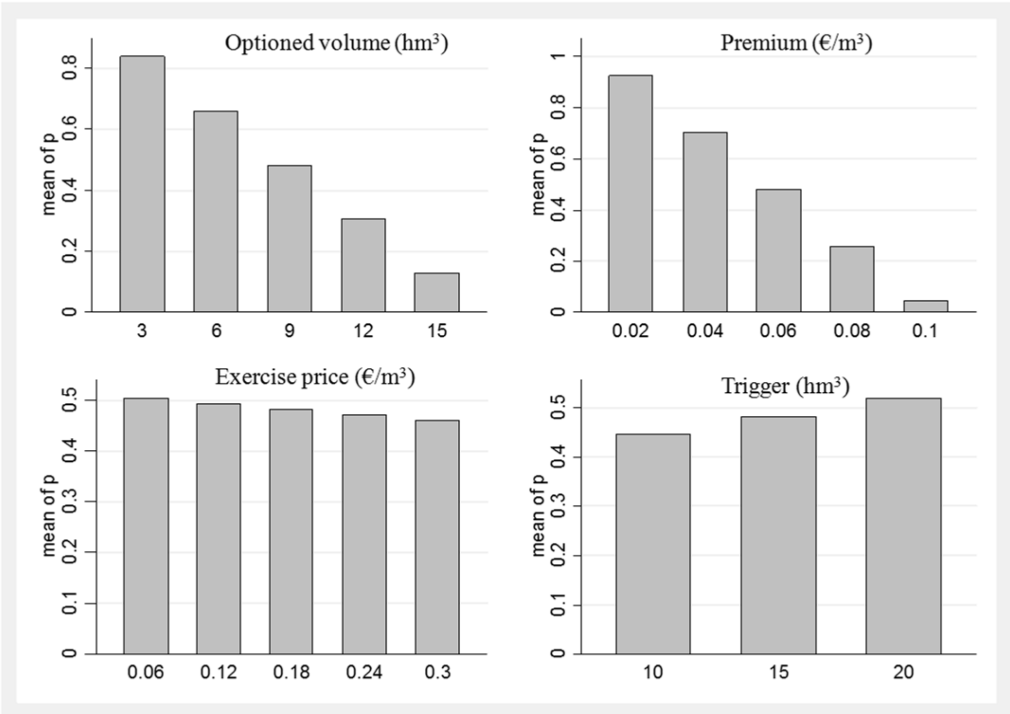
Source: Own elaboration.

The results of the regression show that all variables, except for exercise price (associated p-value = 0.162), are statistically significant. The premium (OP; €/m^3) and the option volume ($A_{opt,k}$ hm^3/year) determine the costs of signing the option contract. This explains the negative value of their coefficients. For higher optioned volumes or premium values, such cost increases and the ID's interest in the contract would decline. On the contrary, a greater trigger increases the probability of signing the contract, increasing its appeal to the district's managers.

The marginal effects show the impact that a change in each variable has on the probability of signing the option contract, measured at the mean values of the explanatory variables. For example, if the trigger increases from 15 hm^3/year to 16 hm^3/year, ceteris paribus, the probability of purchasing the option contract increases by 4%.

From this logistic regression, we obtain the average probability of signing the option contract depending on the parameters' values. As seen in Figure 22 and Table 22, the exercise price of the option is not going to have a significant impact on the probability of signing the contract. Indeed it is the premium that has a considerable effect on the average probability of signing it. For a premium of 0.02 €/m^3, the probability is close to 90% descending to less than 10% when the premium is 0.1 €/m^3. For the highest premium (0.1 €/m^3) and the highest optioned volume (15 hm^3), the ID would never sign the option contract because of the high fixed costs associated with doing so. Obviously, if the ID has other alternative and cheaper water sources, an option contract with that premium is not going to be attractive. We arrive to similar conclusions regarding the optioned value.

Figure 22. Average probability of signing the option contract for each parameter's value



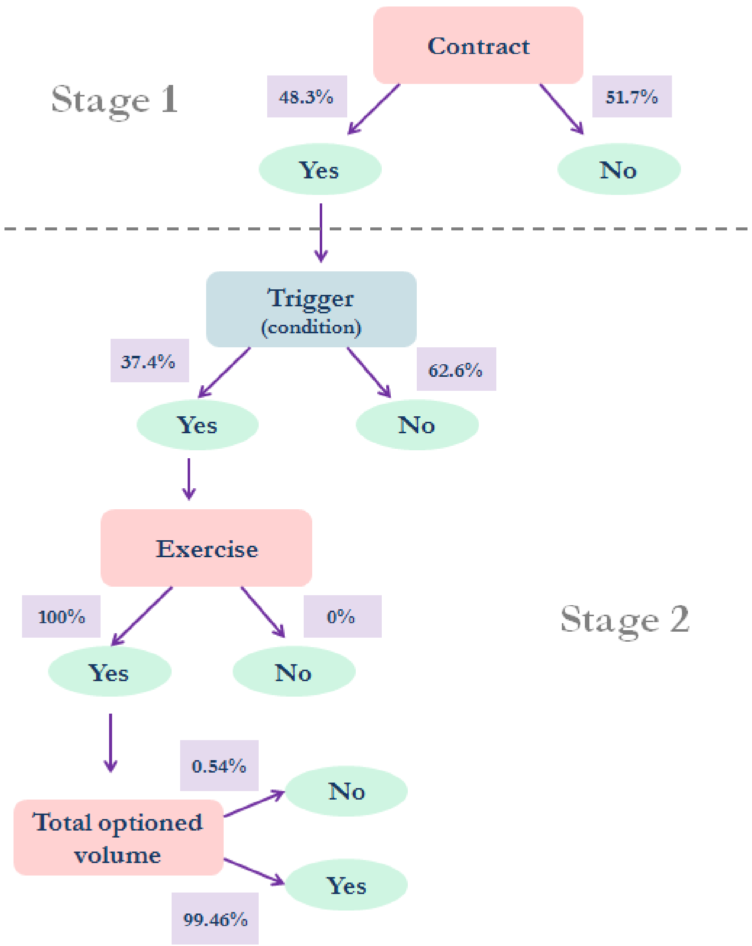
Source: Own elaboration.

6.5.2. Second-stage decision results

In this stage, the decision is taken in the absence of uncertainty. The ID has to decide whether to exercise the option or not, depending on the available water volume from other sources, that is determined by the state of nature, k, and contingent on the trigger condition being met.

