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ABSTRACT

This paper explores the viability of precautionary savings as a hydrological drought risk management instrument in irrigated agriculture. To that end, first, the Drought Savings Account (DSA) is proposed as a personal savings account to which farmers make regular contributions, with withdrawals allowed in the event of water supply gaps to guarantee a minimum income. Second, the implementation of the proposed instrument is empirically assessed in an illustrative case study using an innovative simulation approach. Results obtained suggest the DSA is actuarially sound, supporting its implementation as a cost-effective instrument to hedge hydrological drought risk.

KEYWORDS: Irrigation water supply gap; drought savings account; hydro-economic stochastic modelling; stochastic dominance analysis with respect to a function; Spain

Introduction

Agriculture is an economic activity that is characterized by its high exposure to risk. The different sources of risk in the agricultural sector entail adverse outcomes involving income and wealth losses to farmers (Hardaker, Huirne, Anderson, & Lien, 2004). Among the multiple types of agricultural risks, those affecting yield (production risks such as hail, frost or drought) and agricultural prices (market risks involving price volatility) are the most relevant, and are currently being exacerbated by climate change and globalization, respectively (OECD, 2011).

In Mediterranean-climate farming regions, such as in Spain, farmers are particularly concerned about climatological production risks (Antón & Kimura, 2011). In many of these regions, the major production risk, particularly among irrigation farmers, is related to droughts. When a drought episode occurs, instream flows and reservoir levels are not enough to meet all water needs (hydrological drought), and thus water supply must be rationed. Under this circumstance, irrigators are not allowed to use the full water allotments granted to them in 'normal' hydrological years according to their water rights, and thus suffer from the so-called 'water supply gaps'. These water supply gaps damage the production of irrigated crops, usually leading to large losses since irrigated agriculture is characterized by a relatively high value-added (OECD, 2016). Irrigators' awareness of the need to cope with water supply gaps is being reinforced by the emerging effect of climate change and negative predictions about future climate: lower rainfall (lower irrigation water availability), higher temperatures (larger irrigation water needs) and more intense and frequent episodes of cyclical scarcity (hydrological droughts) (Rasilla, Garmendia, & García-Codron, 2013). In Mediterranean-climate farming regions, these circumstances could even jeopardize the long-term sustainability of this kind of farming activity (Moatti & Thiébault, 2016). Moreover, as farmers are risk-averse economic agents (Just & Pope, 2013), the farming decisions they take in a risky situation (e.g. hydrological drought) cannot be considered efficient from a social welfare point of view. Thus, a risky environment involves lower input use (e.g. labour demand), lower output production (i.e. income and wealth generation in the short run), lower investment (i.e. income and wealth generation in the long run), and may even give rise to opportunistic behaviour such as water theft (Beare, Bell, & Fisher, 1998; Loch, Pérez-Blanco, et al., 2020). For all these reasons, policies reducing risk (i.e. promoting and supporting the adoption of risk management instruments) can be welfare increasing (Rossi & Cancelliere, 2013; OECD, 2016; EC, 2017b).

To date, several studies (e.g. Rigby, Alcón, & Burton, 2010; Guerrero-Baena, Villanueva, Gómez-Limón, & Glenk, 2019) have revealed that irrigators in Mediterranean-climate farming regions are willing to pay an extra irrigation water fee to reduce the risk related to the high variability of their water allotments. Considering that currently no risk management instrument specifically addresses the risk of hydrological drought in irrigated agriculture, this evidence shows a demand for new risk management instruments to cope with irrigation water supply gaps. In this regard, some policy-makers (OECD, 2016; EC, 2017a) and researchers (Colson, Ramirez, & Fu, 2014; van Asseldonk, Jongeneel, van Kooten, & Cordier, 2019) have recently drawn attention to the use of precautionary savings as a potential risk management instrument in agriculture, aiming to overcome some of the problems linked to more traditional instruments such as agricultural insurance.

The purpose of this paper is to explore the suitability of precautionary savings as an effective risk management instrument to cover the risk of hydrological drought in irrigated agriculture. Two specific objectives have been considered. First, the paper presents the design of a new, technically feasible personal precautionary savings account targeted at irrigation farmers voluntarily seeking to cope with the risk of hydrological drought: the Drought Savings Account (DSA). The proposed DSA is conceived as a risk management instrument aimed at guaranteeing a minimum level of farm income to farmers when a hydrological drought episode occurs (i.e. when they are not allowed to use their full water allotments to irrigate, causing income losses). Second, the performance of the proposed DSA is simulated for an irrigation district in the Guadalquivir River Basin (southern Spain); the purpose of this case study is to analyse the effectiveness of precautionary savings as a hydrological drought risk management instrument in a real-life setting. This second objective contributes to the existing literature by proposing an innovative methodological approach combining hydro-economic stochastic modelling (stochastic simulation of annual water allotments and cash flows determining the DSA balance) and farmers' utility gains derived from the change in the probability distribution function of annual farm income (without and with the DSA). To that end, the approach used is stochastic dominance analysis with respect to a function.

Precautionary savings as a risk management instrument to cope with hydrological droughts in irrigated agriculture

Among the different instruments for addressing drought risks (Garrido & Gómez-Ramos, 2009), a specific insurance scheme for irrigated agriculture has repeatedly been suggested as a suitable option, by both international institutions (World Bank, 2005; OECD, 2016; EC, 2017b) and academia (e.g., Zeuli & Skees, 2005; Pérez-Blanco & Gómez, 2014; Rey, Pérez-Blanco, Escriva-Bou, Girard, & Veldkamp, 2018; Gómez-Limón, 2020). However, although agricultural insurance is well developed worldwide, there is currently no specific insurance scheme covering hydrological drought events for implementation in a real-life setting.

There are two main factors behind the lack of protection against hydrological drought in irrigated agriculture (Pérez-Blanco, Delacámara, Gómez, & Eslamian, 2017; Guerrero-Baena & Gómez-Limón, 2019). On the one hand, as with all agricultural insurance schemes, there are problems related to information asymmetries: 'moral hazard' and 'adverse selection'. The former concerns the possibility of insured farmers engaging in dishonest conduct. That is, an insured farmer may show undesirable behaviour regarding the risks covered on his/her farm (e.g. not using the entire amount of the water allotment he/she is granted) that could increase the frequency or severity of losses, with the sole aim of claiming higher losses and indemnities from the insurer. The latter problem refers to the tendency of farmers who are most likely to suffer losses (higher than average) to take out insurance at the average premium. The direct consequence of these two problems is an actuarial imbalance for the insurer (claims exceed premia), gradually driving up the insurance cost and making the instrument inefficient.

On the other hand, there are also a number of specific factors hindering the development of this kind of insurance scheme:

a) Hydrological drought is a systemic risk, meaning that the risk of a water supply gap is highly correlated across a large number of farmers (i.e. all those located in the same river basin). Thus, in the event of a hydrological drought, the large number of indemnities to be paid by the insurer could collapse the insurance firm.

b) Farmers can act as a powerful lobby when river basin agencies make decisions about annual water allotments for irrigation. As farmers are represented in these agencies, they may influence the probability of loss occurrence (i.e. water supply gap), meaning that the risk of hydrological drought would no longer be an entirely accidental hazard and would thus be uninsurable.

c) There is a high level of uncertainty related to the actual probability distribution function characterizing the indemnities of this insurance scheme, especially considering ambiguous expectations about climate change. Future declines in the average volume of water available for irrigation and the increase in the variance of water allotment both complicate actuarial analyses for estimating fair insurance premia.

d) Hydrological droughts damage crop yields, but in extreme cases involving droughts that last several years they can also lead to ‘catastrophic’ damages affecting fixed assets such as orchard trees (Loch, Adamson, & Auricht, 2020). In the latter case, droughts may drive hydrological systems past a tipping point, resulting in large capital losses, meaning that it would only be possible to provide insurance coverage by dramatically increasing the insurance premia.

e) There are alternative sources of water for irrigation (not only surface water, but also groundwater, reclaimed water, desalinated water or even additional resources bought in water markets). During a hydrological drought episode involving cuts in water allotments (surface water), the farmers are encouraged to use any of the other available sources of water, including water markets, without declaring the benefit from this second source of water to the insurance firm.

