Income Impacts of Climate Change: Irrigated Farming in the Mediterranean and Expected Changes in Probability of Favorable and Adverse Weather Conditions

Auswirkungen des Klimawandels auf das Einkommen: landwirtschaftliche Bewässerung im Mittelmeerraum und erwartete Änderungen der Wahrscheinlichkeit günstiger und widriger Witterungsbedingungen

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Abstract

EU rural development policy (RDP) regulation 1305/2013 aims to protect farmers' incomes from ongoing change of climate variability (CCV), and the increase in frequency of adverse climatic events. An income stabilization tool (IST) is provided to compensate drastic drops in income, including those caused by climatic events. The present study examines some aspect of its application focussing on Mediterranean irrigation area where frequent water shortages may generate significant income reductions in the current climate conditions, and may be further exacerbated by climate change. This enhanced loss of income in the future would occur due to a change in climate variability. This change would appreciably reduce the probability of weather conditions that are favourable for irrigation, but would not significantly increase either the probability of unfavourable weather conditions or the magnitude of their impact. As the IST and other insurance tools that protect against adversity and catastrophic events are only activated under extreme conditions, farmers may not consider them to be suitable in dealing with the new climate regime. This would leave a portion of the financial resources allocated by the RDP unused, resulting in less support for climate change adaptation.

Key Words

discrete stochastic programming; RDP measures to adapt to climate change; economic impact of climate change; irrigated agriculture and climate change; insurance tools for adaptation to climate change

Zusammenfassung

Mit der Verordnung 1305/2013 zielt die EU-Politik zur Entwicklung des ländlichen Raums (RDP) darauf ab, die Einkommen der Landwirte vor den Auswirkungen von Änderungen in der Klimavariabilität (CCV) und häufiger werdenden widrigen Witterungsbedingungen zu schützen. Das Instrument der Einkommensstabilisierung (IST) ist vorgesehen, um drastische Rückgänge der Einkommen auszugleichen, die unter anderem durch Klimaereignisse verursacht werden. Die vorliegende Studie untersucht einige Aspekte der Anwendung dieses Instruments. Das Augenmerk ist auf den mediterranen Bereich gerichtet, wo häufiger Wassermangel unter aktuellen Bedingungen, der durch den Klimawandel noch verschärft werden kann, zu erheblichen Einkommenseinbußen führen kann. Stärkere Klimavariabilität dürfte größere Einkommenseinbußen auslösen. Eine deutliche Verringerung der Wahrscheinlichkeit von günstigen Witterungsbedingungen für die Bewässerung ist abzusehen. Eine höhere Wahrscheinlichkeit von ungünstigeren Bedingungen für die Bewässerung und deren Folgen sind jedoch nicht zu erwarten. IST und Versicherungsinstrumente, die gegen Schäden und Katastrophen schützen sollen, werden nur unter extremen Bedingungen zum Einsatz kommen. Sie dürften daher von Landwirten als ungeeignet eingestuft werden, um die

Folgen der Klimaänderung zu bewältigen. Ein Teil RDP-Mittel könnte somit ungenutzt bleiben. Dies könnte eine geringere Unterstützung zur Anpassung an den Klimawandel zur Folge haben.

Schlüsselwörter

diskrete stochastische Programmierung, Politik zur Entwicklung des ländlichen Raums, Anpassung an den Klimawandel, wirtschaftliche Folgen des Klimawandels, Beregnung in der Landwirtschaft, Versicherungsinstrumente

1 Introduction

The EU Rural Development Policy (RDP) regulation 1305/2013 aims to stabilize farmers' incomes by introducing a set of tools to protect them from risks inherent in the agricultural sector (EUROPEAN PARLIAMENT AND COUNCIL, 2013, articles 36-39). This intervention is intended to contribute to premiums for crop, animal, and plant insurance that protects against economic loss caused by adverse climatic events, animal or plant diseases, pest infestations, or an environmental incident (article 36). This approach is in line with literature on risk management in agriculture focused on the effects of adverse atmospheric events on agricultural and livestock production (MOSCHINI and HENNESSY, 2001; MEUWISSEN et al., 2003a, 2003b, 2011; CAFIERO et al., 2007; OECD, 2011; FINGER and LEHMANN, 2012). The EU pays particular attention to these risks, believing that ongoing change of climate variability (CCV) will increase the frequency of adverse climatic events (SHEFIELD and WOOD, 2008) and, therefore, the stress on crops and livestock.