Our results show that, if the ID signed the option contract in the first stage, and if the trigger condition holds, the ID would always exercise the option contract in the second stage (see Figure 23). When the trigger is met and the ID exercises the option, the optioned volume is purchase in full in 99.46% of the cases. The probabilities of meeting each of the considered triggers (i.e., the probability of being able to exercise the option) are: nine out of 19 states of nature for the 20 hm³ trigger; seven out of 19 for the 15 hm³ trigger; and five out of 19 for the 10 hm^3 trigger. For states of the nature with high water availability (k > 9), none of these triggers is met because the water volume received from the TST is higher than 20 hm^3, and as a consequence the ID could not exercise the option.

Figure 23. Option contract decision tree (all the values of the parameters are taking into account to calculate the probabilities of each step)



Whether the trigger is met is not a decision of the ID, but a condition imposed by the option contract itself.

Source: Own elaboration.

To compare the ID’s total water availability and costs, Table 23 reports the main statistics of the total costs and total water volume with and without the option contract.

If the proposed option contract is added to the Lorca ID's water sources pool, average annual water availability is slightly increased due to the access to the optioned volumes. However, the major advantage of the option contract is its risk-reduction effect, as it reduces the variation coefficient of water availability and the probabilities of the left tails of the water availability probability distribution. Although the average effect is small, the impact is quite significant in scarcity situations. As seen in Table 23, water volumes for both the 5 and 25 percentile are higher with the option contract (see also Figure 24) than without it. However, signing the option contract in the first stage, and exercising the option in the second stage entail costs to the ID, slightly increasing the total water procurement costs (on average by 0.01 €/m^3).

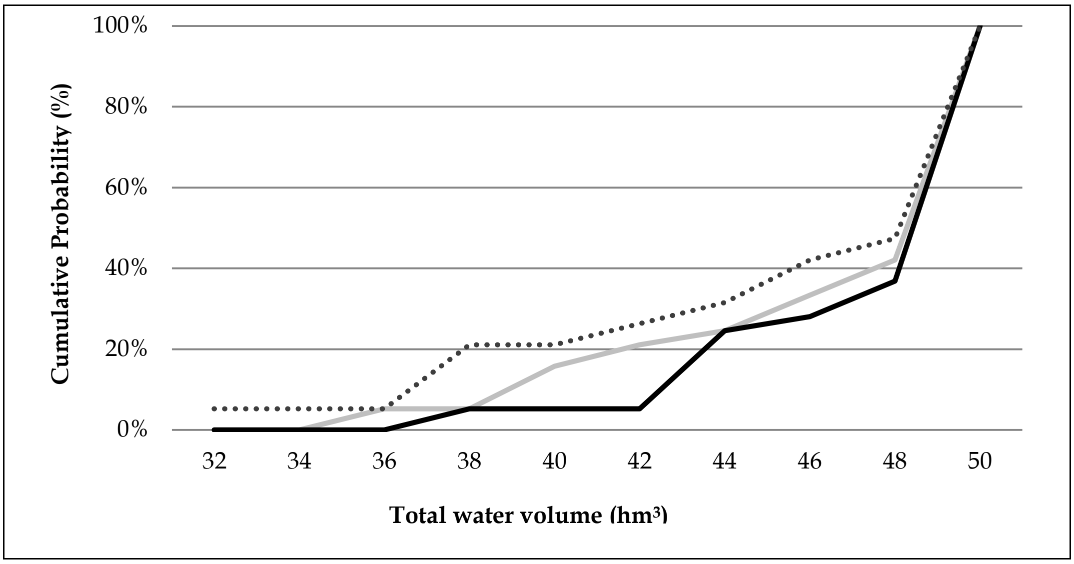
Table 23. Comparison of water procurement costs and total water volume for the Lorca irrigation district, with and without the option contract (average values for all possible states of nature)

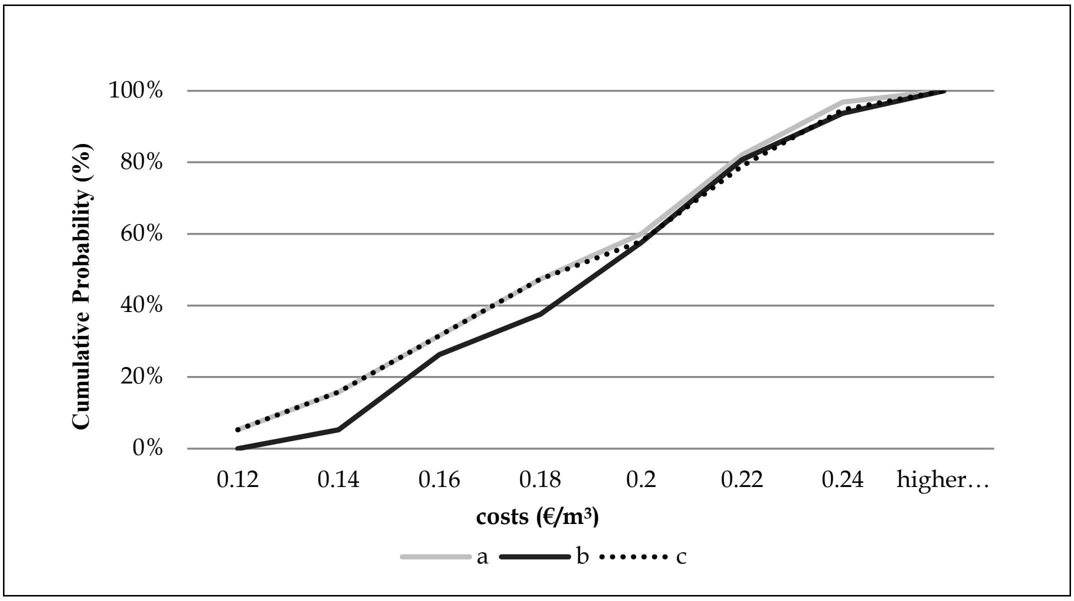
Statistics	With option contract (n=181)			Without option contract (n=194)		
	Total volume (hm^3)	Total costs (mill €)	Average Cost (€/m^3)	Total volume (hm^3)	Total costs (mill €)	Average costs (€/m^3)
Mean	46.51	8.46	0.19	45.47	8.22	0.18
Std. deviation	5.13	1.14	0.04	6.04	1.00	0.04
Variation coefficient	0.11	0.14	0.19	0.13	0.12	0.20
Percentile 5%	36.57	6.26	0.13	31.20	5.90	0.12
Percentile 25%	43.59	7.60	0.15	41.45	7.39	0.15
Minimum	31.20	5.86	0.12	31.20	5.90	0.12
Maximum	50.00	12.54	0.27	50.00	9.51	0.25

Source: Own elaboration.