All these problems impede the development of an affordable hydrological drought insurance scheme for irrigated agriculture. There is thus a need for further developments in risk management tools specifically focused on hedging this farming risk. It should be borne in mind that many of the targeted farmers—especially smallholders, due to their limited knowledge and capabilities and/or financial constraints—could find it difficult to adopt sophisticated and/or expensive risk management strategies to overcome income instabilities at the farm level (Ullah, Shivakoti, Zulfiqar, Iqbal, & Shah, 2017). Therefore, these new risk management instruments to be developed should be straightforward and affordable if they are to be easily and widely implemented by irrigators (Colson et al., 2014).

In this regard, precautionary savings have recently been proposed as a potentially suitable risk management instrument in agriculture (Ramirez & Colson, 2013; Colson et al., 2014; van Asseldonk et al., 2019). The theory of precautionary saving (for an overview, see Lugilde, Bande, & Riveiro, 2019; Baiardi, Magnani, & Menegatti, 2020) holds that people usually build up reserves (in the form of financial or real assets) against unforeseen negative contingencies that may arise in the future, particularly in highly uncertain environments. Precautionary savings may thus be defined as the extra savings made by prudent individuals who seek protection from risk by smoothing consumption.

Saving is a strategy already widely used by farmers as an informal way to smooth income volatility (Mishra & Chang, 2009). Indeed, a majority of irrigators in southern Spain affirm that they use savings as an informal instrument to manage the various sources of farming risk (Gómez-Limón, Guerrero-Baena, & Sánchez-Cañizares, 2020). Despite their extensive use, informal precautionary savings are not perceived by farmers as an entirely suitable instrument to cover hydrological drought risk. The reason behind this dissatisfaction may be that this informal risk management instrument is not used with the intensity required (in terms of the amount of money saved) to adequately cover the deep losses caused by water supply gaps. In this respect, formal precautionary savings—those implemented with fixed operational rules regulating contributions and withdrawals, and supported by agricultural policy—could be a more useful instrument to properly hedge hydrological drought risk in irrigated agriculture.

This instrument can be formally implemented as follows: farmers would simply open a special personal savings account where they would deposit a pre-determined share of their annual income in high-income years, building an accumulative financial fund that could be partially or totally withdrawn in case of need (e.g. low-income years, when the farmer's income falls below a pre-specified threshold). In this way, precautionary savings are a self-insurance tool for farmers that pools their own risks across time and reduces vulnerability to negative shocks, allowing income stabilization, similarly to how agricultural insurance pools fortuitous losses across farmers (Bardají et al., 2016).

Some of the most noteworthy advantages of precautionary savings compared to agricultural insurance relate to its lower costs due to the following factors (Ramirez & Colson, 2013; Colson et al., 2014): i) farm-level risk does not have to be evaluated, so there is no need to carry out complex actuarial analyses to rate premia; ii) there are no expenses related to the assessment of farm damages or claims disputes; iii) administrative costs are lower; and iv) moral hazard and adverse selection problems are minimized (farmers are risking their own money, not the insurer's). Mutual funds (collective saving) also offer some of these advantages, but, unlike precautionary savings, they entail administrative (higher transaction costs in risk-sharing management) and practical (asymmetries in farmers' contributions and compensations) issues hindering their development (Cordier & Santeramo, 2020). Therefore, all the above features make precautionary savings a more cost-effective instrument, potentially allowing widespread participation without requiring substantial external subsidies (Colson et al., 2014).

Another relevant advantage of precautionary savings is that the funds built up are kept by farmers and not transferred to an insurance firm, which may motivate farmers to use such an instrument. In addition, savings accounts encourage a long-term vision of risk management compared to insurance policies, which have to be renewed each year (Miao, 2020). Therefore, precautionary savings could also be considered an effective and economical instrument for climate change adaptation.

Given all these positive characteristics, some authors (e.g. Bardají et al., 2016; van Asseldonk et al., 2019) have proposed including farm-specific precautionary savings as a complement to current risk management instruments supported by the Common Agricultural Policy (CAP) (i.e. agricultural insurance and mutual funds). Indeed, public incentives could be targeted at promoting the adoption of precautionary savings as a useful tool for risk management in the farming sector, following the rules set by the World Trade Organization (WTO) for fair international trade (Bardají et al., 2016). There are different options for doing so: i) governmental contributions to the deposits; ii) tax exemptions upon withdrawal; iii) subsidizing savings by increasing interest rates; and iv) compensation of payments or withdrawals caused by production or income losses.

Despite the pros, there are very few examples of precautionary savings having been formally implemented and supported by agricultural policy to promote its uptake by farmers as a risk management instrument. In fact, the only one is the *AgriInvest* programme in Canada, which provides farmers with a self-managed producer-government savings account held in financial institutions. Farmers can set aside up to 100% of their annual net sales into a savings account and receive a matching government deposit on 1% of the farmer's contribution, up to a limit of 10,000 CAD annually. The main objective of the programme is to help producers to manage small income declines and make investments to cope with risk (Canadian Minister of Agriculture and Agri-Food, 2020). Producer participation in this programme is very high: during the period 2009-2014, it ranged from 75% to 82% of farmers, accounting for 88-94% of the agricultural sector's net sales. However, it is also worth pointing out that there is no restriction on the timing of withdrawals (farmers are allowed to make withdrawals in years with normal income), making the programme more of an income support rather than a risk management tool (Slade, 2020).

To date, few academic studies have proposed the implementation of formal precautionary savings in agriculture. In this respect, only the proposals by Colson et al. (2014) and van Asseldonk et al. (2019) for the US and the European Union (EU) agricultural sectors, respectively, are worth citing. Colson et al. (2014) have suggested an individual precautionary savings account (Crop Insurance Savings Account, CISA) allowing farmers to annually deposit a proportion of their income and draw an indemnity from their accounts in case of revenue losses derived from any source of risk. Van Asseldonk et al. (2019) have proposed the Farmer-Directed Precautionary Savings Account (FDPSA) with similar features to CISA, as a new policy instrument to be considered as part of the CAP. The instrument proposed here, the DSA, is in line with the abovementioned CISA and FDPSA in terms of the main technical features. However, it is worth noting that this paper contributes two key innovations to the existing literature. First, it presents a comprehensive proposal for a precautionary savings instrument specifically designed to hedge the risk of irrigation water supply gaps due to hydrological droughts. Second, a realistic simulation procedure is implemented to analyse the potential performance of the DSA in a real-life setting, the results of which support its suitability for implementation.

The Drought Savings Account

Instrument design

As in many other countries, in Spain, water rights granted to irrigators fix the maximum annual volume (full water allotment, fwa) that these rights holders are allowed to extract from a specific water body (river, aquifer or reservoir). However, the volume of water actually available for these rights holders every year *t* is uncertain, with the annual water allotment ($\widetilde{WA}_t$) being set annually by the River Basin Authority (RBA) depending on the hydrological situation.

In 'normal' hydrological years (i.e. those when water availability allows all demands to be fully met, allocating the fwa to all rights holders), expected farm income with full water allotment is $\bar{I}$. Nevertheless, this is not always the case: in water-scarce years (hydrological droughts) the RBA has to ration water allotments ($\widetilde{WA}_t < fwa$). Farm income in year t (I_t) depends on irrigation water availability in that year, with the two variables being related by the function f: $I_t = f(\widetilde{WA}_t)$. According to economic theory, f is an increasing function ($f'\left(\widetilde{WA}_t\right) \geq 0$) showing diminishing marginal value of water ($f''(\widetilde{WA}_t) \leq 0$). These two characteristics have been empirically evidenced worldwide since water rationing usually involves an increasing drop in farm profitability; and the lower the water allotments, the greater the reduction in farm income. In any case, the shape of the function f depends on water productivity under local conditions, mainly based on farms' characteristics (pedo-climatic conditions, production technology, and crop-mix decision-making), the market environment and the institutional framework regulating their operations. Thus, this function needs to be estimated empirically for each farm considered for the analysis. As explained in the section devoted to the case study, the estimation of the function f relating irrigation water availability and farm income under local conditions has been obtained by modelling irrigators' behaviour when facing cyclical water scarcity (i.e. water supply gaps due to a hydrological drought) using a positive mathematical programming approach.