In cases where farmers experience a drastic drop in income exceeding 30% of the average annual value (art. 36/1c and 39/1)[1], an additional income stabilization tool (IST) is activated to make financial contributions to mutual funds that provide compensation to farmers. The IST should be activated regardless of the causes of income fluctuations, which implies that it could be used to offset income reductions caused by current and future climate conditions, even when they do not involve catastrophic events or natural disasters. This is of interest to Mediterranean farmers who are vulnerable to CCV.

DONO et al. (2013b) examine the possible production and income impacts of the joint occurrence of two independent climatic variables relevant to irrigation in at a study site in the Mediterranean. The first variable is water accumulation in a reservoir used for irrigation, which depends on the autumnal and winter rainfall, and the second variable is ET_N, or net evapotranspiration, which is a proxy for crop irrigation requirements. It is considered that those variables do not generate *adverse climatic events*, defined in article 2 of the Regulation as "*weather conditions, such as frost, storms and hail, ice, heavy rain or severe drought, which can be assimilated to a natural disaster*". However, they generate adverse conditions that may result large production decreases, particularly if they occur concurrently.

DONO et al. (2013b) use discrete stochastic programming (DSP) to simulate the economic choices of farmers under the current and near future climate, and to identify the impacts of CCV by comparing production and income under those two scenarios. DSP simulates the choice process of a decision-maker who plans his or her activities without knowing the precise value of variables that control the final result (COCKS, 1968; RAE, 1971; MCCARL and SPREEN, 1997). Some decisions that affect activities in the planning period are therefore based on assumptions about the probability distribution of these variables and the different conditions in which they may arise. This can result in errors if one of the possible variable states does not occur. In these circumstances, planning will be guided by the possibility of compensating for this error by making adjustments in the course of work. The DSP considers the sequence of decisions and adjustments applied during the planning period and, given that the possible variable states are not known with certainty, identifies the solution with the highest expected income.

DONO et al. (2013b) calculated the highest expected income, from sub-optimal and optimal outcomes, resulting from choices made under current and near-future climatic scenarios. The present study deepens this analysis by evaluating all single economic results from the expected income; i.e., the results that

[1] Support under Article 37(1)(c) shall only be granted where the drop in income exceeds 30% of the average annual income of the individual farmer in the preceding three-year period or a three-year average based on the preceding five-year period excluding the years with the highest and lowest income. Income for the purposes of Article 37(1)(c) shall refer to the sum of revenues the farmer receives from the market, including any form of public support, deducting input costs. Payments by the mutual fund to farmers shall compensate for less than 70% of the income lost in the year the producer becomes eligible to receive this assistance (art. 40/1).

farmers could expect in each possible states of nature, favorable and unfavorable. The overview of the singular states appears to be relevant given that participation in the IST occurs if farmers expect to be exposed to income losses exceeding 30% of the annual average value. The near-future scenario considered by DONO et al. (2013b) simulates expectations of meteorological conditions in a year between 2010 and 2020, when farmers will be considering whether to adhere to the RDP measures such as the IST. Therefore, it is relevant to discuss whether the new climate scenario can increase farmers' interest in using insurance-type instruments for adaptation to CCV.

The remainder of this paper is organized as follows. Section 2 describes the characteristics of the study area and the two climatic variables examined in the study. Section 3 outlines the three stages of the DSP model developed by DONO et al. (2013b) to simulate productive choices under two uncertain climatic variables in current and near-future climate scenarios, and the key economic results. This is followed by a description of the current analysis, which shows the expected income of farmers in two climate scenarios, followed by a discussion of the implications and of the potential for success of the IST.

2 Materials and Methods

DONO et al. (2013b) utilize a DSP model to simulate agricultural production and income in current (baseline) and near-future scenarios. Their study area is located in the Cuga hydrographical watershed (40°36′N, 8°27′E; 350 km2) in north-west Sardinia (Italy), in the homogenous climate of the central Mediterranean basin (BRUNETTI et al., 2002, 2004; DONO et al., 2013a). The model is territorial and consists of 13 representative types of farms that use resources such as land, groundwater, temporary labour, and family work, and share surface water distributed by a Water User Association (WUA). In this area, irrigation is dependent on water stored in the Cuga-Temo artificial lake system. This water resource is dependent on autumnal and winter rains, and the low storage capacity of the lakes means that they must be managed season-by-season. The amount of irrigation required is mainly controlled by the evapotranspirational demands of summer crops (ET_N). For some crops, the Environmental Policy Integrated Model (EPIC) has also been used to simulate productive yields under different climatic CO_2 scenarios and in different climatic conditions (WILLIAMS, 1995).