Figure 24 shows the cumulative probability distribution of the water use and unitary water cost for two specific option contracts and the baseline scenario. The upper part of Figure 24 shows that water availability without the option contract (“c”) is always lower than with option contract (curves “a” and “b”). If there is no option contract among the available water sources (scenario “c”), the probability of meeting the ID's water demand (50 hm^3) is lower than with the option (52% without contract, and 57 and 63% for cases “a” and “b”, respectively). Between the two scenarios with option contract (“a” and “b”), scenario “b” allows the ID to get more water from the option contract, but for this water volume the total costs would be higher. Regarding the costs per m^3, the scenario ‘b’ is the one that entails higher costs for the ID. Scenario ‘a’ would be the one with lowest costs per m^3 among the three presented scenarios.

Figure 24. Cumulative ascending probability distribution of total water volume (hm^3) and costs (€/m^3) in the irrigation district for three scenarios (a and b, with option contract; c without option contract)



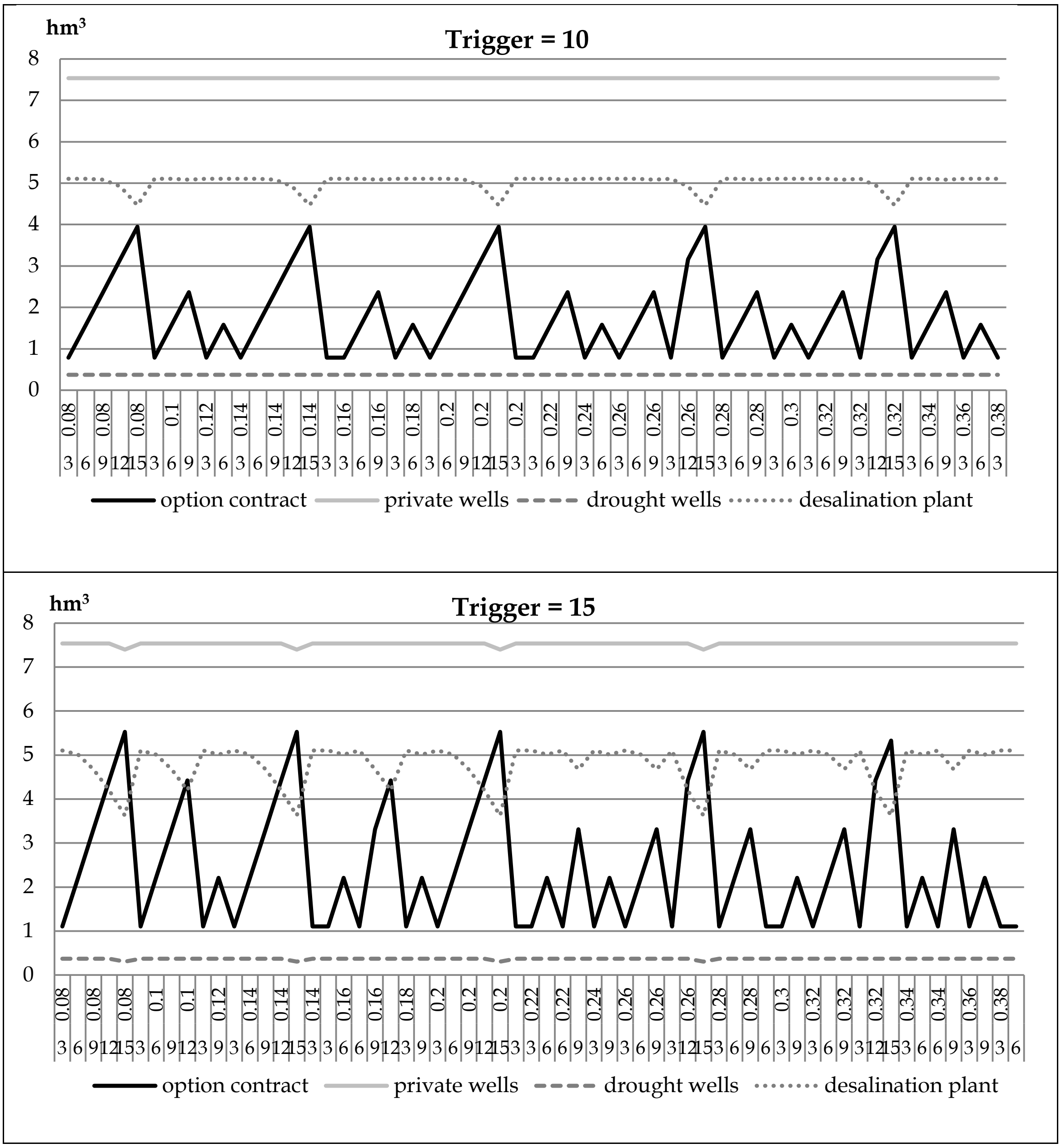


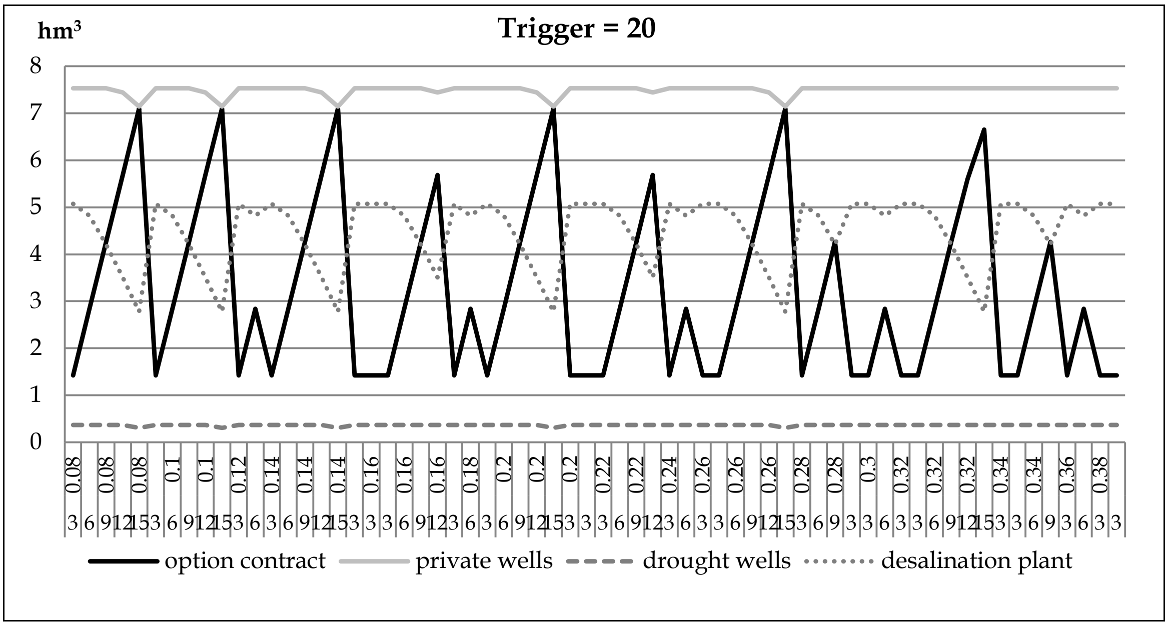
a: premium= 0.02 €/m^3 and optioned volume =3 hm^3; b: premium = 0.06 €/m^3 and optioned volume = 6 hm^3; c: without contract.