Within this framework, the DSA is designed to guarantee that farmers get at least a predefined share of the expected farm income with full water allotment: $I^g = \alpha \cdot \bar{I}$, with α being a share (i.e. $0 \leq \alpha \leq 1$) of $\bar{I}$. For this purpose, this account operates with a single cash-flow or movement of money a year (contribution or withdrawal), depending on the farm income I_t (i.e. I_t is subject to $\widetilde{WA}_t$) obtained each year:

- When $\widetilde{WA}_t \geq c \cdot fwa$, with c (denoting contribution) being a large share of fwa leading to farm income I_t close to $\bar{I}$, farmers are allowed to pay into the DSA with a regular annual contribution $\beta \cdot \bar{I}$ (β being a share of $\bar{I}$).
- When $\widetilde{WA}_t < w \cdot fwa$, with w (denoting withdrawal) being a proportion of fwa leading to I_t lower than I^g, farmers are allowed to withdraw funds to reach the farm income guaranteed (i.e. $I^g - I_t$).

Obviously, c should be higher than or equal to w. In fact, it is reasonable to propose that $c > w$, thus considering a range of I_t (i.e. WA_t) neither high enough to allow DSA contributions nor low enough to involve withdrawals. Thus, when $c \cdot fwa \leq \widetilde{WA}_t \leq w \cdot fwa$, there would be no cash-flow movement in year t.

It is worth pointing out that the dynamic proposed for the DSA with just one fund movement a year, or none at all, involves low management costs for both the farmers and the depository institutions (i.e. banks). In this sense, it is suggested that the annual cash-flow movement (contribution or withdrawal) be dated at the end of the agricultural year (1st November for the European agricultural regions).

Considering that the implementation of agricultural risk management instruments protecting farmers' income from deep losses could be supported by government programmes (EC, 2017b), the DSA could also be fed by public contributions matching farmers' contributions: $\delta \cdot \beta \cdot \bar{I}$, with δ being a share of the regular annual contribution.

Moreover, as with any other bank account, DSA balances are affected by interest rates levied on deposits (r_d, for positive balances) and money borrowed (r_b, for negative balances). In both cases, the interest rates considered for modelling purposes are expressed in real terms. Considering usual banking practices, $r_d < r_b$.

Given the features explained above, the balance of the DSA in year t (DSA_t) can initially be calculated as follows:

$$\begin{aligned} DSA_t = max\left\{0, \frac{\widetilde{WA}_t - c \cdot fwa}{\left|\widetilde{WA}_t - c \cdot fwa\right|}\right\} \cdot \beta \cdot \bar{I} \\ - max\left\{0, \frac{w \cdot fwa - \widetilde{WA}_t}{\left|w \cdot fwa - \widetilde{WA}_t\right|}\right\} \cdot \left(I_g - I_t\right) \\ + (1 + r) \cdot DSA_{t-1} \end{aligned} \tag{1}$$

where the rate parameter r takes the value r_d in case $DSA_{t-1} > 0$ (i.e. an interest rate for deposits is applied), or r_b if $DSA_{t-1} < 0$ (i.e. the rate for funds borrowed is applied).

Since under this basic design annual cash-flow movements are not limited by any further management rule, over long enough periods the balance DSA_t may well reach extremely high values (positive or negative), mainly depending on the values fixed for the parameter β, although α and δ also have a significant influence on values reached by DSA_t in the long term. The DSA proposed is designed as a risk management instrument to cover losses derived from hydrological drought events. Thus, it is neither an investment fund to manage farmers' savings nor a mechanism to finance farm operations; the idea is to avoid DSA_t with large positive (becoming an investment fund) or negative (becoming a financing instrument) balances. For this reason, there should be an upper and lower limit on DSA_t, to ensure rational risk coverage:

- Upper cap on DSA_t: $u \cdot \bar{I}$, with u (denoting upper cap) being a share of $\bar{I}$.
- Lower cap on DSA_t: $-l \cdot \bar{I}$, with l (denoting lower cap) being a share of $\bar{I}$.

Therefore, when $DSA_{t-1} \geq u \cdot \bar{I}$, no further contributions are allowed in year *t*. When $DSA_{t-1} \leq -l \cdot \bar{I}$, no further withdrawals are allowed in year *t*.

It is also proposed that in the case of negative balances in the DSA ($DSA_t < 0$), farmers must make higher contributions in the following years, at least until their balance becomes positive. In these situations, the additional contribution is equal to $\gamma \cdot \bar{I}$ (γ being a share of $\bar{I}$), with the farmers' total annual contribution being $(\beta + \gamma) \cdot \bar{I}$. These catch-up contributions are proposed to minimize the probability of capping withdrawals when DSA_t reaches large enough negative values ($DSA_{t-1} \leq -l \cdot \bar{I}$).

Finally, it is worth mentioning that the proposed DSA policy is designed to be voluntarily taken up by the targeted irrigators. In fact, this risk management instrument is considered as a potential substitute for other financial instruments (i.e. informal savings accounts) that are currently available to these producers. As a further measure to ensure a flexible design, in drought years (when $\widetilde{WA}_t < w \cdot fwa$) the design of the proposed DSA allows fund withdrawal also on a voluntary basis. This means that farmers who have additional savings could use them instead of having a credit with the DSA (i.e. a negative balance with interest paid for funds borrowed).

Modelling the DSA performance

The design proposed for the DSA can be mathematically represented as explained in this section. First, $C_t\{\cdot\}$ denotes an indicator function that equals 1 if the farmer must contribute to the DSA in year *t*, and 0 otherwise:

$$C_t\{[\widetilde{WA}_t \geq c \cdot fwa] \wedge [DSA_{t-1} < u \cdot \bar{I}]\} = 1 \tag{2}$$

$$C_t\{[\widetilde{WA}_t < c \cdot fwa] \vee [DSA_{t-1} \geq u \cdot \bar{I}]\} = 0 \tag{3}$$

Thus, the farmer's regular contribution to the DSA in year *t* (FC_t) can be calculated using the following equation:

$$FC_t = C_t\{\cdot\} \times min\,\{\beta \cdot \bar{I}, max[0\,, (1-\delta) \cdot (u \cdot \bar{I} - DSA_{t-1})]\} \tag{4}$$

In years when the farmer is requested to contribute to the DSA and he/she has a negative balance in the previous year ($DSA_{t-1} < 0$), an additional contribution to this account is required. This extra contribution (EFC_t) can be modelled using the indicator function $EC_t\{\cdot\}$ as follows:

$$EC_t\{[\widetilde{WA}_t \geq c \cdot fwa] \wedge [DSA_{t-1} < 0]\} = 1 \tag{5}$$

$$EC_t\{[\widetilde{WA}_t < c \cdot fwa] \vee [DSA_{t-1} \geq 0]\} = 0 \tag{6}$$

$$EFC_t = EC_t\{\cdot\} \times \gamma \cdot \bar{I} \tag{7}$$

Denoting $W_t\{\cdot\}$ as an indicator function that equals 1 if the farmer can withdraw funds from the DSA in year *t*, and 0 otherwise, the farmer's withdrawal from the DSA in year *t* (FW_t) can be obtained using these equations:

$$W_t\{[\widetilde{WA}_t < w \cdot fwa] \wedge [DSA_{t-1} \geq -l \cdot \bar{I}]\} = 1 \tag{8}$$

$$W_t\{[\widetilde{WA}_t \geq w \cdot fwa] \vee [DSA_{t-1} < -l \cdot \bar{I}]\} = 0 \tag{9}$$

$$FW_t = W_t\{\cdot\} \times min\,\{\, I^g - I_t\,, l \cdot \bar{I} + DSA_{t-1}\} \tag{10}$$

Although fund withdrawal from the DSA is voluntary for farmers, for modelling purposes it is assumed that farmers adopting this instrument withdraw the funds allowed in every drought year (i.e. they do not have additional savings or using DSA funds is simply cheaper for them). The balance of the DSA in year *t* can thus be calculated as follows:

$$DSA_t = (1+\delta) \cdot (FC_t + EFC_t) - \ FW_t + (1+r) \cdot DSA_{t-1} \tag{11}$$

Simulation procedure: indicator performance for policy design

The irrigators' annual water allotment $\widetilde{WA}_t$ is a random variable depending on the water availability at the basin level, meaning that all cash-flows determining the DSA balance (FC_t, EFC_t, FW_t and $(1+r) \cdot DSA_{t-1}$) also become stochastic variables. To simulate the performance of the proposed risk management instrument, we modelled periods of 30 years, including equations (2) to (11) 30 times (from t=1 to t=30), in every case starting from an initial value of $DSA_{t=0} = 0$. Using @Risk 7.6 software, this 30-year model was simulated for 100,000 iterations implementing Latin Hypercube sampling techniques for time series of the stochastic variable $\widetilde{WA}_t$ from t=1 to t=30 drawn from the hydrological simulation model built by Gómez-Limón (2020). Running the simulation model, we obtained the probability distributions for the whole set of variables describing the DSA performance with 100,000 simulated observations for every year t, from t=1 to t=30.