2.1 Expectation on the uncertain variables

The stochastic components of the model are related to the autumnal-winter rain and consequent water availability in the dam, and the ET_N, and thus the irrigation requirements of crops. These variables are considered to be controlled by mutually independent processes, and farmers are assumed to evaluate the probability distributions of these meteorological variables on the basis of experience gained in the decades preceding their management decisions. This approach led to a baseline scenario, generated by fitting the probability distribution function (pdf) onto meteorological data for the 30 years before 2004. The near-future scenario was built using data from the last decade, when the trends emerged in previous decades for the main meteorological variables become more marked: this accentuation was assumed to be central in determining climate expectations and choices of farmers in the second half of 2010-2020. The climate scenario obtained in this way is consistent with climate trends over the past 50 years, and with Mediterranean climatological studies (GARCÍA-RUIZ et al., 2011).[2] Figures 1a and b show the resulting pdfs of ET_N and Water Accumulation (WA) for both baseline and near-future scenarios.

The discretization of the pdf was driven primarily by the objectives of identifying states of nature that are: a. easily identifiable by farmers in the area, therefore a few of them; b. well represented by the original data; c. not far from the calibration values of the agronomic model EPIC. This latter aspects led to avoid the bounding of particularly extreme and exceptional temperatures and states of ET_N. Therefore, the pdf of the ET_N has been discretized with a threshold that, in both climate scenarios, identifies two states of nature. The first occurs in 25% of cases and regards the high irrigation requirements, while the other 75% concerns the lower irrigation requirements. Instead, three states, derived from the reservoir management policy that

[2] Assuming that farmers understand the variation in the distribution of the variables by observing the influence of weather on crops is definitely strong and difficult to verify. However, it is not uncommon in economic research. For example, the Ricardian approach of MENDELSOHN assumes that the econometric relationship between the value of the land and the weather conditions in different climatic zones reflects the natural ability of farmers to adapt to long term climate change (MASSETTI and MENDELSOHN, 2011). Our attitude in this paper is that, based on this hypothesis, we identify the best results that farmers can obtain on the basis of observations of climate trends.

was in effect until 2010, were considered for irrigation water availability. The low availability state was set with the upper bound at the reservoir level at which public authorities had historically restricted irrigation in order to guarantee potable supply. The medium availability state occurs when the allocation of water among farms must be decided by the WUA. Its lower bound coincides with the upper bound of the low state, and its upper bound is symmetrical with respect to the pdf average. The high-availability state is only restricted by the capacity of the dam. The central values of those boundaries and the related probabilities are the farmers' expectations in the DSP models.