Source: Own elaboration.

A relevant issue is the amount of water volume that the ID is going to purchase from each water source. Specifically, we focus on which water sources act as substitute of the other, i.e., whether the water option contract is used instead of other water source, and vice versa (see Figure 25).

Figure 25. Water volumes from different sources, for each parameterization of the option contract (only those cases when the option is signed are shown in the graph). Volumes represent the mean of the purchased volumes in the 19 states of nature (X axis, unitary costs of the option contract (€/m^3) and optioned volume below (hm^3))





Source: Own elaboration.

Figure 25 shows that the desalinized water and the option contract are acting like substitutes between them. As the volume of water established in the option contract increases, the average volume of desalinized water purchased is reduced and substituted by water from the option seller. Average water volumes obtained from groundwater sources (private wells and drought wells) are also reduced when the ID has access to the greatest optioned volume. As Figure 21 shows, these groundwater resources are the most expensive ones after the desalinized water. However, that reduction only occurs for total option prices smaller than 0.27 €/m³ (the price of water from emergency drought wells). Table A2.1 (Appendix 2), more detailed results of the water volume obtained from different sources for several states of nature are shown. When the optioned volume is not available (because the trigger is not met, or because it was not signed in the first stage), the ID would purchase the maximum volume to the desalination plant (8 hm³) (not shown in Figure 25).

6.6. Conclusions

Irrigators have to take key production decisions facing uncertain prospects about how much water they will utilize during the season. Reducing this uncertainty improves farms' planning and promotes economic efficiency. Collective organizations (Irrigation Districts or Communities) manage water for more than two thirds of Spanish irrigation area (3.5 mill. hectares). Optimizing water procurement decisions can help IDs to reduce costs and water availability risks and help their growers be more efficient. We have developed a model to represent the water procurement decisions of an ID when different water sources are available, including water supply option contracts. This model can be applied to any other ID which relies on multiple water sources.

During drought periods, water users can rely on spot water markets to get the needed water volume to meet their demands. However, under these conditions it might be difficult to find a water seller and prices are normally high. With option contracts this situation can be avoided. Option contracts could have an important risk-reduction potential. This type of contract allows the option holder to secure access to a certain water volume for a given price (exercise price) in the future in exchange of the payment of an annual premium. As our model shows, option contracts can be combined with other sources, including groundwater, adding more flexibility to the entire source pool.

As expected, an ID would be more interested in signing the option contract when the associated costs (exercise price, premium) and the conditions (optioned volume and trigger) are more favorable for its business. The most relevant variables for this decision are the optioned volume and the premium, i.e. the cost of contracting the option. The district considers the probability of not meeting its target supply with the other available water sources and weights the cost of purchasing the option against the relative cost of the alternative water sources. Our results show that, for the considered option parameters' values, the probability of the ID signing the option contract is 48 per cent, i.e. the district would be interested in signing nearly half of the considered option contracts, and that greater optioned volumes require lower annual premiums for the district to sign the contract. Besides, when the ID signs the option contract and the trigger condition is met, the ID would always exercise the option.

The benefits in terms of reduced risk exposure of the option contract, at an average unitary cost of 1 cent of € per cubic meter, highlight its advantages for irrigation districts in water-scarce areas. Moreover, our case study considers an irrigation district that, despite being subject to a high degree of supply variability, is relatively well endowed compared with other districts in south Spain that can rely on a more restricted pool of water sources. The potential benefits of water supply option contracts for more vulnerable district are thus likely to be much superior.

In practical terms, the ID’s decisions are more complex than they are presented in our model. The main complication not addressed in the paper is finding the contract’s counterpart. Water sellers in Spain have been agricultural users that use their resources in normal years and sell them in dry years rather than right holders that have water trading as their main activity. The advantages of option contract for the former are numerous. There has also been a large multi-annual lease contract between irrigator’s associations that resembles an option contract; so we can adventure that there will also be potential option sellers. However, the obtained results are an indication of the potential of option contracts for an irrigation district facing an uncertain water supply. Our model can be further developed to include several interesting aspects, including varying levels of risk tolerance of the ID. Besides, here we are assuming that the spot price for water is known in a first stage, when uncertainty related to water availability exists. Nevertheless, the spot price would depend on the hydrological situation, increasing sharply during drought periods.

7. CONCLUSIONS

7.1. General conclusions

Water resources are essential for all users and to conserve ecosystems, but are becoming increasingly scarce and, as a consequence, more valuable. Competition for water has always existed and will be exacerbated in the coming decades. Water crises are ranked number three amongst the most relevant global risks (World Economic Forum, 2014). The same source put water supply risks at number two amongst Top 5 Global Risks in terms of impact in its annual reports of 2012 and 2013 (World Economic Forum, 2014). In these documents, as well as in many other international reports and assessments, droughts and floods embody such risks. They are considered major hazards and threats for social well-being, environmental conservation and economic development. Besides, climate change is expected to cause increase in the severity and frequency of extreme events, such as floods and droughts (Mills, 2005; IPCC, 2007, 2014). Because of its dependence on water availability and climatic conditions, agriculture is and will be one of the most affected sectors.

All water problems are policy problems. This quote by Getches (2014) cannot express it more clearly: “Water issues are typically discussed as physical problems […]. But essentially all water problems have a policy nexus. It is rare that a water problem cannot be solved if public policy can be harnessed and directed effectively. […] Often these problems of competition can be privately resolved by payments from one party to another. But public policy must intervene if water is to serve more and varied interests inasmuch as water is a public good. “Wise” choices are also inhibited, even in public decision making, unless broadbased values are represented in the process […] in the end, behaviors must be guided not by self-restraint alone, but also by a combination of regulation and market forces” (Getches, 2014 p.18).

Water problems will become more acute in a drier climate. Irrigation water demand is expected to increase in the Mediterranean region, while water resources will become scarcer. As a result of the increased competition for water, it is likely that the opportunity cost of water, and thus its price, will rise significantly, threatening the profitability of irrigated agriculture in some areas and for some crops, or at least questioning its socio-economic rationale. Apart of increased water tariffs, other allocation mechanisms to manage the sharing of water resources, such as water markets, can alleviate tensions among competing users. Once water rights are correctly established and enforced, a market for water can be created.

Water markets allow for a more efficient use of available water resources, reallocating water from low to high value uses, provided the right regulatory framework. As with other allocation mechanism, water markets have some advantages and disadvantages that should be taken into account (see section 2.3). Water markets are not the panacea to water scarcity and drought, but they can be part of the solution. Trading mechanisms should be considered together with other water management tools.