In this paper we focus on the results obtained for t=5 and t=20, in order to analyse two different time frames that farmers could consider when deciding on whether to open a precautionary savings account.[1] The probability distribution functions obtained for t=5 are considered useful for assessing the DSA as a risk management instrument in the short- to medium-term, while those obtained for t=20 are appropriate for evaluating the use of the DSA to hedge the hydrological drought risk in the long-term.

The variables considered in the simulation model that support the assessment of the proposed DSA are:

- Farmer's annual contribution to the DSA, calculated as the sum of the regular contribution (FC_t) and the occasional extra contribution (EFC_t). As complementary indicators regarding the farmer's contributions, the model also yields results for the percentages of the years that: a) the farmer is requested to contribute, b) the farmer is requested to contribute with catch-up payments, and c) the farmer's contribution is capped because the upper limit set for the DSA balance is reached.
- Public matching contribution ($\delta \cdot (FC_t + EFC_t)$).
- Farmer's annual withdrawal (FW_t). This variable is complemented with the indicators regarding the percentages of the years that: a) the farmer is allowed to make withdrawals, and b) the farmer's withdrawal is capped because the lower limit set for the DSA balance is reached (i.e. when the instrument fails to guarantee the minimum farm income I^g).
- DSA annual cash-flow ($DSA_t - DSA_{t-1}$) and DSA balance (DSA_t).

All the abovementioned variables are measured in Euros per hectare.

Regarding the policy criteria guiding the design of this instrument, it is worth pointing out that the parameters involving the DSA should be set to minimize the percentage of years that drought risk is not properly hedged (the farmer's withdrawals are capped) while also minimizing the farmer's and public sector's contributions. Moreover, it is also desirable that the DSA keeps a (slightly) positive balance as this minimizes the financial costs (i.e. interests related to negative balances) and possible problems regarding farmers who end up with negative terminal balances (e.g. payback in full or transfer with the farm to heirs).

It is worth remarking that the DSA is a risk management instrument because it enables a change in the probability distribution function of annual farm income, from an initial distribution quantified by I_t to a more stable income distribution computed as $I_t^{DSA} = I_t - FC_t - EFC_t + FW_t$. In this sense, the assessment of this instrument should also take into account the farmer's utility gains derived from this change in the probability distribution function. For this purpose, we used the stochastic dominance analysis with respect to a function (SDRF) approach proposed by Hardaker, Richardson, Lien, and Schumann (2004). SDRF allows the user to evaluate individuals' preferences regarding a set of risky alternatives (i.e. income or revenue probability distributions) in terms of certainty equivalents for a specified range of attitudes to risk.

For the implementation of the SDRF method, we assume that farmers' attitude to risk can be modelled relying on the expected utility theory, using a negative exponential utility function defined as $U(I_t) = e^{-r_a \cdot I_t}$, where r_a is the Arrow-Pratt coefficient of absolute risk aversion ($r_a = -U''(I_t)/U'(I_t)$) and I_t is the annual farm income (Moschini & Hennessy, 2001). Considering this utility function, the expected utility of any risky prospect can be measured in terms of certainty equivalent (the sure sum with the same utility as the expected utility of the prospect, *CE*) as follows (Hardaker, Richardson, et al., 2004):

$$CE(I_t, r_a) = ln\left[\left(\frac{1}{n}\sum_{i}^{n} e^{-r_a \cdot I_t}\right)^{\frac{-1}{r_a}}\right] \tag{12}$$

where *n* is the size of a random sample from the risky alternative I_t (or also I_t^{DSA}). If the risky prospect is represented by a cumulative distribution function (CDF), then the *CE* estimation can be done using a set of fractile values (deciles or percentiles) as samples. In our case study, we estimated *CE* accounting for all deciles of the CDF obtained for I_t and I_t^{DSA}.

Following the SDRF approach, the risky prospect which has the highest CE values is utility efficient; all other prospects are dominated in the SDRF sense. The risk premium (*RP*) can thus be used to quantify the preference of individual farmers (i.e. considering his/her own r_a) for the risky alternative represented by I_t^{DSA} over the risky alternative represented by I_t:

$$RP_{I_t^{DSA},I_t,r_a} = CE(I_t^{DSA}, r_a) - CE(I_t, r_a) \tag{13}$$

The calculation of *CE* depends on the farmers' utility function; that is, on their individual preferences determined by their own coefficients of risk aversion r_a. According to the existing evidence (e.g. Gollier, 2004, p. 31), risk preferences measured in terms of the Arrow-Pratt coefficient of relative risk aversion ($r_r = -R_t \cdot U''(I_t)/U'(I_t) = I_t \cdot r_a$) typically vary across farmers, ranging between 0.5 (slightly risk-averse) and 4.0 (extremely risk-averse). In our case study, this range of risk attitudes can also be expressed in terms of absolute risk aversion coefficients considering the lower bound $r_{a_L} = 0.5/\bar{I}_t$ and the upper bound $r_{a_U} = 4.0/\bar{I}_t$. Taking into account farmers' heterogeneous risk aversion, for the empirical assessment of the DSA we calculated $RP_{I_t^{DSA},I_t,r_{a_L}}$ and $RP_{I_t^{DSA},I_t,r_{a_U}}$ as estimates of the range of famers' utility gains derived from implementing this risk management instrument measured in monetary units per year.

Case study

The Sector BXII irrigation district

Sector BXII (henceforth SBXII) is an irrigation district (ID) located close to the mouth of the Guadalquivir River (Southern Spain). This irrigated area covers a total of 14,643 hectares, operated by 569 farmers (average farm size of 25.7 hectares). Due to its Mediterranean climate, the main cultivated crops are cotton, corn, sugar beet, wheat and vegetables such as tomatoes, carrots and onions. Currently, modern sprinkler irrigation systems are used on 72% of all irrigated land in the ID (drip −22%− and surface irrigation −6%− are also used depending on the crop). Irrigators in the SBXII are organized into a water users' association that collectively holds water rights allowing an annual maximum water use of 6,000 cubic metres per hectare (full water allotment). Annual water allotments are provided by the RBA from its reservoir network through an irrigation channel. These surface resources are the only ones available to local irrigators; there is no possibility of pumping groundwater or obtaining alternative water resources (desalinated or reclaimed water). However, due to the recurrent drought events, the amount of water annually available for this ID is usually lower than the full water allotment, resulting in water supply gaps that negatively affect farm income.

In this regard, it is also worth pointing out that although water trading is legally possible in Spain, the water market is very narrow because of the high transaction costs (Palomo-Hierro, Gómez-Limón, & Riesgo, 2015). This option for obtaining additional water resources during drought periods is unaffordable for irrigators in the SBXII (market prices are only affordable for farming activities with the highest economic values such as growing vegetables in greenhouses).

Prior studies focused on this ID have revealed a high degree of heterogeneity among farmers. In this regard, several farm types have been identified according to their production orientation (Montilla-López, Gómez-Limón, & Gutiérrez-Martín, 2018; Gómez-Limón, 2020). Among these farm types, the most important group is *'large professional farmers'* (average farm size of 35.5 hectares), comprising 39% of farms in the ID and accounting for 52% of the total irrigable area. This farm type is mainly oriented towards the most profitable crops under local conditions, the horticultural ones (tomato, 30.3%; carrot, 5.3%; and onion, 1.6%), as well as other crops such as cotton (29.6%) and sugar beet (24.0%). However, it should be noted that this crop mix corresponds to a situation where irrigators are granted their full water allotments. The productive orientation of the *'large professional farmers'* justifies the relatively high average productivity of water (0.541 €/m^3) and farm income (3,021 €/ha) compared to other farm types in the ID. In this paper, all the DSA analyses are carried out considering a virtual farm simulating this farm type as a case study. Thus, the empirical analysis performed should be viewed as simply an illustrative example of how this instrument could be implemented on any individual farm. For the same reason, the results obtained can only be extrapolated to farms similar to the one simulated.

