Design of optimum private insurance schemes as a means to reduce water overexploitation during drought events. A case study in Campo de Cartagena (Segura River Basin, Spain)

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Abstract

Water is a key input in the production of many goods and services and under certain conditions can become a critical limiting factor with significant impacts on regional development. This is the case of many agricultural European Mediterranean basins, where water deficit during drought events is partially covered by illegal abstractions, mostly from aquifers, which are tolerated by the authorities. Groundwater overexploitation for irrigation has created in these areas an unprecedented environmental catastrophe that threatens ecosystems sustainability, urban water supply and the current model of development. Commercial drought insurance systems have the potential to introduce the necessary incentives to reduce overexploitation during drought events and the high costs of the drought indemnity paid by the government. This paper develops a methodology to obtain this socially desirable basic risk premium based on concatenated stochastic models. The methodology is applied to the agricultural district of Campo de Cartagena (Segura River Basin, Spain). Results show that the basic premiums in a hypothetic commercial drought insurance market would be reasonable and the expected environmental outcomes significant.

Keywords [Drought insurance, stochastic models, groundwater, agriculture, Drought Management Plan]

JEL code (Q15, Q18, Q25, Q51, Q58 - see: www.aeaweb.org/jel/guide/jel.php?class=Q)

1. **Introduction**

Water is an economic asset that might be managed efficiently and sustainably (Winpenny, 1994). However, in the allocation of water resources, the criteria and methods of economic analysis have historically played a secondary role. Prevailing political consensus considers that water management policies must play an instrumental role aimed at providing a package of services, which are either essential for life or strategic for the economy. Besides that, it is believed that its demand, therefore, must be taken as exogenously defined outside the field of water management policy (Saleth and Dinar, 1999). Following this paradigm, water policy in the European countries has been almost exclusively oriented to guarantee the public provision of water services at subsidized prices. This paradigm has inevitably resulted in the overexploitation of water resources, especially in arid and semi-arid Mediterranean regions. Instead of using economic instruments to adjust prices of water to their real cost, traditional response has consisted of the implementation of palliative command and control policies with limited or even negative impact.

As a result, water agencies and water users have been insulated from the influence of market forces (Dinar, 2000; Young, 2005). In such a frame, instead of leading to higher prices that reduce demand and encourage greater efficiency in the multiple uses of water, the limited water availability and the public support to put increasing amounts of water services available to users has led to a growing demand for water infrastructures. This has led to water overuse, has worsened shortages and has deepened the water crisis (Dinar and Saleth, 2005; Dinar and Subramanian, 1997).

Water scarcity in Southern European Regions poses a significant menace over riparian ecosystems sustainability, development dynamics and even household supply. Although command and control policies are still being applied, it is generally acknowledged that the current situation cannot be reverted only with regulation (CE, 2000 and 2007). However, the reversion of current dynamics is complicated. The complexity of social-ecological systems makes them unpredictable, and the effects of policy interventions can be highly uncertain. Surprise and crisis are regular occurrences. This uncertainty, coupled with legacies of past management actions, often leaves decision makers few options other than to reinforce the current trajectory of the system with further command and control policies (Anderies, 2004, 2005 and 2006). Therefore decision making becomes reactive and incremental as the system moves from one crisis to another (Gunderson, 2001), and ultimately the system becomes extremely vulnerable to external shocks.

This dynamics are present in several agricultural Mediterranean catchments. As a result water scarcity has become a central issue in the European agenda (EC, 2000 and 2007). To avoid this perverse cycle, the Water Framework Directive in its article 9 acknowledges the limited impact of traditional command and control policies and advocates instead for the implementation of Economic Policy Instruments (EPIs) for water management (EC, 2000). These instruments can adapt water demand to available resources, but so far there are only a few case studies on EPIs and water management available in Europe.

Population and economic growth of the last two decades in Southern European countries have significantly increased water demand from urban areas. However, the main water consumer continues being agriculture (EEA, 2009), which is largely responsible of the structural water deficit characteristic of many semi-arid Mediterranean basins. Water overexploitation in these areas is especially intense during drought events, *which makes drought insurance one of the EPIs with the highest potential to prevent water overexploitation*.

Agricultural insurances are generally plagued by problems of moral hazard and adverse selection due to asymmetric information between the insurer and the insured (Miranda, 1991). Climate change dynamics is also a factor of risk (Bielza et al., 2008b). Although relevant, these problems have been addressed by recent research with increasing success (Genovese et al., 2001; Senay and Verdin, 2003; Wilkens, 2003; Bielza et al., 2004; Vedenoy and Barry, 2004; World Bank, 2005; Bryla and Syrpka, 2007; Dick, 2007; Breustedt et al., 2008) and are outside the scope of this paper. However, it is important to keep in mind that these problems add up to the uncertainty inherent to catastrophic events and may increase the basic risk premium.

What is more difficult to resolve is the uncertainty on the institutional performance during a drought. In the case of a drought event, irrigation restrictions in Southern European regions are subject to the discretionary assessment made by institutions. As drought is a highly systemic risk and the institutional response is difficult to predict, authorities commit themselves to cover the unexpected financial losses in which the private agents may incur. This income safety net largely removes the incentives to estimate an accurate risk premium and to implement an efficient supervision mechanism. Consequently, the operating costs in the insurance market are high, and so are the public expenses to cover them (Miranda, 1991; Bielza et al., 2008b). More importantly, illegal water abstractions, especially from aquifers, become the real insurance system for income stabilization as they offer 100% income coverage during droughts[1] and are scarcely controlled and rarely pursued and punished (Gómez and Pérez, 2012).