The potential of water markets as a reallocation mechanism has been evaluated in many different institutional settings and both in real and hypothetical scenarios. Some studies have also addressed its potential to reduced risks related to water availability. Despite their greatest potential for managing such risks, water option contracts have received less academic attention, and have also been less implemented in practice, than, for example, spot water markets. In the case of Spain, they have been proposed as a strategic source of water for cities during drought periods. This thesis addresses, both theoretically and empirically, their potential for agricultural users.

This thesis evaluates the role of option contracts as a water supply risk management tool for agricultural users. Focusing on the Spanish case, an assessment of the water market in the country motivates the need to improve the management of water supply availability risks. Option contracts are proposed as a possible improvement for all the advantages provided by them (see section 2.6). An empirical application to one of the most water-stressed agricultural areas in the country further highlights their benefits.

The main contributions of this thesis touch on the following aspects:

i) a deep description and evaluation of Spanish water markets;

ii) a design of an innovative inter-basin water option contract between water users in the Tagus and the Segura basins, that could be applicable to other cases;

iii) a theoretical framework to assess farmers' preferences for different water supply risk management tools, including option contracts and insurance, the farmers' WTP for them and their prices;

iv) an evaluation of the role of option contracts in the optimization of water procurement decisions under an uncertain water supply.

7.2. Spanish water markets

Since the approval of the 1999 Reform of the Water Act, several water rights exchanges have taken place in the Spanish territory, involving different water users, water resources and basins. Although market participants make a positive assessment of these experiences, which have alleviated their water availability problems during drought periods, trading activity has been limited. There are a number of shortcomings in Spanish water markets, similar to those in other countries, that can provide an explanation to this: high transaction costs, slow administrative procedures, difficulties in finding buyers/sellers, prices fixed under non-competitive regimes, rigid legislation, insufficient control of environmental externalities and unchecked market power. Overall, there is still ample room for improving their functioning.

Chapter 3 contains a thorough description of the Spanish water market, including past trading experiences, the economics of water trading and the reasons behind limited success of water markets in this country. At the end of that chapter, some improvements are proposed to overcome the main shortcomings of the regulatory system. The following conclusions about the main problems can be derived:

a) Lack of transparency. There is hardly any public information about who uses the water, for what, what are the benefits and externalities. Information availability and transparency would encourage market participation.

b) The need for more flexibility in the priorities' system in the water use.

c) The need to clarify the conditions under which those exchanges that involve more than one region could be made. Also, the integration of water trading in the process of Hydrological Planning would be desirable.

d) The existing legislation should clarify aspects such as the spatial and temporal restrictions to trading or the criteria for the approval or rejection of water exchanges by the Water Authorities (e.g. the environmental or third-party effects, social impacts and damage to cultural heritage and landscape).

e) Water prices are too high due to unbalanced negotiation standpoints among trading partners, in which sellers have a dominant position. The Government should regulate market prices making use of existing regulatory provisions.

The existence of informal water markets along the Mediterranean basins proves that there is a demand for water resources reallocation among users and for improving supply reliability. There is also a demand to manage differently quality-graded waters and allow each user to meet their requirements at the least possible cost. This demand is not met within the current regulatory framework, which is too limited and lacks provisions to cope with extremely diverse, quality graded, poorly monitored groundwater users. There is clearly a need for a new improved regulatory framework that provides sufficient flexibility for users in the most water-stressed basins, while at the same time allowing for protection of the public interests.

As important as trying to improve and encourage water markets there is also a need to achieve a deeper knowledge and understanding of how water is actually used in each Spanish basin and to control the effective use of this water while reviewing water concessions and increasing control of illegal extractions. Better control of the existing water resources and their final destination will lead to a much more efficient use of water and, eventually, will also improve the functioning of water markets.

7.3. Option contracts for water

Water option contracts have been studied in this thesis as a potential improvement for the Spanish water market. In section 2.6, the main characteristics of option contracts and the advantages derived from this trading mechanism have been discussed. The main advantage of an option contract for both the buyer and the seller is the institutional and legal stability it provides.

Chapters 4, 5 and 6 evaluate different aspects of option contracts for water. In general, results show the potential for this type of contracts for reducing water supply availability risks. Although this thesis is applied to the Spanish case, the conclusions can be extrapolated to other countries or regions experiencing water supply reliability problems.

These chapters follow a conceptual sequence, that begins with chapter 4, in which models the hydrological parameters of the contract, including a synthetic cost-benefit analysis of both the area-of-origin (Tagus Basin) and of the recipient area (Segura Basin), and performs a risk assessment using Monte-Carlo simulations. Chapter 5 delves into the potential demand of irrigators for two alternative supply risk management instruments: option contract and drought insurance. It presents the theoretical conditions under which one is preferred to the other, adding as a complement a comparison of the willingness to pay for them and the cost of both insurance and option contracts. Lastly, chapter 6 takes the original approach of modeling the optimal water procurement decisions of an irrigation district in the Segura Basin in a stochastic context, with a view to the find optimal choice of water supply sources and the decision to sign an option contract. Option contracts combined with eight other water sources, including conventional and non-conventional water sources, are analyzed with a stochastic recursive optimization model.

7.3.1. Inter-basin option contracts

The Spanish Tagus-Segura Transfer has alleviated water scarcity in the Segura Basin. It operates under management rules that depend on stochastic hydrological variables, but also under some political discretionary rule. The change implemented in 2014 with the approval of the Tagus River Basin Plan in the Transfer management rules will entail a reduction in the transferable volumes to water users in the Segura Basin, especially in dry periods. The transferred water volume from the Tagus to the Segura Basin through the Tagus-Segura Aqueduct has an enormous importance in the recipient area, both for irrigation and urban supplies. Irrigated agriculture in the Segura Basin represents an important economic activity for the GDP of the region. Guaranteeing irrigators' access to the needed water volumes and reducing their water supply availability risks is crucial for maintaining the activity of this sector.

Chapter 4 proposed an innovative inter-basin option contract to reduce the negative impacts derived from this change. The proposed option contract has two different components with different purposes. The first tranche is intended to protect Segura's irrigators in those years when the stock level in the *Entrepeñas-Buendía* reservoir (Upper Tagus Basin) is very low and thus the probability of receiving water through the transfer based on the institutional management rule is low. The second tranche of the contract would allow irrigators in the Segura Basin to have access to a higher water volume in those years when the stock level in the reservoir is high, as a compensation for the change in the Transfer's management rules.

With the new Transfer's management rule, irrigators in the Segura Basin would receive less water when the upstream storage is low, allowing for a better and faster recovery of the water stock in the Upper Tagus Basin. In these years, irrigators in the Segura Basin could have access to the first part of the option contract and purchase a certain water volume from an irrigation district in the Tagus Basin. When the stock level in the *Entrepeñas-Buendía* reservoir is high, the option contract would allow irrigators in the Segura Basin to benefit from this situation, having access to even more water than with the current rule.