Before modelling the DSA proposed in the case study, we must take into consideration the fact that the annual water allotment for irrigation ($\widetilde{WA}_t$) is a stochastic variable because the volume of water to be allocated to irrigators depends on the uncertain volume of water available each year. The most widely-used method to estimate the probability distribution of this stochastic variable consists of fitting historical records to different probability distribution functions to determine the most suitable one based on different goodness-of-fit statistics (e.g. Rey, Garrido, & Calatrava-Leyva, 2016). However, this method is not appropriate for characterizing $\widetilde{WA}_t$ in the SBXII, because of recent changes in water management regulations in the Guadalquivir River Basin (GRB) affecting demand (new water rights granted), water supply (new infrastructure making it possible to store more water) and minimum ecological flows (Expósito & Berbel, 2019). Alternatively, a stochastic hydrological simulation model could account for all these changes. Therefore, in this paper we use the stochastic hydrological simulation model for the GRB built by Gómez-Limón (2020), which considers all these changes in demand, supply and the institutional framework included in the current GRB Management Plan (CHG, 2015). Figure 1 shows the empirical histogram of $\widetilde{WA}_t$ for the SBXII. As the shape of this histogram does not fit to any of the theoretical distribution functions, we opted for using 100,000 simulated observations obtained from the abovementioned hydrological model to empirically analyse the potential performance of the DSA instrument proposed.

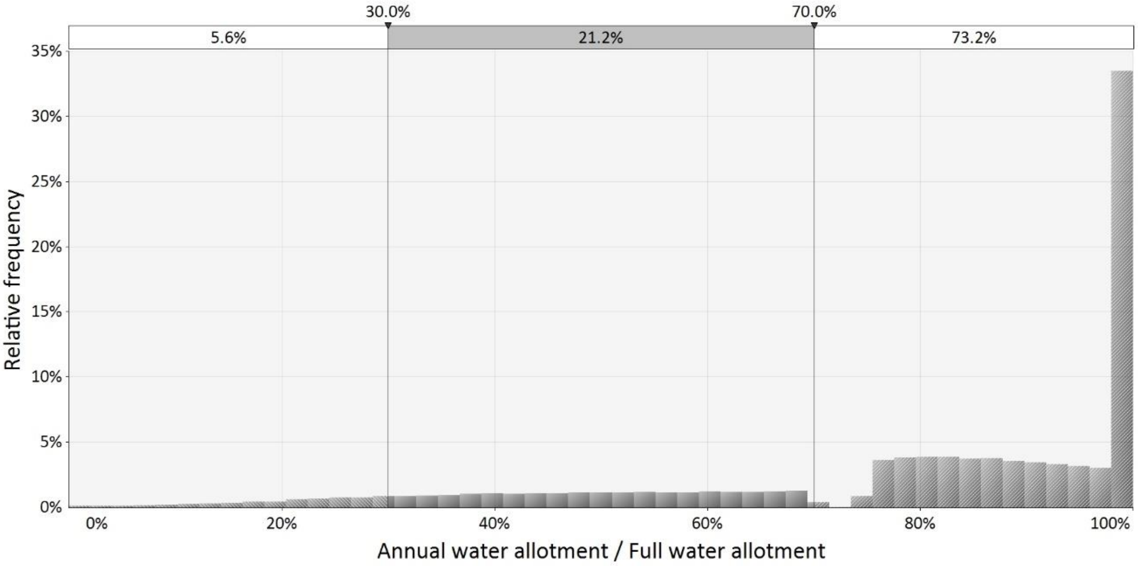

Figure 1. Distribution of the annual water allotment ($\widetilde{WA}_t$) for the SBXII. Source: Gómez-Limón (2020).

To simulate the performance of the proposed DSA, we have to determine the shape of the function f relating irrigation water availability and farm income ($I_t = f(\widetilde{WA}_t)$). For this purpose, we rely on a mathematical programming model to simulate farmers' decision-making in the event of water rationing (i.e. $\widetilde{WA}_t < fwa$).

To understand the alternatives that the targeted irrigators can use to cope with cyclical water scarcity, it is worth commenting that most crops cultivated in the SBXII are 'summer crops' (i.e. sown in spring, grown throughout the summer, and harvested at the beginning of autumn). Irrigators usually begin preparing the soil for sowing in late winter, taking advantage of the existing soil moisture accumulated during the wet season (autumn and winter). Irrigation operations start in May, at the beginning of the dry season (late spring and summer). It is important to note that crop mix decisions are taken by farmers in winter when these producers do not know how much water will be available for the upcoming irrigation season. In fact, it is only at the end of the wet season (1st May) that the RBA sets annual water allotments, once the total water availability at the basin level for the irrigation season (i.e. water stored in the reservoirs) is known.

By 1^{st} May irrigators have little leeway to cope with eventual water supply failures. For instance, they cannot replace crops that have higher water requirements with crops that have lower water needs or even rainfed crops since no crop can be sown at the beginning of the dry season. Similarly, improving irrigation efficiency at the farm level is not a solution in modern irrigation districts like the one considered as a case study. The only options they have for dealing with the water shortages are: a) to implement irrigation doses lower than full water requirements (i.e. deficit irrigation), and b) to stop irrigating and cultivating the least profitable crops and leaving these parcels as fallow land. However, deficit irrigation is most suitable for ligneous crops; for annual crops, this irrigation strategy is unlikely to produce a more profitable solution since the relationships between irrigation doses and herbaceous crop yields are almost linear (Steduto, Hsiao, Fereres, & Raes, 2012). This explains why most of the irrigators in the SBXII rule out this irrigation strategy and rely on stopping irrigating as the only realistic strategy to cope with water shortages.

Following mainstream mathematical programming techniques used for *ex-ante* policy analysis (Mérel & Howitt, 2014), we have built a Positive Mathematical Programming (PMP) model to simulate how an irrigator under water shortage conditions replaces irrigated crops with fallow land. This modelling approach, initially developed by Howitt (1995), calibrates a non-linear function for profit based on the observed behaviour of farmers (i.e. observed crop mix under a full water allotment scenario) to exactly reproduce activity levels. The PMP calibrated model can then be used for simulating farmers' decision-making in other scenarios. In our case, water rationing scenarios have been simulated by parametrizing the value of the annual water allotment ($\widetilde{WA}_t$) in the right-hand side of the water availability constraint.

Among the alternative options for eliciting the PMP calibrating parameters, we use the average cost approach, assuming a quadratic cost function for every crop (Heckelei, Britz, & Zhang, 2012). As a result, a non-linear objective function has been estimated to simulate irrigation water shortage scenarios, allowing the estimation of farm income for any level of water availability considered. Full details of the PMP model built for this purpose are available for interested readers on request. Following this procedure, the shape of the function f relating $\widetilde{WA}_t$ and I_t was empirically determined, as shown in Figure 2.

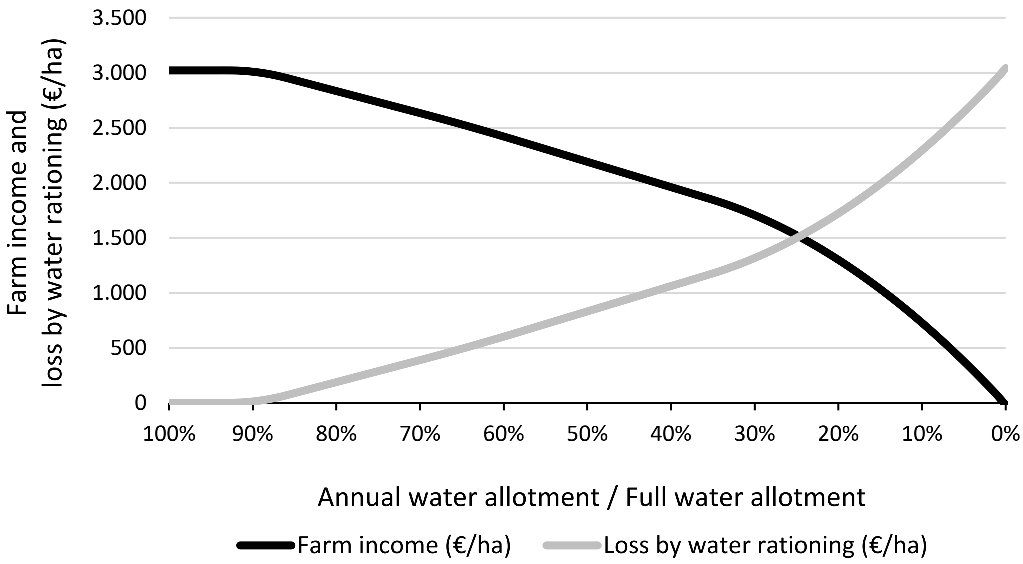

Figure 2. Farm income and loss by water rationing depending on the annual water allotment ($\widetilde{WA}_t$).