As a result, although commercial drought insurance is regarded as more efficient and effective both financially and environmentally than mixed insurance systems (Meuwissen et al., 2003), the latter prevail in Southern European countries such as Italy, France or Spain, where the percentage of subsidies over total indemnity equals 67%, 35% and 49%, respectively (Bielza et al., 2008a; OECD, 2011; Enjolras et al., 2012). This institutional framework is changing in some European basins as River Basin Management Plans (RBMPs) are approved and the former discretionary decision rules are progressively being replaced by Drought Management Plans (DMPs)[2]. With the new RBMPs basin authorities have to show a clear commitment to improve the quantitative status of water bodies and stop illegal water abstractions. On the other hand, DMPs are specifically intended to avoid water overexploitation during drought events[3]. To do so, DMPs introduce a set of objective indicators which clearly specify when and what restrictions have to be put in force in case of a drought event for every type of water use. If properly enforced, drought indicators allow the removal of institutional arbitrariness and the introduction of a new insurance framework under which uncertainty is considerably reduced. This framework favors a new insurance design

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[1] In order to avoid moral hazard behavior, commercial insurance only covers a percentage of the total losses (Miranda, 1991).

[2] DMPs are not prescriptive and only a few European regions have DMPs in force, although the European Commission earnestly recommends their use. Basins from UK, Spain, Portugal, Finland, Italy, Netherlands and France have presented DMPs (EC, 2008).

[3] However, DMPs focus mainly on surface waters management and barely take into consideration groundwater (nor other alternative sources), which in semi-arid Mediterranean basins is a key resource. Without a serious institutional commitment to stop illegal groundwater abstractions and without the implementation of efficient and effective commercial drought insurance, DMPs may strengthen incentives towards illegal groundwater overexploitation in several Mediterranean areas, instead of saving water (Gómez and Pérez, 2012).

which makes possible a larger private capital share in insurance systems. Consequently a more accurate premium and a better surveillance mechanism can be put into place and relevant welfare gains can be obtained. *The main hypothesis of this paper is that under this new framework the informal, spontaneous and individual insurance system consisting of illegal water abstractions can be replaced by a coherent and formal collective risk sharing scheme*.

The paper assesses the expected financial and environmental performance of this new framework. The methodology consists of concatenated stochastic models and an institutional decision model which serve to estimate the likelihood of every possible drought scenario and its expected impact over agricultural production. From these values, a basic risk premium for commercial drought insurance is obtained. The methodology is illustrated with an application to the ligneous crops of a Mediterranean agricultural district in Spain (Campo de Cartagena to the south east). The reason to choose Spain is twofold: i) first, as Spain suffers frequent droughts, it has been pioneer in the introduction of DMPs in the European Union and all its relevant basins have already approved their respective DMPs; ii) second, the Spanish insurance system is the most developed in Europe, with all the insurance companies operating within a pool that assumes the risk in a co-insurance regime, which offers a good scenario to test our hypothesis.

Our results show that premiums under this hypothetic commercial drought insurance market would be reasonable and the expected environmental outcomes significant. This methodology is general and can be replicated in any Mediterranean catchment or agricultural district.

The paper is structured as follows: the second section introduces the area of the case study, the agricultural district of Campo de Cartagena in the Segura River Basin (SRB), Spain; the third section describes the methodology; the fourth section displays the results; and the fifth section concludes.

2. Background for the case study: Campo de Cartagena, Segura River Basin (Spain)

The semiarid SRB has significant competitive advantages for irrigated agriculture because the land is abundant and cheap and few alternative uses for the land exist. Furthermore, solar radiation is guaranteed and, apart from the abundance of cheap labor, many of these areas are located near high-demand markets. In fact, everything except water seems to be in place for developing a prosperous agricultural sector.

Water demand in the SRB, which comes mainly from irrigated lands (85%), is much larger than available water resources (CHS, 2010a). Besides, this demand is growing steadily: in 2003, the ratio between water abstraction and renewable resources was an alarming 1.27; by 2009, this ratio had shot up to 2.5, denoting the most serious case of overexploitation in Europe (EEA, 2009). Authorities have tried to stop water demand growth by implementing a set of command and control policies which included the prohibition to issue additional water rights for irrigation since 1986. However, only between 1990 and 2000 irrigated land grew at an average rate of 6,500 ha/year. This illegal surface was estimated to equal 100,000 ha in the year 2005 (IDRUICM, 2005) and since then has continued growing. Illegal irrigated lands are supplied with illegal resources, mostly from aquifers[4]. However, rather than enforcing property rights by

[4] The SRB accumulated groundwater overexploitation amounts to 7,000 million cubic meters (hm^3) (CHS, 2010b), including aquifers whose resources have been exhausted to such a degree that, even in the absence of more abstractions, it would take more than a century for them to completely recover.

closing illegal mills, the traditional response has been to tolerate offenders[5] (CHS, 2010a; Llamas, 2007). Not surprisingly, the drought risk has increased along with the increase in water scarcity, and under the current water supply and demand a drought can occur in one of every six years (Gómez and Pérez, 2012). During these extreme events regulated surface water use is restricted and neglected groundwater becomes *de facto* the cheapest possible agricultural drought insurance.