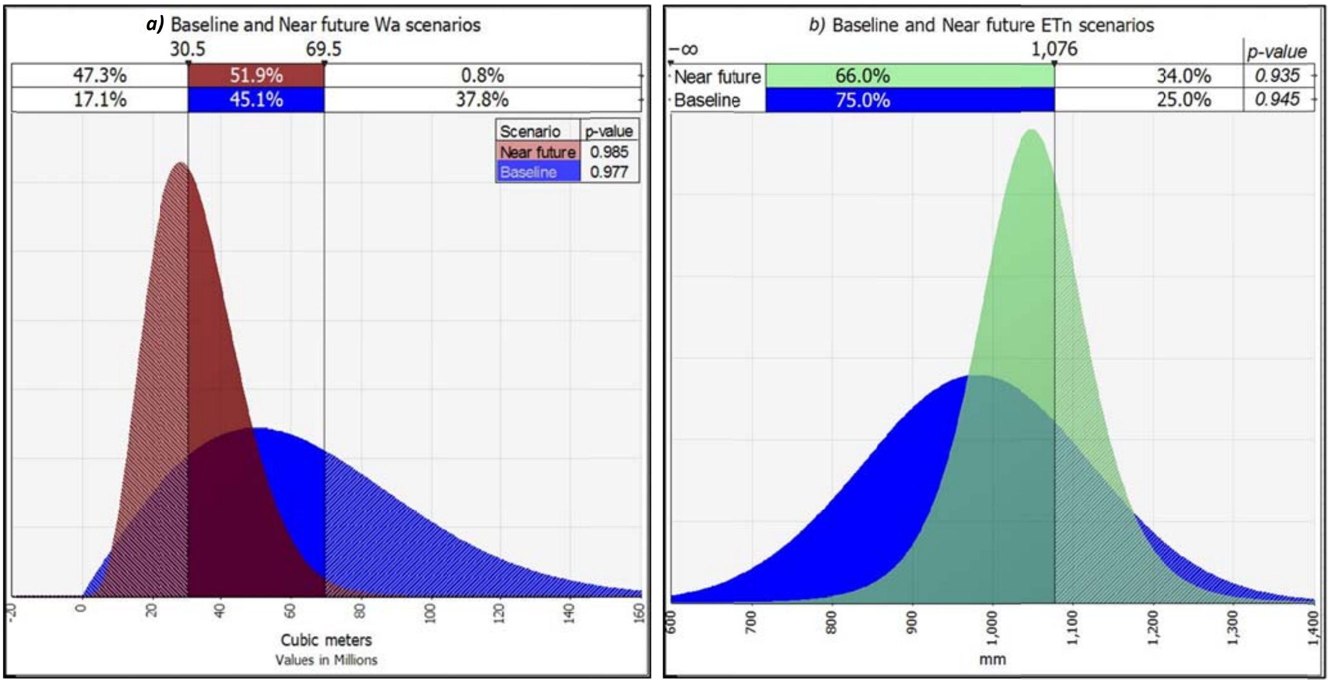
Figures 1a and 1b show the occurrence probability of any state of nature in each scenario. The probability of the high water availability state in the dam (more than 69.5 million cubic meters) is reduced from 37.8% in the baseline scenario to 0.8% in the near-future scenario. In contrast, the probability of the low water availability state (less than 30.5 million cubic meters) increases from 17.1% in the baseline scenario to 47.3% in the near-future scenario. The changes can also be assessed by keeping the probabilities constant and varying the threshold between the states. On the other hand, the water requirements associated with the upper 25% of the pdf is bounded by an ET_N value that is much higher in the near-future scenario than in the baseline scenario.

Table 1 shows representative values used in the DSP model for the states of nature of the two variables, with the respective probabilities in the baseline and near-future scenarios. Note that by assigning a fixed probability of 75% to the lower ET_N (Normal) state, the water demand increases by 9.9% from the current climate scenario to the near-future scenario.

2.2 The DSP Agricultural Production Model

The economic analysis of this study was based on DSP (COCKS, 1968; RAE, 1971; MCCARL and SPREEN, 1997; CONNOR et al., 2009), a modelling technique used for representing the economic impacts of various uncertainties related to agriculture, e.g., irrigation water availability (CALATRAVA and GARRIDO, 2005a, 2005b), productive results of technologies (COULIBALY et al., 2011), weather risk (MOSNIER et al., 2009), and changes in climate variability (DONO and MAZZAPICCHIO, 2010). The DSP represents a decision-making process, in which the farmer decides how to use resources given some uncertainty about variables. It makes choices by formulating hypotheses about the probability distributions of variables and considering the course of the actions that can be taken in the occurrence of the different, possible states of nature. Specifically, each variable state is evaluated to generate an optimal result under preferred conditions, and sub-optimal results when one of the alternative

Figure 1. Pdfs of a) ET_N and b) Water Accumulation (WA), for the baseline and near-future scenarios (DONO et al., 2013b)



Source: DONO et al. (2013b)

Table 1. Values and probability of WA and ET_N in the baseline and near-future scenarios

		Baseline		Near future	
		Value of the state	Probability	Value of the state	Probability
Water accumulation WA (,000 m^3)	Low (K1)	12,235	***17.1***	13,249	***47.3***
	Medium (K2)	29,050	***45.1***	23,229	***51.9***
	High (K3)	52,824	***37.8***	42,900	***0.8***
ET_N (mm)	Normal (R1)	934	***75.0***	1,026	***75.0***
	High (R2)	1,145	***25.0***	1,132	***25.0***

Source: DONO et al. (2013b)

states occurs. To account for this uncertainty, the farmer evaluates various states based on the possibility of correcting decisions. Many kinds of adjustments have been considered in the DSP model literature, such as applying water to crops, crop abandonment, purchasing or selling water, pumping water from the private wells, and feed purchase.