As the reader can observe, initial reductions in the annual water allotment do not involve any income loss since full water allotment is slightly higher than the water requirements for the farm type taken as a case study (its water needs are only 92% of the full water allotment granted). Moreover, this figure illustrates that the $\widetilde{WA}_t$ threshold beyond which regular annual contributions must be made to the DSA ($c \cdot fwa$) can be reasonably set by fixing c=80% since expected farm income considering this 20% reduction in the water allotment is close enough to the expected farm income with fwa (I_t=93.8%$\cdot \bar{I}$).

Scenario setting for simulation

Table 1 presents the values used for the set of parameters defining the model simulating the potential performance of the proposed DSA for the case study farm type. A brief justification of the values taken for each parameter is also provided in the last column of this table.

As can be observed, there are three parameters where multiple values are suggested. These are the most relevant parameters for the design of the DSA instrument, and are thus worth considering for defining the scenarios examined in the empirical analysis. The first one is the *farm income guaranteed* I^g, defined as the share α of $\bar{I}$. According to WTO Green Box requirements establishing a threshold for income drop as the trigger for the withdrawal of funds (Bardají et al., 2016), the initial value considered for α was 70%. This is the same as the percentage initially proposed for agricultural insurance supported by the CAP (Regulation (EU) 1305/2013). However, the EU has recently increased this percentage to 80% (Omnibus Regulation (EU) 2017/2393), justifying this exemption to WTO requirements under the "*de minimis*" rule. Thus, a value for α

equal to 80% has also been considered. These two values would allow an assessment of the effectiveness of the precautionary savings proposed to hedge against marketable and normal risks associated with deep (α=70%) and shallow (α=80%) losses of farm income (van Asseldonk et al., 2019). As can be seen in Figure 2, these values of α lead to values of the parameter w used to calculate the $\widetilde{WA}_t$ threshold for withdrawals from the DSA ($w \cdot fwa$) equal to 59.9% and 46.8%, respectively.

Table 1. Parameters used in the DSA simulation model.

Parameter	Value for simulations	Justification
Full water allotment (fwa)	6,000 m^3/ha	Water rights granted to the SBXII
Expected farm income with fwa ($\bar{I}$)	3,021 €/ha	Observed average farm gross margin considered as a proxy of farm income
Farm income guaranteed I^g (α)	70%-80% of $\bar{I}$	Design parameter under analysis
Regular annual contribution to DSA (β)	2%-4%-6% of $\bar{I}$	Design parameter under analysis
Catch-up payment when DSA_{t-1}<0 (γ)	5% of $\bar{I}$	To more rapidly replenish accounts
Public matching contribution (δ)	0%-2%-5% of farmers' contrib.	Design parameter under analysis
$\widetilde{WA}_t$ threshold for contributions to DSA (c)	80% of fwa	According to $\bar{I}$
$\widetilde{WA}_t$ threshold for withdrawals from DSA (w)	59.9%-46.8% of fwa	According to I^g
Upper cap on DSA balance (u)	200% of $\bar{I}$	Prevent DSA from becoming an investment fund
Lower cap on DSA balance (l)	100% of $\bar{I}$	Prevent DSA from becoming a finance instrument
Interest rate for deposits (r_d)	0.0%	Current and expected rate for deposits
Interest rate for fund borrowed (r_b)	5.0%	Current and expected rate for borrowed money

The second parameter studied is the *regular contribution rate to the DSA* (β), as the cornerstone of DSA performance. Contributions accounting for 2%, 4% and 6% of the expected farm income with full water allotment ($\bar{I}$) are proposed, considering the distribution of the annual water allotment ($\widetilde{WA}_t$) and the funds required to guarantee the income I^g. This range of values for β would allow an assessment of the actuarial soundness of the DSA in case this rate turns out to be too high or too low.

Finally, the third parameter under analysis is the *public matching contribution* (δ). In order to support instrument design decision-making, three values have been selected: a) δ=0%, denoting no public support, equivalent to the current situation; b) δ=2%, in line with the Canadian experience and the values proposed for the EU (van Asseldonk et al., 2019), assuming moderate-to-low public support; and c) δ=5%, representing significant public support. In any case, it is worth noting that all these percentages are considerably lower than the current support for agricultural insurance premium rates (Meuwissen, de Mey, & van Asseldonk, 2018).

Considering the values proposed in Table 1 for the parameters involving the performance of the DSA, 18 (3×2×3) scenarios have been defined for simulation.

Results and discussion

Performance assessment of the DSA instrument in the short to medium term

A summary of the results obtained (8 out of 18 scenarios analysed)[2] for the performance assessment of the DSA instrument in the short to medium term (t=5 years) is shown in Table 2. For this purpose, we have selected 8 out of the 18 scenarios defined for the proposed precautionary savings account; specifically, those that are useful for the analysis of the design parameters under study.

In order to assess the DSA as a risk management instrument for coping with hydrological drought, we must first focus on the variable measuring the percentage of years that the farmer's withdrawals are capped (i.e. those when drought risk is not properly hedged). In this regard, it can be seen that in all analysed scenarios, the percentage of years that the farmer's withdrawals are capped is below 0.3%, underlining the suitability of the DSA as a useful risk management instrument, since it is able to fully cover drought risk in more than 99.7% of the years. In any case, it is worth noting that where the farm income guaranteed is defined as 80% of average income with full water allotment (α=80%, see scenarios 2, 8 and 14 in Table 2), the percentage of years that the farmer's withdrawals are capped is higher than 0.2%; conversely, where income guaranteed is defined as 70% of average income with full water allotment (α=70% considered in the other scenarios), this percentage is negligible (below 0.1% in every case). This indicates that the proposed precautionary savings instrument is suitable for hedging both shallow losses (α=80%) and deep losses of farm income (α=70%). However, if the farmer's and public sector's contributions to the DSA are intended to be reasonably low, it is advisable to design the DSA to cover only deep losses, fixing α=70%. The reason for this is that if shallow losses of farm income (α=80%) were also covered, more frequent withdrawals would be made (in more than 20% of the years), a situation leading to regular low or negative DSA balances that would involve higher financial costs (i.e. interest charged on borrowing) and problems with negative terminal balances (e.g. payback in full or transfer with the farm to heirs).

Table 2. DSA performance in the short to medium term (*t*=5 years) for selected design scenarios.