Campo de Cartagena, in the SRB, is an agricultural district with approximately 13,000 ha of irrigated ligneous crops (28.9% of the total irrigated land). Water demand for irrigation amounts to 58 million cubic meters (hm^3) in a normal hydrological year. Approximately 16.7 hm^3 of irrigation demand is supplied by the three aquifers in the area (Carrascoy, Victorias and Campo de Cartagena). These aquifers are overexploited even in normal hydrological years (CHS, 2010a; MARM, 2007), and in average 36% of total abstractions are non-renewable. (CHS, 2010a). Although it suffers from severe water scarcity, Campo de Cartagena is one of the largest and most profitable irrigated areas in Spain (CHS, 2010a), with production levels well over 20,000 kg/ha for some fruit trees (such as lemon, *Citrus reticulata*, orange and *Prunus persica*s) (Pérez et al., 2011). Thus, the incentives for aquifer overexploitation are high, even in the presence of high abstraction costs.

3. **Methodology**

The viability of a commercial insurance depends on the experimental design of the feasible scenarios with their associated financial losses and their corresponding probabilities, from which the basic risk premium is estimated (Skees and Barnett, 2001)[6]. Basic risk premium is the key element in the design of commercial insurance and is estimated as the ratio between the expected indemnity (a function of expected losses) and the expected production in a reference year (in this case, a normal –or expected- hydrological year). However, basic risk premiums should not be confused with actual risk premiums paid by insured agents. Basic insurance premium is exclusively a reference value for the calculation of the actual insurance premium. The latter are larger because of several reasons: i) first, farmers and public administration are risk averse and their willingness to pay in order to transfer part of the risk they bear to an insurance agent is greater than the expected drought losses; ii) second, the implementation of an insurance system requires that an agent constitutes a financial fund in which stochastic indemnities are compensated by the money paid by the insured, and this fund has intrinsic operating costs which are assumed by the agent and have to be recovered; iii) third, agricultural insurance markets are generally plagued by adverse selection and moral hazard problems that may generate additional losses for the insurer (Miranda, 1991); iv) last, the effect of external variables such as climate change over insurance markets is difficult to assess, adding uncertainty (Bielza et al., 2008b).

This is the case of the Alcoy-Sopalmo aquifer, where during some hydrological years it has been pumped out twenty times its renewable resources (CHS, 2010b).

[5] The concession of new water use rights has been legally forbidden in the Segura River Basin since 2005, when aquifers were declared overexploited. Nevertheless, agricultural use increased by 5% each year since 2005 (CHS, 2010a and 2011). This is possible because of a lack of control over irrigation water demand. For example, only 155,313 ha of the 225,356 ha irrigated in the Region of Murcia (71.4% of the total irrigated land in the SRB) are officially registered by the water authority.

[6] Although alternative coverage methods do exist, such as index financial products or derivatives, they are still in their early stages and are usually experimental designs (Barnett et al., 2005; Bielza et al., 2008b).

Actuaries estimate the expected indemnity and the expected production from the assessment of the historical evolution of the insured product (Martin et al., 2001), which follows a non-deterministic pattern. The following methodology allows the calculation of these values and the resulting basic risk premium through the development of a risk-production model which depends on three stochastic variables (rainfall, runoff and stock) and a set of institutional decision rules. The model is made up of three stages:

i) The first stage uses a standard method to obtain water requirements for each ligneous crop. We compare the evapotranspiration requirements with the amount of water available, which is from the following five sources: three stochastic sources (rainwater, runoff and stored water), the existing stock of groundwater and a variable but deterministic amount of non-conventional sources (wastewater reuse and desalinated water). Finally, the amount of water to be delivered to the irrigation system is determined in accordance with the two alternative decision rules (traditional vs. drought contingency rules). This serves to measure the resulting excess demand for water as well as the moral hazard incentive to engage in illegal abstractions.

ii) The second stage develops a deterministic agronomic model. This model allows us to estimate agricultural yield for every crop as a function of the percentage of evapotranspiration satisfied in i).

iii) Finally the basic risk premium is estimated as the ratio of the expected drought indemnity to the expected production value (which are both a function of the production obtained in ii) and the probabilities estimated in i)).

3.1. First Stage. The decision context: water requirements and water availability

Following the Spanish Ministry of Environment standard method (MARM, 2011)[7], the amount of water required by a single crop, or its evapotranspiration (ET), is measured by using the evapotranspiration registered during the period from 1941 to 2009 (MARM, 2011). In the case of irrigated crops, these water requirements are partially covered by the effective rainfall (ER) received from nature, which is a function of rainfall (a stochastic variable in the model). Thus, the amount of water required from the irrigation system, or the agronomic water required (WR) by a particular crop, is equivalent to the difference between the crop's evapotranspiration (ET) and the effective rainfall (ER). Agronomic water requirements can either be satisfied or not satisfied, depending on the region's natural capital (stochastic runoff) and human capital (surface water stored).

The effective coverage of the agronomic water requirements depends on three stochastic variables: rainfall, runoff and surface water stored. We consider the probability density function (PDF) of these three factors to determine the water supply at any moment in time.

3.1.1. Effective Rainfall

[7] MARM methodology follows a combination of the Thornthwaite and Penman-Monteith Methods (see, for example, Allen et al., 2006).