Results show that the proposed inter-basin option contract would reduce the negative impacts of the change in the Tagus-Segura management rules, without compromising the main objective of this change (guarantee minimum environmental flows in the middle Tagus). Besides, the average net benefit of the whole Tagus-Segura system would increase as a result of the proposed inter-basin option contract. Therefore, the establishment of a similar agreement as the one proposed here could have important benefits for the whole system, and it would allow to maintain the high-productive agriculture in the Segura Basin.

7.3.2. Farmer's preferences for different water supply risk management tools (option contracts and drought insurance)

Water supply uncertainty is one of the main risks faced by irrigators. Chapter 5 presents a theoretical framework to obtain farmer's willingness to pay for option contracts and drought insurance, and the tentative prices of these risk management tools. From the application of this theoretical framework to one of the most productive irrigation districts in Spain (*Campo de Cartagena*, Segura Basin) it can be concluded that farmers would be willing to pay a considerable amount of money for reducing their water availability risks through option contracts or drought insurance. This shows the relevance of reducing water supply risks for irrigators, conforming to the previous literature.

Results show that farmers' decisions to contract a water supply option or a drought insurance policy depends on his attitudes towards risk, profit function, risk premium for each instrument, the administrative additional costs and fees, and the trustworthiness of the instrument. Unlike option contracts, an insurance policy transfers the water supply risk outside the water and agricultural markets. This feature may be crucial and worth pursuing under conditions of extreme scarcity and very unstable sources.

The WTP values are consistent with previous works in the same area, and higher than the obtained prices for these tools, highlighting the feasibility of these risk reduction mechanisms for protecting farmers in the region. Droughts are recurrent phenomena in Spain. Thus, the development of tools to reduce water users' risks is crucial and the potential demand for them is high.

Currently, neither water option contracts nor drought insurance exist in Spain. However, the potential of these risk management tools has been considered and studied. The Spanish insurance system is one of the most developed worldwide (OECD, 2011), so our country has the needed legal and institutional framework to implement drought insurance policies. Besides, the familiarity of farmers with crop insurance might favor the success of this mechanism. On the contrary, legislative changes would be needed for the establishment of option contracts in the Spanish water market, together with activities aimed at encouraging the participation of farmers in the water market.

7.3.3. Finding irrigation district's optimal water procurement decisions: the role of option contracts

Taking optimal water procurement decisions is essential to increase users' supply reliability and reduce costs. The resource to temporary water markets, such as spot purchases or water supply option contracts, can provide flexibility to this decision process.

In chapter 6 a stochastic recursive mathematical programming model is applied to simulate the water procurement decisions of an irrigation district in a context of water supply uncertainty and analyze the role that different option contracts may play to secure its water supply.

Results show that the irrigation district would be more interested in signing the option contract when the associated costs (exercise price, premium) and the conditions (optioned volume and trigger) are more favorable for its business. The contract's premium and optioned volume are the variables that have a greater impact on irrigation district's decisions. When the optioned volume is not available because the option was not previously signed or because the trigger is not met, the irrigation district would have to rely on more expensive water resources, such as desalinized water. Option contracts and desalinized water are substitutes within the pool of water sources. Water from desalination plants is extremely expensive, and irrigation districts only resort to it during drought periods when there is no other alternative. If drought insurance, such as the one proposed in chapter 5 were available for farmers, the received compensation could be used to buy water from another water source, including desalinized water.

The large benefits in terms of reduced risk exposure of the option contract, at an average increased unitary cost of 1 cent of € per cubic meter, highlight its advantages for irrigation districts in water-scarce areas. These benefits could be even higher for other irrigation districts with access to a more restricted water supply.

7.4. Limitations and further research

This thesis represents an attempt to evaluate the potential of option contracts for reducing water supply availability risks. Different aspects of option contracts have been studied and interesting results have been obtained. However, there are some limitations or aspects that should be further developed:

- More sophisticated and complex versions of the inter-basin option contract presented in chapter 4 could be developed. This thesis represents the first step in the design of this kind of water sharing mechanisms in such a unique case. Different versions of the proposed water option contract could be further studied.

- The theoretical framework presented in chapter 5 gives us an approximation to the farmer's willingness to pay for different water supply risk management tools. All the needed assumptions to obtain the mathematical expressions of the risk premium for each case could be affecting the real values of the WTP, but they are essential for carrying out the analysis. Relaxing some of the most offensive assumptions would represent a natural continuation of this thesis.

- The two-stage stochastic recursive optimization model developed in chapter 6 does not take into account the risk aversion level of the irrigation district's managers. Risk aversion, should it be large, would affect the water procurement decisions. Thus, the model could be further developed in order to include risk aversion or alternative types of risks preferences in the decision process.

- Water markets are only part of the solution to achieve an efficient allocation of water resources. The combination of water markets with other economic or administrative instruments is desirable. The role of water markets in the whole allocation system could be further assessed, as well as the most suitable mechanisms to be established together with water markets.

- In this thesis, the potential of option contracts as risk reduction tools has been studied from the point of view of a farmer or irrigation district, because agriculture is the main water user in Spain. Similar interest for water option contracts could be expected for other water users, as urban water suppliers, industries or the government (for the preservation of minimum environmental flows). The analysis carried out here could be applied to any other water sector, basin or country.

- Although an evaluation of the prices of option contracts has been done in chapter 6, this thesis is mainly focused on the demand side of the instrument. The analysis of the supply side of water option contracts, the definition of their functioning, the contract terms, and the required legislative framework would be very interesting to have the whole picture.

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APPENDIX 1

A: Farmer's expected utility with no risk management tool

$$EU_0(\tilde{\pi}) = \int_0^{\overline{w}} U(\tilde{\pi}_0) f(w) dw = \int_0^{\overline{w}} \left[1 - e^{-r(a+bw)}\right] f(w) dw$$

$$= \int_0^{\overline{w}} f(w) dw - \int_0^{\overline{w}} e^{-ra} e^{-rbw} f(w)\, dw$$

$$= 1 - e^{-ra} \int_0^{\overline{w}} e^{-rbw} f(w)\, dw$$

$$= 1 - e^{-ra} MGF_w(-rb) \qquad \text{(a.1)}$$

B: Expected utility and risk premium with option contract (a)