		Scen. 2	**Scen. 5**	**Scen. 8**	**Scen. 10**	**Scen. 11**	**Scen. 12**	**Scen. 14**	**Scen. 17**
Farm income guaranteed (α)		80%	70%	80%	70%	70%	70%	80%	70%
Regular contribution DSA (β)		6%	6%	4%	4%	4%	4%	2%	2%
Public matching contribution (δ)		2%	2%	2%	5%	2%	0%	2%	2%
Farmer's contribution (€/ha·year)	Mean	130.7	124.9	94.5	87.8	87.9	88.2	58.6	51.7
	CV	76.9	73.0	58.8	54.1	54.6	54.4	42.7	39.0
Public matching contribution (€/ha·year)	Mean	2.6	2.5	1.9	4.4	1.8	0.0	1.2	1.0
	CV	1.5	1.5	1.2	2.7	1.1	0.0	0.9	0.8
Years with contributions (%)		64.3%	64.2%	64.2%	64.2%	64.0%	64.2%	64.2%	64.1%
Years with regular contributions capped (%)		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Years with catch-up payments (%)		23.6%	14.2%	28.0%	16.9%	17.4%	17.5%	32.9%	21.4%
Withdrawals (€/ha·year)	Mean	114.1	62.4	113.3	61.9	63.4	62.1	113.0	62.4
	CV	795.2	778.7	787.2	771.9	783.2	772.6	784.8	782.4
Years with withdrawals (%)		21.1%	13.8%	21.1%	13.8%	13.9%	13.7%	21.1%	13.8%
Years with withdrawals capped (%)		0.22%	0.05%	0.26%	0.05%	0.05%	0.04%	0.29%	0.06%
DSA cash-flow (€/ha·year)	Mean	5.7	58.4	-32.9	22.4	18.3	18.1	-72.2	-19.4
	CV	22,998	1,264	-3,540	2,870	3,594	3,517	-1,448	-2,954
DSA final balance (€/ha)	Mean	29.2	291.1	-167.0	107.8	93.9	86.4	-364.7	-101.0
	CV	22,867	1,273	-3,607	3,034	3,483	3,759	-1,502	-2,874
Original distribution I_t (€/ha·year)	Mean	2,711	2,711	2,711	2,711	2,708	2,711	2,711	2,711
	CV	91.7	91.3	91.1	90.9	92.5	90.9	90.9	91.5
New distribution I_t^{DSA} (€/ha)	Mean	2,700	2,706	2,696	2,707	2,703	2,702	2,693	2,702
	CV	29.5	40.4	31.8	44.1	44.4	43.9	34.4	47.9
Risk premium (€/ha·year)	r_r=0.5	37.1	33.3	31.0	31.6	33.2	25.2	24.7	26.3
	r_r=4.0	302.5	264.8	288.5	254.0	257.0	232.5	277.5	243.0
Risk premium (%)	r_r=0.5	1.4%	1.2%	1.2%	1.2%	1.2%	0.9%	0.9%	1.0%
	r_r=4.0	11.5%	10.2%	11.1%	9.9%	10.0%	9.0%	10.7%	9.5%

CV: Coefficient of variation (ratio of the standard deviation to the mean).

The second variable worth analysing for the DSA performance assessment is the farmer's regular annual contribution to the DSA. When comparing scenarios, in those where α=70% and δ=2% (scenarios 5, 11 and 17 in Table 2) it can be observed that the range of values considered for β provides fairly similar performance in terms of hydrological drought risk hedging, with all these scenarios properly hedging the hydrological drought risk (percentage of years that the farmer's withdrawals are capped around 0.05%). This result is possible, despite the different amounts of money regularly paid into the DSA, because the design proposed for this instrument includes catch-up contributions to minimize negative balances. These catch-up contributions make it possible to compensate for any shortfall in regular contributions. This buffering mechanism can be seen to follow the evolution of the variable percentage of years with catch-up payments, increasing from 14.2% in Scenario 5 (β=6%) to 21.4% in Scenario 17 (β=2%). These results provide evidence of the actuarial soundness of the proposed DSA for a relatively wide range of the farmer's regular annual contributions. At any rate, for the case study analysed here, the most suitable values of β are around 4%. This value for β (4%) is high enough to ensure that the percentage of years when hydrological drought risk cannot be hedged does not rise above 0.1% and to prevent regular negative DSA balances (higher financial costs and negative terminal balances), unlike with the performance variables for Scenario 17 (β=2%). Additionally, the 4% proposed for the parameter β is low enough to avoid regular high positive DSA balance (unnecessary, unprofitable deposits), unlike with the performance variables for Scenario 5 (β=6%).

Finally, the role of the public matching contribution (δ) also merits analysis. For this purpose, the scenarios where α=70% and β=4% (scenarios 10, 11 and 12 in Table 2) are compared. As can be seen, the performance of the DSA instrument is quite similar in all these scenarios both in terms of risk hedging (percentage of years that the farmer's withdrawals are capped between 0.04% and 0.05%) and the average DSA final balance (between €107.8/ha and €86.4/ha). Obviously, the only relevant difference is the average public matching contribution measured in euros per hectare, which is €0.0/ha·year for δ=0%, €1.8/ha·year for δ=2% and €4.4/ha·year for δ=5%. To properly assess the efficiency of public contributions to support the adoption of the DSA, the farmer's utility gains estimated using the SDRF approach are taken into account. As can be noted in Table 2 for any DSA scenario, the implementation of this precautionary savings account would involve a sharp change in the probability distribution of farm income, significantly reducing the dispersion of I_t (measured as the coefficient of variation, CV), while basically maintaining the average farm income. This change would lead to utility gains for all adopter farmers with ordinary individual risk aversion (i.e. r_r varying between 0.5 −slightly risk-averse− and 4.0 −extremely risk-averse), gains that can be measured in monetary terms using risk premia. For the case of δ=0% (Scenario 12), the utility gains for the adoption of the DSA range from €25.2/ha·year (0.9% of average income) for farmers with r_r=0.5 to €232.5/ha·year (9.0% of average income) for farmers with r_r=4.0. These gains even without public support explain why precautionary savings have already been adopted on an informal basis. Public support through matching contributions could increase the farmer's utility gains: for δ=2% (Scenario 11), risk premia range from €33.2/ha·year to €257.0/ha·year; and for δ=5% (Scenario 10), from €31.6/ha·year to €254.0/ha·year. A comparison of the public matching contribution and the increase in the farmer's utility gains, both measured in euros per hectare and year, suggests small overall economic efficiency gains (public contributions are lower than the increases in risk premia). Nevertheless, it is worth pointing out that efficiency gains in terms of social welfare exceed farmer's utility gains since improved risk management also leads to higher agricultural production (income and employment generation), both in the short (higher input use) and the long run (higher production investment), and to improved environmental status of water bodies (prevention of water theft). Unfortunately, measuring such efficiency gains is beyond the scope of this research and no conclusive evidence regarding the overall efficiency effect of the policy proposed can be obtained.

The above results suggest that public support for the proposed precautionary savings account plays a secondary role, with only a marginal effect on the efficiency of the DSA as a risk management instrument and farmers' willingness to adopt it. However, it is worth mentioning that there is evidence pointing to the success of public support in promoting DSA adoption, as the Canadian experience has shown (Canadian Minister of Agriculture and Agri-Food, 2020). In fact, with public matching support corresponding to just 1% of the farmer's contribution, the *AgriInvest* programme has achieved coverage of over 75% of farmers. Moreover, taking into account the high level of public support to promote other agricultural risk management instruments (e.g. subsidies for taking out agricultural insurance, currently up to 50% of insurance premia in many schemes), a call for moderate public support for the DSA (e.g. δ=2%) could be deemed fair (Meuwissen et al., 2018).

Therefore, considering the policy criteria guiding this policy design and the explanations of the results provided above, Scenario 11 (α=70%, β=4% and δ=2%) can be selected as the most suitable option for the implementation of the proposed DSA in a real-life setting in the short to medium term.

Performance assessment of the DSA instrument in the long term

Turning now to the DSA performance assessment in the long term, Table 3 shows a summary of the results obtained for *t*=20 years, depicting the same eight scenarios as presented for the short-term analysis.

The results achieved for the long-term are similar to those obtained for the short-term analysis, although the cumulative effects of DSA cash-flows over 20 years more clearly reveal any potential actuarial imbalance in the design of this instrument. Thus, scenarios with α=80% (scenarios 2, 8 and 14 in Table 3) should also be ruled out, since the percentages of years with withdrawals capped are much higher than in the short-term case (0.93%, 1.20% and 1.57%, respectively) and the DSA final balances are even further in the negative.

Table 3. DSA performance in the long term (*t*=20 years) for selected design scenarios.