Effective rainfall (ER) is the amount of rainfall in mm (p) that effectively contributes to satisfy evapotranspiration[8]:

$$ER = g(p) \quad [1]$$

To represent ER_i under every possible state of nature, the observed data were adjusted to a probability density function (PDF)[9] that allows assigning a probability ($y = z(p)$) to each rainfall level (p). This function is obtained as the best fit gamma function[10] of the following type (McWorther et al., 1966; Martin et al., 2001; Gómez and Pérez, 2012):

$$y = z(p|a,b) = \frac{1}{b^a \Gamma(a)} p^{a-1} \exp(\frac{-p}{b}) \quad [2]$$

where *a* and *b* are, respectively, the scale and the shape parameters. Table 1 presents the maximum likelihood estimators (MLEs) of this function's parameters. Higher probabilities correspond to rainfall levels that are low or even very low for a region supporting a highly productive and water-dependent agriculture.[11]

Table 1: Rainfall Gamma function. The dependent variable is mm of rainfall.

Variable	Coefficient
a (scale)	16.358[a]
	(2.821)
b (shape)	22.9964[a]
	(2.286)
No. of observations	68

Estimated by maximum likelihood. Standard errors in parentheses.
a: significant at 1 the per cent level.
Source: Authors' elaboration from MARM, 2011

The water deficit (WR) representing the part of evapotranspiration (ET) that is not covered by effective rainfall (ER) is also a stochastic variable, which can be defined as:

$$WR = ET - g(p) \quad [3]$$

3.1.2. Runoff

The amount of water available to cover the agronomic water requirements is estimated using two proxy variables measured in percentage units. The first proxy variable is the percentage of annual cumulative runoff over the river basin surface water storage

[8] Effective rainfall (ER) is estimated using the Soil Conservation Service–USDA methodology for Spain (Cuenca, 1989), and it is a function of humidity deficit (f(D)), rainfall (p) and evapotranspiration (ET). It is measured in annual mm:
$ER = f(D) \cdot [\, 1{,}25\, p^{0{,}824} - 2{,}93] \cdot 10^{0{,}000955 \cdot ET}$

[9] Data on cumulative annual rainfall are obtained from the *Sistema Integrado de Información del Agua* (SIA) (MARM, 2009) for the period 1941 to 2009.

[10] The gamma function is defined by a scale parameter (a) and a shape parameter (b). It is consistent with rainfall measures because negative values are not allowed. The function reaches a maximum for intermediate values, decreases according to its scale parameter and converges to a normal distribution function as the shape parameter increases.

[11] The Segura River Basin (SRB) is exposed to a higher meteorological drought risk than most of the basins in Spain. The average evapotranspiration is similar to that of the Guadalquivir River Basin in the south, although the rainfall distribution is concentrated in lower values (90% of rainfall values are between 400 and 800 mm).

capacity (r), and the second proxy variable is the percentage of water stored over the river basin surface water storage capacity at the beginning of the crop season (s) (CHS, 2010b; Gómez Ramos et al., 2001). Both are stochastic variables in our model.
Following Martin et al. (2001) and Gómez and Pérez (2012), we adjust the runoff probability distribution function to a gamma function.[12] This allows assigning a probability (q) to each runoff level (r):

$$q = f(r|a,b) = \frac{1}{b^a \Gamma(a)} r^{a-1} \exp(\frac{-r}{b}) \quad [4]$$

Table 2 shows the best fit parameters for the runoff function.

Table 2: Runoff gamma function. The dependent variable is the percentage of runoff over the total surface water storage capacity.

Variable	Coefficient
a (scale)	6.1813[a]
	(1.088)
b (shape)	0.1143[a]
	(0.012)
No. of observations	68

Estimated by maximum likelihood. Standard errors in parentheses.
a: significant at the 1 per cent level.
Source: Authors' elaboration from MARM, 2009

3.1.3. Available surface stored water

Following Gómez Ramos et al. (2001), Pérez et al. (2011) and Gómez and Pérez (2012) we adjust the probability distribution function of the level of available stored surface water by using the Weibull function,[13] which allows assigning a probability (w) to each stored water level (s)[14]:

$$w = j(s|a,b) = \frac{b}{a}\left(\frac{a}{b}\right)^{b-1} \exp\left(-\left(\frac{s}{a}\right)^{b}\right) \quad [5]$$

Table 3: Surface water stored: Weibull function

The dependent variable is the percentage of dam stored water over dam storage capacity.

Variable	Coefficient
a (scale)	0.3411[a]
	(0.063)
b (shape)	4.1286[a]
	(0.497)
No. of observations	68

Estimated maximum likelihood. Standard errors in parentheses.

[12] Runoff values range from 0% to 225% over the river basin dam storage capacity.
[13] The Weibull distribution is a continuous probability distribution with a scale parameter (a) and a shape parameter (b).
[14] The s data series, as a percentage of the total dam storage capacity, is obtained from *Anuario de Aforos* (MARM, 2008).

a: significant at the 1 per cent level.
Source: Authors' elaboration from MARM, 2008.