B.1)

$$EU_{opt_a}(\tilde{\pi}) = Z \int_0^{w_g} \left[1 - e^{-r\left(a+bw_g-P_{opt_a}-P_e\left(w_g-w\right)\right)}\right] f(w) dw +$$

$$(1-Z) \int_0^{w_g} \left[1 - e^{-r\left(a+bw-P_{opt_a}\right)}\right] f(w) dw + \int_{w_g}^{\overline{w}} \left[1 - e^{-r\left(a+bw-P_{opt_a}\right)}\right] f(w) dw =$$

$$Z\gamma - Ze^{-r(a+bw_g-P_{opt_a}-P_e w_g)} LIMGF_w(-rP_e) + \gamma - e^{-r(a-P_{opt_a})} LIMGF_w(-rb) - Z\gamma +$$

$$Ze^{-r(a-P_{opt_a})} LIMGF_w(-rb) + (1-\gamma) - e^{-r(a-P_{opt_a})} UIMGF_w(-rb) =$$

$$1 - e^{-r(a-P_{opt_a})}\left(UIMGF_w(-rb) + LIMGF_w(-rb)\right) -$$

$$Ze^{-r(a+bw_g-P_{opt_a}-P_e w_g)} LIMGF_w(-rP_e) + Ze^{-r(a-P_{opt_a})} LIMGF_w(-rb) = 1 -$$

$$e^{-r(a-P_{opt_a})} MGF_w(-rb)$$

$$-Ze^{-r(a+bw_g-P_{opt_a}-P_e w_g)} LIMGF_w(-rP_e) + Ze^{-r(a-P_{opt_a})} LIMGF_w(-rb) \qquad \text{(b.1)}$$

B.2)

$$EU_0(\tilde{\pi}) = EU_{opt_a}(\tilde{\pi})$$

$$1 - e^{-ra} MGF_w(-rb)$$

$$= 1 - e^{-r(a-R_{opt_a})} MGF_w(-rb) - Ze^{-r(a+bw_g-R_{opt_a}-P_e w_g)} LIMGF_w(-rP_e)$$

$$+ Ze^{-r(a-R_{opt_a})} LIMGF_w(-rb)$$

$$-e^{-ra} MGF_w(-rb) = -e^{-ra} e^{rR_{opt_a}} \left[MGF_w(-rb) + Ze^{-r(b-P_e)w_g} LIMGF_w(-rP_e) \right]$$

$$- ZLIMGF_w(-rb)$$

$$R_{opt_a} = \frac{1}{r} \; ln\left(\frac{MGF_w(-rb)}{(1-Z)\; MGF_w(-rb) + \mathrm{Z}\left[e^{-r(b-P_e)w_g} LIMGF_w(-rP_e) + UIMGF_w(-rb) \right]} \right) \qquad \text{(b.2)}$$

C: Upper Incomplete Moment Generation Function (UIMGF)

We consider that variable $\tilde{w}$ follows a Gamma distribution$f(w)$:

$$f(w) = \frac{\lambda^{\alpha}}{\Gamma(\alpha)} w^{\alpha-1} e^{-\lambda w}$$

$$UIMGF_w(-rb) = \int_{w_g}^{\overline{w}} e^{-rbw} \frac{\lambda^{\alpha}}{\Gamma(\alpha)} w^{\alpha-1} e^{-\lambda w}\, dw = \left[-\frac{\lambda^{\alpha} w^{\alpha} E_{1-\alpha}((\lambda+rb)w)}{\Gamma(\alpha)} \right]_{w_g}^{\overline{w}} \qquad \text{(c.1)}$$

E is an exponential integral function.

$$E_n(z) = z^{n-1} \Gamma(1-n, z)$$

$$E_{1-\alpha}\big((\lambda+rb)w\big) = \big((\lambda+rb)w\big)^{-\alpha} \Gamma(\alpha, (\lambda+rb)w)$$

So, the expression of $UIMGF_w(-rb)$ is:

$$UIMGF_w(-rb) = -\frac{\lambda^\alpha}{\Gamma(\alpha)}\left[w^\alpha\left(w(\lambda+rb)\right)^{-\alpha}\Gamma(\alpha,(\lambda+rb)w)\right]_{w_g}^{\overline{w}} =$$

$$-\frac{\lambda^\alpha}{\Gamma(\alpha)}\left[(\lambda+rb)^{-\alpha}\Gamma\left(\alpha,(\lambda+br)w_g\right)\right]_{w_g}^{\overline{w}} = \frac{\lambda^\alpha}{(\lambda+rb)^\alpha}\left[\frac{-\Gamma(\alpha,(\lambda+rb)w_g)}{\Gamma(\alpha)}\right]_{w_g}^{\overline{w}} = MGF_w(-rb)(\left[Q\left(\alpha,(\lambda+rb)w_g\right)\right] - \left[Q(\alpha,(\lambda+rb)\overline{w})\right]) \quad \text{(c.2)}$$

$Q(.)$ is the regularized gamma function, whose domain is [0,1].

D: Expected utility and risk premium with option contract (b)

If we assume that the irrigator will always exercise the option at the maturity date when his water allotment is below w_g, his profit function is:

$$\tilde{\pi}_{opt_b}(w) = a + b\widetilde{w} - P_{opt_b} \quad if\ \widetilde{w} \geq w_g$$

$$\tilde{\pi}_{opt_b}(w) = a + b\mathrm{w}_g - P_{opt_b} - P_e(w_g - \widetilde{w}) \quad if\ \widetilde{w} < w_g$$

D.1)

$$EU_{opt_b}(\tilde{\pi}) = \int_0^{w_g}\left[1 - e^{-r\left(a+bw_g-P_{opt_b}-P_e(w_g-w)\right)}\right]f(w)dw$$

$$+\int_{w_g}^{\overline{w}}\left[1 - e^{-r\left(a+bw-P_{opt_b}\right)}\right]f(w)dw = \gamma - e^{-r\left(a+bw_g-P_{opt_b}-P_e w_g\right)}\int_0^{w_g} e^{-rP_e w} f(w)dw + (1-\gamma) - e^{-r\left(a-P_{opt_b}\right)}\int_{w_g}^{\overline{w}} e^{-rbw} f(w)dw = 1 - e^{-r\left(a+bw_g-P_{opt_b}-P_e w_g\right)}LIMGF_w(-rP_e) - e^{-r\left(a-P_{opt_b}\right)}UIMGF_w(-rb) \quad \text{(d.1)}$$

D.2)

$$EU_0(\tilde{\pi}) = EU_{opt_b}(\tilde{\pi})$$

$$1 - e^{-ra}MGF_w(-rb)$$

$$= 1 - e^{-r\left(a+bw_g-R_{opt_b}-P_e w_g\right)}LIMGF_w(-rP_e) - e^{-r\left(a-R_{opt_b}\right)}UIMGF_w(-rb)$$

$$-e^{-ra}MGF_w(-rb)$$

$$= -e^{-r\left(a+bw_g-R_{opt_b}-P_e w_g\right)}LIMGF_w(-rP_e) - e^{-r\left(a-R_{opt_b}\right)}UIMGF_w(-rb)$$

$$MGF_w(-rb) = e^{rR_{opt_b}}\left[e^{-r(b-P_e)w_g}LIMGF_w(-rP_e) + UIMGF_w(-rb)\right]$$

$$R_{opt_b} = \frac{1}{r}\, ln\left(\frac{MGF_w(-rb)}{e^{-r(b-P_e)w_g}LIMGF_w(-rP_e) + UIMGF_w(-rb)}\right) \quad (d.2)$$