		Scen. 2	**Scen. 5**	**Scen. 8**	**Scen. 10**	**Scen. 11**	**Scen. 12**	**Scen. 14**	**Scen. 17**
Farm income guaranteed (α)		80%	70%	80%	70%	70%	70%	80%	70%
Regular contribution DSA (β)		6%	6%	4%	4%	4%	4%	2%	2%
Public matching contribution (δ)		2%	2%	2%	5%	2%	0%	2%	2%
Farmer's contribution (€/ha·year)	Mean	132.0	122.4	100.2	88.3	88.7	89.2	69.5	58.4
	CV	78.0	70.7	61.7	54.4	54.8	55.0	44.3	42.6
Public matching contribution (€/ha·year)	Mean	2.6	2.4	2.0	4.4	1.8	0.0	1.4	1.2
	CV	1.6	1.4	1.2	2.7	1.1	0.0	0.9	0.9
Years with contributions (%)		64.2%	64.2%	64.1%	64.3%	64.2%	64.3%	64.2%	64.2%
Years with regular contributions capped (%)		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Years with catch-up payments (%)		26.1%	9.9%	37.6%	17.7%	18.4%	19.0%	50.8%	32.5%
Withdrawals (€/ha·year)	Mean	103.3	60.8	93.6	60.5	59.8	59.9	81.1	58.1
	CV	781.4	773.9	772.8	776.7	770.4	772.9	762.6	762.7
Years with withdrawals (%)		19.8%	13.5%	18.3%	13.4%	13.4%	13.3%	16.3%	13.1%
Years with withdrawals capped (%)		0.93%	0.12%	1.20%	0.21%	0.19%	0.19%	1.57%	0.39%
DSA cash-flow (€/ha·year)	Mean	-0.6	55.2	-42.5	15.7	13.3	11.2	-89.6	-32.2
	CV	-182,988	1,288	-2,251	4,039	4,645	5,492	-826	-1,671
DSA final balance (€/ha)	Mean	54.3	1,130.4	-756.3	385.2	332.2	295.8	-1,596.1	-481.5
	CV	51,742	1,438	-3,429	3,976	4,652	5,245	-1,508	-3,266
Original distribution I_t (€/ha·year)	Mean	2,711	2,712	2,712	2,711	2,711	2,712	2,711	2,711
	CV	91.1	90.5	90.9	91.5	90.9	90.9	91.2	91.5
New distribution I_t^{DSA} (€/ha)	Mean	2,685	2,707	2,667	2,702	2,699	2,698	2,643	2,686
	CV	23.0	30.9	31.3	36.2	36.3	36.2	42.1	42.4
Risk premium (€/ha·year)	r_r=0.5	16.1	40.8	-6.5	37.2	28.5	32.5	-41.0	16.5
	r_r=4.0	282.0	297.3	224.2	289.4	259.7	282.3	140.1	236.2
Risk premium (%)	r_r=0.5	0.6%	1.5%	-0.2%	1.4%	1.1%	1.2%	-1.6%	0.6%
	r_r=4.0	10.8%	11.3%	8.8%	11.1%	10.0%	10.8%	5.7%	9.2%

CV: Coefficient of variation (ratio of the standard deviation to the mean).

Analysing suitable values for the farmer's regular annual contribution to the DSA, it can be observed that when a long time frame is considered for the DSA, the buffering effect provided by the catch-up contributions mechanism is less effective than in the short time frame. In fact, comparing scenarios in which α=70% and δ=2% (scenarios 5, 11 and 17 in Table 3), it can be observed that even when catch-up payments with different frequencies (9.9%, 18.4% and 32.5%, respectively) are implemented, the percentage of years that the farmer's withdrawals are capped yields more heterogeneous results than in the short term: 0.13% for Scenario 5 (β=6%), 0.19% for Scenario 11 (β=4%) and 0.39% for Scenario 17 (β=2%). However, the hydrological drought risk is reasonably hedged in every case. Thus, under this time frame, the farmer's regular annual contribution for our case study should be similar to the one proposed for the short term (i.e. β=4%).

When a long time frame is considered, public support through matching contributions also plays a secondary role regarding the efficiency of the DSA and its attractiveness for farmers as a risk management instrument. Nevertheless, it is worth pointing out that for this time frame, the increase in the farmer's utility gains compared with the public matching contribution, both measured in euros per hectare and year, indicate mixed contributions to overall economic efficiency; depending on the scenario in question, increases in risk premia are slightly lower or higher than increases in public contributions.

Concluding remarks

This paper has explored the use of precautionary savings as a new risk management instrument that can be implemented to hedge hydrological drought risk in irrigated agriculture, a risk currently not covered by any policy instrument. For this purpose, the Drought Savings Account has been proposed as a theoretically suitable policy instrument that can overcome the problems hindering the implementation of agricultural insurance and allow more cost-effective risk management. This cost-effectiveness is a key advantage of precautionary savings over agricultural insurance, since the former instrument minimizes moral hazard and adverse selection problems, and the transaction costs of risk-sharing. Moreover, in this context, precautionary savings may play a significant role as an efficient climate change adaptation measure since the self-insurance strategy adopted does not distort the signals underlying farmers' own risk exposure, leading to better individual assessment and management of water supply gaps.

The instrument proposed has been evaluated empirically through a simulation exercise assessing the potential performance of the DSA in a representative farm located in an irrigation district in Southern Spain. The simulation results obtained suggest the actuarial soundness of the DSA since it can provide a reasonable hedge of hydrological drought risk (farm income guaranteed is assured in more than 99% of the years) for a relatively wide range of regular annual contribution rates. The key design feature ensuring actuarial soundness is the catch-up contributions mechanism, which makes it possible to (partially) compensate for any shortfall in regular contributions. This result is policy-relevant because it could support the implementation of this instrument across farm types with only minor adjustments in the annual contribution rates, and without the need for complex actuarial analyses. In any case, further research is needed to confirm that simulation results are robust enough (i.e. verifying that simulated farm income and losses in drought years are close to the real values).

Moreover, the assessment of the DSA instrument has also revealed that precautionary savings lead to significant utility gains for adopters, even without public support, explaining the current informal use of this tool. In any case, moderate public support is suggested to make it clear that agricultural risk management is a top policy priority, similar to other policy instruments (i.e. agricultural insurance), and also to promote wider adoption, especially among more vulnerable farms. In this regard, it is worth pointing out that, besides the abovementioned private utility gains, public subsidies of the DSA would be justified on the basis of the substantial public benefits that may be generated by the widespread adoption of this instrument. In particular, these public gains would be related to the more intensive use of inputs (i.e. more labour demand, reducing the current unemployment rate in rural areas), more agricultural investments and higher output production (i.e. improving wealth generation and food security), and the enhancement of the environmental status of water bodies (i.e. prevention of water theft).

In any case, additional refinements to the public support for the implementation of the DSA merit further discussion. In order to cope with inequity issues, it may be worth considering the possibility of focusing on farms with fewer options for risk management; for instance, implementing higher matching contributions for smaller farms or those managed by young farmers with fewer available assets. Similarly, as has been done in Canada to promote faster adoption, DSA design could involve an initially high public matching contribution (e.g. 5% for the first year) that would decrease over a period of 3 to 5 years to the level of support proposed above. The implementation of the refined DSA in a real-life setting could be undertaken as a pilot study of precautionary savings within the EU context, in order to evaluate the potential of this agricultural risk management instrument as an alternative or a complement to widespread agricultural insurance.

Finally, the main limitation of the analysis performed is that the simulation exercise is based on expected utility theory, assuming irrigators behave as expected utility maximizers in the short run, regardless of whether or not they adopt the DSA (i.e. the adoption of the DSA does not change their farming decision-making). However, recent research in behavioural economics (e.g. Buchholz, Holst, & Musshoff, 2016; Chabé-Ferret, Le Coent, Reynaud, Subervie, & Lepercq, 2019) provides new insights into this issue, suggesting that farmers' behaviour is shaped by the whole decision context, accounting for information that goes beyond monetary outcomes (i.e. utility gains). Thus, exploring policy-induced behavioural change (e.g. ‘nudges’) is proposed as a future avenue for research, in order to provide a more complete picture of irrigators’ decision-making when facing water rationing and the adoption of the different policy instruments such as the DSA. Moreover, further research is called for more detailed modelling of decision-making accounting for possible changes in production technologies (investments in irrigation systems or perennial crops) and heterogeneity in farmers’ risk preferences. These new avenues for research pose challenges, since uncertainty about the future state of water systems creates difficulties in simulating farmers’ strategic decision-making (i.e., decisions involving investments in fixed capital), and assessing the multiple impacts of investments made chasing higher economic returns (i.e. further specialization in higher profitability farming systems), as has been evidenced worldwide (e.g. Kumar, Malla, & Tripathy, 2008; National Water Commission, 2010).

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[1] The full simulation results for every t in any policy scenario considered are available for interested readers on request.

[2] The full descriptive results for the 18 scenarios considered are available for interested readers on request.