3.1.4. Decision rules

At the beginning of each crop season, the water authority observes runoff and the level of water stored in the reservoirs and assesses the overall irrigation water required (TIR).[15] Accordingly, the water authority then applies a rule to determine the amount of surface water to be delivered to the crop fields.[16] The amount of irrigation resources actually delivered each year from is a public decision that is based on water availability. Until the SRB's DMP was implemented, the percentage of TIR effectively satisfied followed discretional decision rules. On the other hand, the new DMP establishes a set of drought thresholds and below them the percentage of TIR satisfied with surface sources is predetermined. Actually both systems are in force. During normal years, as no explicit percentage of TIR is specified in the DMP, traditional decision rules will hold. During drought events the DMP will apply, although under extreme drought events it is unlikely that the optimistic amounts to be transferred will hold[17] and the DMP rules may not be kept.

3.1.4.1. Traditional decision rules to determine water delivery for irrigation

In contrast with the situation created by the recently approved drought plans, the decision rules followed thus far have been the result of a combination of social agreements, opinions of expert judges and discretion with no written rules to be applied in any case, depending on the water available for the crop season. To formalise these decisions, we use the available data on the amount of water effectively delivered to farmers measured as a percentage of irrigation resources conceded over TIR. Available data span a range of 14 years (1992 to 2007) (CHS, 2010b). We represent the percentage of TIR satisfied as a proportion of runoff, r[18] [19] by using ordinary least squares (Gómez Ramos et al., 2001).[20] The parameters of the linear function relating the percentage of TIR satisfied ($h(r)$) with runoff are presented in Table 4.

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[15] TIR is the maximum amount of irrigation resources that can be conceded in an ideal hydrological year. Spanish river basins estimate TIR as the agronomic water required to cover the 80th percentile of annual historical evapotranspiration (from 1941 to 2009) with a global efficiency of the water provisioning system of 60% (MARM, 2008). TIR is then higher than the percentage of TIR actually conceded, and it is generally higher than WR.

[16] The irrigation resources actually conceded by the river authority in the SRB cover only a percentage of the estimated TIR ($\%\mathrm{TIR}$).

[17] As the empirical data suggest, the estimated satisfied agronomic crop requirements under the new drought plan are too optimistic compared with past drought events. For example, during the 2005-2008 drought less than 25% of TIR were satisfied, well below the amount established by the DMP.

[18] The r data as a percentage of dam storage capacity were obtained from *Anuario de Aforos* (MARM, 2008).

[19] Stored water (s) was not found to be statistically correlated with the percentage of TIR satisfied, which could be a consequence of the small storage capacity of the Segura River Basin. The ratio of reservoir storage capacity (1,141 hm^3) over average yearly water use (1,905 hm^3) is only 60% in the SRB, far lower than that of the drought-prone Guadalquivir (238%) and the rainfall-abundant Ebro River Basin (90%) (see: CHS, 2011; CHE, 2011; CHG, 2011).

[20] For values of TIR over 100%, the function is truncated and equals 1.

Table 4: Irrigation resources estimation under the traditional decision. The dependent variable is a percentage of TIR conceded in the SRB.

Variable	Coefficient
r	1.351[a]
	(.131)
R2	0.89
Adjusted R2	0.88
No. of observations	15

Estimated by maximum likelihood. Standard errors in parentheses.
a: significant at the 1 per cent level.
Source: Authors' elaboration from CHS (2010b)

3.1.4.2. DMP decision rules over water for irrigation

The recently approved DMP for the SRB quantifies the particular situation at hand and the severity of the problem by using an objective and publicly observable drought index, I_e. This plan establishes the following four drought thresholds (CHS, 2010b) i) when water stored levels are regarded as *normal* ($I_e > 0.5$), there are no additional explicit restrictions, and thus water delivery is the same as in the baseline or traditional rule scenario; ii) water for irrigation is reduced by 10% ($h = 0.9$) when available water falls below the pre-alert threshold ($0.35 < I_e \leq 0.5$); iii) if the alert limits are exceeded ($0.2 < I_e \leq 0.35$), water for irrigation is reduced by at least 25% ($h = 0.75$); and iv) in emergency situations ($I_e \leq 0.2$), water for irrigation is halved ($h = 0.5$). According to our model, a drought is quite likely in the SRB, occurring with a probability of 14%.[21]
In the case of Campo de Cartagena in the SRB, the drought index (I_e) depends on the observed values of both runoff and stock[22] (CHS, 2010b). Therefore, we define $l_{r,s}$ as a discrete water restriction variable whose value depends on the drought index (and thus on runoff and stock values) and its corresponding h. As the empirical data suggest, the estimated satisfied agronomic crop requirements under the new drought plan are too optimistic compared with past events. Therefore, we set $l_{r,s}$ as the minimum between $h(r)$ defined in the baseline scenario and the SRB's DMP parameters above (h):

[21] This is a minimum threshold. Historical data underestimate drought risk because the data do not consider that today's water resources are jeopardized significantly more than in the past.