E: Expected utility and risk premium with insurance

Farmer's profit function in this case is:

$$\tilde{\pi}_{ins}(w) = a + b\widetilde{w} - P_{ins} \quad if\ \ \widetilde{w} \geq w_g$$

$$\tilde{\pi}_{ins}(w) = a + \mathrm{b}w_g - P_{ins} \quad if\ \ \widetilde{w} < w_g$$

E.1)

$$EU_{ins}(\tilde{\pi}) = \int_0^{w_g} 1 - e^{-r\left(a+bw_g-P_{ins}\right)} f(w)dw +$$

$$\int_{w_g}^{\overline{w}} 1 - e^{-r(a+bw-P_{ins})} f(w)dw =$$

$$\gamma - \gamma e^{-r\left(a+bw_g-P_{ins}\right)} + (1-\gamma) - e^{-r(a-P_{ins})}UIMGF_w(-rb) = 1 - \gamma e^{-r\left(a+bw_g-P_{ins}\right)} -$$

$$e^{-r(a-P_{ins})}UIMGF_w(-rb) \quad (e.1)$$

E.2)

$$EU_0(\tilde{\pi}) = EU_{ins}(\tilde{\pi})$$

$$1 - e^{-ra}MGF_w(-rb) = 1 - \gamma e^{-r\left(a+bw_g-R_{ins}\right)} - e^{-r(a-R_{ins})}UIMGF_w(-rb)$$

$$R_{ins} = \frac{1}{r}\, ln\left(\frac{MGF_w(-rb)}{\gamma e^{-rbw_g} + UIMGF_w(-rb)}\right) \quad \text{(e.2)}$$

F: Comparison of instruments

Comparison between the two option contracts (a) and (b)

First the comparison of the risk premiums is presented; and then the assessment of the conditions that make one instrument more attractive to the farmer than the other. R_{opt_b} is going to be higher than R_{opt_a} for all cases. Intuitively, the same conclusion can be obtained, as the option contract (b) offers higher guarantees than contract (a), allowing the farmer to purchase the optioned volume at the maturity date with higher probability.

If $R_{opt_b} > R_{opt_a}$, then:

$$e^{-r(b-P_e)w_g}LIMGF_w(-rP_e) + UIMGF_w(-rb)$$
$$< (1-Z)\, MGF_w(-rb) + \mathrm{Z}\left[e^{-r(b-P_e)w_g}LIMGF_w(-rP_e) + UIMGF_w(-rb)\right]$$

$$e^{-r(b-P_e)w_g}LIMGF_w(-rP_e) + UIMGF_w(-rb) < MGF_w(-rb) \quad \text{(g.1)}$$

For R_{opt_b} to be positive, the above expression must hold (as the numerator of the logarithm, on the right side of the expression has to be higher than the denominator, on the left side).

The conditions that determine the participation of the farmer in the option contract or the insurance are obtained:

$$P_{opt_b} - P_{opt_a} < \frac{1}{r} \ln\left(\frac{D_{opt_a}}{D_{opt_b}}\right) \tag{g.2}$$

If $P_{opt_b} < P_{opt_a} + \frac{1}{r} \ln\left(\frac{D_{opt_a}}{D_{opt_b}}\right)$; he would choose the option contract (b). And if $P_{opt_b} > P_{opt_a} + \frac{1}{r} \ln\left(\frac{D_{opt_a}}{D_{opt_b}}\right)$; he would purchase the option contract (a) (D_{opt_a} is always higher than D_{opt_b}). The farmer would be indifferent between them if $P_{opt_b} = P_{opt_a} + \frac{1}{r} \ln\left(\frac{D_{opt_a}}{D_{opt_b}}\right)$.

APPENDIX 2

Table A2.1. Optimization results for several states of nature (k) under different parameterizations of the option contract.

OP (€/m³)	$A_{opt,k}$ (hm³)	P_{opt} (€/m³)	T (hm³)	k	Total volume (hm³)	option contract	desalinized water	Groundwater†	Rest of sources
						Volume from different sources (%)			
0.08	3	0.06-0.3	10;15;20	1	34.20	8.77	23.39	36.17	31.67
			10;15;20	3	39.59	7.58	20.21	31.25	40.97
			10	7	44.29	0	18.06	25.29	56.65
			15; 20		47.29	6.34	16.92	23.68	53.06
			10;15;20	13	50.00	0	7.14	22.40	70.44
			10; 15; 20	18	50.00	0	0	17.90	82.10
0.06	6	0.06-0.3	10;15;20	1	37.20	16.13	21.51	33.25	29.11
			10; 15; 20	3	42.59	14.09	18.78	29.04	38.08
			10	7	44.29	0	15.42	25.29	56.65
			15; 20		50.00	12.00	15.42	22.40	50.18
			10; 15; 20	13	50.00	0	7.14	22.40	70.44
			10;15;20	18	50.00	0	0	17.90	82.10
0.04	9	0.06-0.3	10;15;20	1	40.2	22.39	19.90	30.77	26.94
			10;15;20	3	45.59	19.74	17.55	27.13	35.58

			10	7	44.29	0	18.06	25.29	56.65
			15;20		50.00	18.00	9.42	22.40	50.18
			10;15;20	13	50.00	0	7.14	22.40	70.44
			10;15;20	18	50.00	0	0	17.90	82.10
0.02	12	0.06-0.3	10;15;20	1	43.2	27.78	18.52	28.63	25.07
			10;15;20	3	48.59	24.67	16.461	25.46	33.38
			10	7	44.29	0	18.06	25.29	56.65
			15;20		50	24.00	3.42	22.40	50.18
			10;15;20	13	50	0	7.14	22.40	70.44
			10;15;20	18	50	0	0	17.90	82.10
0.02	15	0.06-0.3	10;15;20	1	46.20				
			10;15;20	3	50	30.00	12.82	24.74	32.44
			10	7	44.29	0	18.06	25.29	56.65
			15;20		50	30.00	0	19.82	50.18
			10;15;20	13	50	0	7.14	22.40	70.44
			10;15;20	18	50	0	0	17.90	82.10

†Groundwater sources: private wells, drought wells and ID's own wells.

P_{opt}: exercise price; *OP*: premium, $A_{opt,k}$: optioned volume, T : trigger; k : state of nature.