[22] I_e is calculated as follows (CHS, 2010a):

$$I_e = \frac{1}{2}\left(1 + \frac{V_i - V_{med}}{V_{max} - V_{min}}\right), if\ V_i \geq V_{med}$$

$$I_e = \frac{1}{2}\left(\frac{V_i - V_{min}}{V_{med} - V_{min}}\right), if\ V_i < V_{med}$$

where V_i is an indicator that is unique for each *junta de explotación* (a group of agricultural districts or comarcas). In *Sistema Cuenca*, which is Campo de Cartagena's corresponding sub-basin, V_i is obtained as follows:

$$V_i = \frac{2 * DSC * r + DSC * s}{3}$$

Where r is the runoff as a percentage of the total dam storage capacity (DSC) and s is dam stored water as a percentage of the total DSC. Using r and s maximum, minimum and average observed values during the reference period, we obtain V_{max}, V_{min} and V_{med}, respectively.

$$l_{r,s} = \begin{cases} \min(h(r), 0.5), if\ I_e \le 0.2 \\ \min(h(r), 0.75), if\ 0.2 < I_e \le 0.35 \\ \min(h(r), 0.9), if\ 0.35 < I_e \le 0.5 \\ h(r), if\ I_e > 0.5 \end{cases} \quad [6]$$

Finally, water delivery for irrigation (TIRr) after the implementation of the DMP would be:

$$TIRr(r,s) = l_{r,s} * TIR \quad [7]$$

3.1.5. Percentage of evapotranspiration satisfied

Only a fraction of the TIRr effectively contributes to satisfy evapotranspiration. The effective surface irrigation resources ($EIR(r)$), or the part of the irrigation resources (TIR) that effectively satisfy evapotranspiration, is a function of $TIRr$ and the overall efficiency of the irrigation system (e_s):

$$EIR(r,s) = TIRr(r,s) * e_{sw} \quad [8]$$

Other publicly controlled water sources, such as the groundwater legally used (gw), the treated water (tw) and the desalinated water (dw), are provided to farmers in proportion to the surface irrigation resources delivered ($TIRr(r,s)$)[23]. The amount of water delivered from each of these sources is converted into an effective irrigation resource by using its own technical efficiency index (e_{gw} for groundwater, e_{tw} for treated water and e_{dw} for desalinated water),[24] as follows:

$$gw(r,s) = \frac{\lambda}{\eta} * TIRr(r,s) * e_{gw} \quad [9]$$

$$tw(r,s) = \frac{\gamma}{\eta} * TIRr(r,s) * e_{tw} \quad [10]$$

$$dw(r,s) = \frac{\theta}{\eta} * TIRr(r,s) * e_{dw} \quad [11]$$

The percentage of the evapotranspiration satisfied ($\%ET$) can now be obtained from the previous equations, as follows:

$$\%ET_{r,s,p} = \frac{g(p) + (EIR(r,s) + gw(r,s) + tw(r,s) + dw(r,s))}{ET} \quad [12]$$

Each $\%ET$ has an associated probability ($prob_{\%ET}$), which depends on stock, (s), runoff (r) and rainfall (p) values. Using expressions [2], [4] and [5] this probability can be expressed as follows:

$$prob_{\%ET_{r,s,p}} = f(r) * z(p) * j(s) \quad [13]$$

The expected level of evapotranspiration coverage (E_{ET}) and the resulting expected irrigation deficit (ID) and potential groundwater depletion are defined as follows:

$$E_{ET} = \int_{r=0}^{225} \int_{p=0}^{1300} \int_{s=0}^{100} \left[z(p) * g(p) + f(r) * j(s) * \left(EIR(r,s) + gw(r,s) + tw(r,s) + dw(r,s)\right)\right] \quad [14]$$

$$ID = ET - E_{ET} \quad [15]$$

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[23] In an average hydrological year, Campo de Cartagena irrigation resources come primarily from dam stored water (65.31%, η, 37.6 hm^3 of effective water) and groundwater (29%, 16.92 hm^3 of effective water, λ). Desalinated water (0.39%, θ) and treated water (5.3%, γ) are negligible (3.32 hm^3 of effective water) (MARM, 2007). These percentages are assumed to be constant in the model.

[24] Piping and irrigation techniques determine the final amount of effective water applied to satisfy a certain amount of a crop's water demand. Global efficiency of the system for the Campo de Cartagena region is approximately 87% for dam stored water, 60% for desalinated water and treated water and 25% for groundwater (CHS, 2010a; MARM, 2007).

$$PotGW = \frac{ID}{e_{gw}} \quad [16]$$

3.2. Second stage. Agronomic production functions and production value

The agronomic production of a given crop depends largely on available water, either from rainfall or irrigation. However, making the production function of a crop dependent only on the level of satisfaction of agronomic water needs implies that other variables that may affect the production function (soil type, fertilizers and phytosanitaries, climatic variables, etc.) are excluded. On the other hand if we consider this set of variables constant it is still possible to develop sound and rigorous agronomic production functions which provide results close to observed values (SCRATS, 2005). In our model we make the agronomic production (in kg) ($Q_{r,s,p}$) dependent on the percentage of evapotranspiration satisfied (and in turn on three stochastic variables: rainfall, runoff and water stock).

$$Q_{r,s,p} = f(\%ET_{r,s,p}) \quad [17]$$

The reference agronomic production functions for the crops considered are obtained after a comprehensive bibliographical review. Then these functions are adapted to the characteristics of the area of the case study, if there are not site-specific production functions (MARM, 2010; SCRATS, 2005). To do so it is assumed that the local characteristics have fixed effects that shift the reference agronomic production functions but maintain their elasticity and marginal productivity. Resulting production functions are quadratic:

$$Q_{r,s,p} = a * \%ET_{r,s,p}{}^2 + b * \%ET_{r,s,p} + c \quad [18]$$

Now we estimate agricultural production value through a set of site- and crop-specific parameters[25] for prices, variable costs and fixed costs. These parameters are estimated by the Ministry of Environment from agrarian statistical data (MARM, 2007). The value of the production ($V_{r,s,p}$) results from the product of total agronomic production ($Q_{r,s,p}$) and the updated average prices of the last 10 years (P) (MARM, 2007).

$$V_{r,s,p} = Q_{r,s,p} * P \quad [19]$$

This is the reference value for the calculation of the basic risk premium. The reason to assume prices constant is that neither revenue insurance (price, yield and costs) nor income insurance (price and yield) do exist in the European Union, where yield insurance prevails. As a result price variability is not considered in our model.

3.3. Third stage. Basic risk premium

The key element of any insurance market is the estimation of the basic risk premium that, given the likelihood of a catastrophic event, guarantees full cost recovery (excluding operating costs) in a medium-long term.

The indemnity conceded by drought insurance in case of drought losses is subject to two requisites: i) losses must be institutionally acknowledged; and ii) losses have to be larger than a minimum threshold predetermined by the insurance company, usually as a percentage of the NI.

i) For any drought losses to be institutionally acknowledged as such the Basin Authority has to formally declare that irrigation restrictions are going to be implemented (that is to say, DMP enters into force). In the case of the SRB a

[25] These parameters are estimated for every type of crop at an agricultural district level (comarca).

hydrological system is considered to suffer a drought when it is under an emergency, alert or prealert state (i.e., $I_e \leq 0.5$). We generate a dichotomous variable, $a_{r,s}$, to include this condition in our model.

$$\begin{cases} a(r,s) = 1, if\ I_e \leq 0.5 \\ a(r,s) = 0, if\ I_e > 0.5 \end{cases} \quad [20]$$

ii) Additionally, insurance systems only cover at the most a percentage of the expected production value in a normal hydrological year (In_{exp}). This threshold aims to reduce the moral hazard problem (Miranda, 1991) and in Spain is around 70%. Indemnity for every state of nature ($IND(r,s,p)$) is then defined as follows:

$$IND(r,s,p) = \begin{cases} \mu * V_{r,s,p} \ , if\ V_{r,s,p} < 0 \\ \mu * V_{exp} - V_{r,s,p}, if\ 0 \leq V_{r,s,p} < \mu * V_{exp} \\ 0\ , if\ V_{r,s,p} \geq \mu * V_{exp} \end{cases} \quad [21]$$

Expected Indemnity ($IE_{r,s,p}$) for each crop is obtained from the following equation:

$$IE_{r,s,p} = \int_{r=0}^{225} \int_{p=0}^{1300} \int_{s=0}^{100} [z(p) * f(r) * j(s) * a(r,s) * IND(r,s,p)] \quad [22]$$

Finally the risk basic premium ($BRP_{r,s,p}$) is obtained as a percentage of expected value of production in a normal hydrological year:

$$BRP_{r,s,p} = \frac{IE_{r,s,p}}{V_{exp}} \quad [23]$$

4. **Results**

The methodology has been applied for our case study in the Campo de Cartagena agricultural district. The following table shows the outcome of the model in terms of the expected rates of evapotranspiration satisfied and the associated irrigation deficits in an average year (in both volume and per cent units).

Table 5: Expected evapotranspiration satisfaction (E_{ET}), expected irrigation deficit (ID) and Expected potential groundwater depletion ($PotGW$) in absolute terms (hm^3) and as a percentage of ET satisfied (%ET) in the Campo de Cartagena agricultural district.

Variable		Value
Total Expected Evapotranspiration Satisfaction	E_{ET} (hm^3)	43.31
	$E_{\%ET}$	92.32%
Expected Irrigation Deficit	ID (hm^3)	2.41
	$ID_{\%ET}$	7.68%
Expected potential groundwater depletion	$PotGW$ (hm^3)	9.45

Source: Authors' elaboration

The irrigation deficit above has to be understood as the potential of commercial drought insurance schemes to prevent illegal water use. Under high institutional uncertainty insurance and with a legal framework tolerant with illegal irrigation, expected illegal abstractions from aquifers equal 9.45 hm^3/year. On the other hand, with a pure commercial insurance system supported with a serious institutional commitment to pursue illegal irrigation, all this water could be saved. As uncertainty still persists in the form of moral hazard, adverse selection and other variables, and a more serious institutional commitment to prevent illegal irrigation is still pending, illegal abstractions may still exist. However, it is reasonable to assume that the removal of institutional uncertainty may result in significant water savings within this range, especially during extreme droughts.

According to our stochastic assessment of historical data, drought events have a likelihood of 14%. This high probability originates a relevant expected irrigation deficit during an average year of 2.41 hm^3, a figure high enough to induce a significant incentive towards overexploitation (Gómez and Pérez, 2012). However, this is just the average. Irrigation deficits and resulting incentives for overexploitation can be actually much worse.

Finally the expected production in a normal hydrological year (Q_{exp}) and its corresponding value of production (V_{exp}), the expected indemnity ($IE_{r,s,p}$) and the basic risk premium ($BRP_{r,s,p}$) are displayed below for every relevant ligneous crop[26] in Campo de Cartagena:

Table 6: Expected Income ($In_{r,s,p}$), expected production in a normal hydrological year (Q_{exp}) and Basic Risk Premium ($PRB_{r,s,p}$) for ligneous crops in Campo de Cartagena agricultural district.

Variable/Crop	*Prunus dulcis*	*Prunus armeniaca*	*Citrus × limon*	*Citrus reticulata*	*Prunus persica*	*Citrus × sinensis*	*Olea europaea*	*Pyrus communis*	*Vitis*
Q_{exp} (kg)	9,159	15,210	23,010	23,398	25,001	23,726	4,305	19,441	13,999
V_{exp} (EUR)	5,428	5,286	5,825	2,559	9,630	2,351	234	3,775	2,313
$IE_{r,s,p}$ (EUR)	0	-50	-213	-234	-14	-199	-6	-5	0
$BRP_{r,s,p}$	0.01%	0.94%	3.66%	9.13%	0.14%	8.48%	2.45%	0.14%	0.01%

Source: Own elaboration. Production functions were obtained from MARM (2010) (all crops), SCRATS (2005) (citrus trees), Pastor et al. (2005) (Olea europaea), Mañas et al. (2007) (Prunus dulcis), Almarza (1997) (Vitis), Alarcón et al. (2006) (Prunus persica), Vivas Cacho (2010) (Pyrus communis) and Pérez Pastor (2001) (Prunus armeniaca).

Greater basic risk premium is observed in citrus trees: the *Citrus reticulata* (with a premium of 9.13% and representing 5.24% of the total irrigated surface in Campo de Cartagena) and *Citrus × sinensis* (8.48%; 11.63%) have the highest premium. The *Citrus × limon*, the most relevant crop in the area (21.98% of total irrigated surface),

[26] Main ligneous crops in Campo de Cartagena are *Prunus dulcis*, apricot tree, *Citrus × limon*, *Citrus reticulata*, *Citrus × sinensis*, *Prunus persica*, *Olea europaea*, *Pyrus communis* and *Vitis* (both for wine and grape production) (MARM, 2007).

has a moderate basic risk premium of 3.66%. Other fruit trees as the *Pyrus communis*, *Prunus armeniaca* and *Prunus persica* have a premium under 1%, while traditional rainfed crops now under irrigation show higher resilience and have the lowest premium. The case of the *Olea europaea*, a traditionally rainfed species which nonetheless shows a relatively high premium, may seem surprising. However, this can be explained by the displacement of olive groves to marginal and less productive lands more vulnerable to drought events and also by the relatively small surface that occupy (256 ha), which reduces the significance of the results.

4. Conclusion

Water overexploitation is the most important threat faced by Mediterranean European basins (EEA, 2009). As a result of it, the fulfillment of the environmental goals prescribed by the Water Framework Directive (EC, 2000) is being delayed by many Basin Authorities. Also, recent droughts in southern European regions have even forced to stop household water supply, being both priority objectives in any European water management plan. The main water consumer in these regions is irrigation. Traditional approaches to reduce water consumption in agriculture (apart from the largely ineffective command and control policies) have consisted of the increase of water supply or the improvement of irrigation systems. However, these and similar supply-side policies are costly and some have shown significant rebound effects which have resulted in higher water consumption (Pérez et al., 2010; Gómez, 2009; Alcott, 2005 and 2008; Brookes, 1990; Khazzoom, 1989). It seems then rather obvious that an effective and feasible solution for overexploitation has to deal with agricultural water *demand*.

In many Mediterranean overexploited catchments irrigated land makes a marginal increase in productivity compared to the traditional rainfed alternative, only possible because water prices are subsidized. Under these conditions a feasible solution consists of encouraging the progressive replacement of irrigated by rainfed lands (Mendelsohn and Saher, 2011) through the implementation of economic instruments such as water fees (Ecotec, 2001) or water markets (Tirado et al., 2006). However the implementation of these measures can be insufficient in the SRB, where irrigated agriculture is ten times more profitable than rainfed agriculture and illegal abstractions are generalized and tolerated (WWF, 2006).

A properly designed agricultural drought insurance market represents a useful instrument to soften the negative impacts of drought over water resources. So far institutional uncertainty has been an obstacle in the development of commercial insurance and significant public intervention has been necessary. However new DMPs, if properly enforced, may serve to bestow larger responsibilities on private agents and thus allow the development of commercial insurance with more effective and cheaper surveillance mechanisms. This has at least two clear advantages: i) first, the removal of public support provides incentives for the estimation of an accurate risk premium which reflects the actual costs of drought, with no costs for the taxpayers; ii) second, the surveillance mechanism of commercial insurance systems is more effective and efficient and focuses on final production, which avoids the costly search for illegal wells and better prevents overexploitation.

The potential of commercial insurance to reduce overexploitation stemming from drought events is especially relevant in areas with significant water deficits, high drought exposure and profitable irrigated lands. This is the case of Campo de Cartagena as well as of many other Southern European catchments. In this agricultural district expected water deficit in agriculture is about 2.41 hm^3 every year, although during extreme droughts ($I_e \leq 0.2$), with a likelihood of 9.9% in our model, the deficit can soar up to 9.38 hm^3.Gómez and Pérez (2012) have estimated that potential groundwater overexploitation in Campo de Cartagena during extreme events equals 38.83 hm^3/year. The magnitude of this figure implies that the negative effects over aquifers after such a drought may not be reverted.

Insurance markets guarantee a minimum safety income to farmers during drought junctures provided that observed production levels are according to legal water availability. This design considerably reduces incentives towards water overexploitation during droughts and makes insurance markets an optimal instrument against aquifer depletion in drought prone areas.

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