DONO et al. (2013b) proposed a three-stage DSP model where uncertainty involves two climatic variables, WA and ET_N, considered mutually independent in the decision-making process. The first decision is made at the beginning of the agricultural season (September) when the farmer allocates land to winter crops, harvested from April to July, and conversely reserves land for summer crops, sown in March and harvested until October. Those decisions are based on expectations concerning both climatic variables. At the end of March, the farmer selects summer crops to be cultivated over all (or part of) land not cultivated with winter crops. This decision is taken knowing how much surface water is stored in the reservoir and available for irrigation, and is based on the expected irrigation requirements of summer crops. During the summer, the farmer can determine the actual irrigation requirements of crops and no longer faces any of the uncertainties considered in the analysis. If the actual watering needs exceed the available surface water, the farmer can supplement this with ground water by paying pumping costs. The model is formalized as follows:

$$\max_{x_1, x_{3_{k,r}}} Z = GI * x_1 + \sum_k \sum_r P_k * P_r * GI_r * x_{3_{k,r}} \quad (1)$$

subject to

$$A * x_1 + A * x_{2_k} \leq b_k \ \forall k \quad (2)$$

$$A * x_1 + A_r * x_{3_{k,r}} \leq b_{k,r} \ \forall k, r \quad (3)$$

$$x_{3_{k,r}} = x_{2_k} \ \forall k, r \quad (4)$$

The objective function Z is the total gross income where x_1, x_{2_k}, and $x_{3_{k,r}}$ are vectors of cropping activities (in hectares) influenced by the conditions in the first, second, and third stages; P_k is the probability of different water availability states; P_r is the probability of different ET_N states; GI is the gross income of each activity; A is a matrix of technical coefficients; and b is the quantity of available resources. Constraint (2) refers to choices at the first and second stages and relates to land and labour resources (b_k). It includes two variables: x_1 (autumn crops), which is not dependant on the states of nature; and x_{2_k} (spring crops), which is an intermediate variable that begins in the second stage. Constraint (3) denotes water-resource choices at the third stage ($b_{k,r}$) and concerns variables x_1 and $x_{3_{k,r}}$. Constraint (4) retains the area of summer crops when moving from the second to the third stage, and prevents changes of land use when an expected state of nature does not occur. The matrix coefficients, and the availability resources, are specified on a monthly base from October to May, and on a ten days base from June to September. Most crops are subject to varied production techniques, with different seeding and harvest dates, and other field operations. The periodization of the crop calendars and the use of a wider range of production techniques for each crop represent the flexibility of Mediterranean agriculture in adapting to climate variability. The productive heterogeneity of the region is illustrated by 13 different farm types with differing sizes, specializations, and groundwater availability.

DONO et al. (2013b), following the usual approach with DSP-type models[3], examine the outcome

[3] Recently BELHOUCHETTE et al. (2012) compared the amount of nitrogen fertiliser applied, irrigation, nitrogen leaching, soil salinization rate, and gross margins for two scenarios and various rainfall states. In their analysis, the results of the recursive stochastic model are an average of 10 years of simulations and are not related to a probability distribution.

with the highest expected income, and show the use of resources and the level of income associated with this outcome. The analysis compares the results obtained in the baseline scenario to that of the near-future scenario to identify which of the various farm types could find it harder to adapt to CCV. Table 2 reports the main economic results: gross margins (GM), net income (NI), and net income plus payments to farms under the Common Agricultural Policy (NI + CAPp) in the baseline scenario (2004) for each type of farm and for the entire area. The last column of the table shows the percentage changes of NI + CAPp in the near-future scenario compared to the baseline. It is of note that, with an overall decrease of 3.6% in total agricultural income in the region, there are strong differences in the impacts on different types of farm. Horticultural farms and medium size mixed-arable farms, which represent a large part of the region's production, may not adapt well to CCV when exposed to changes in the probability distributions of WA and ET_N (Figure 1), and could suffer the most significant drops in income.

3 Results

The DSP solution with the highest expected income includes the probabilities of all possible weather conditions. The contribution of those outcomes, both optimal and sub-optimal, to baseline and future climate scenarios is also provided. Following the focus is on each of these single outcomes, with special attention paid to the lowest economic result, i.e., income generated when the worst state of nature occurs and not the preferred scenario. The states of nature comprise the joint occurrence of single states of the two uncertain climatic variables, whose independence implies that the joint probability equals the product of marginal probabilities.

Table 3 presents the contribution of the joint states under the baseline and the near-future scenarios for the entire agricultural area. The first two columns give the total values of agricultural NI + CAPp (€ 000) that could be obtained under each of the six joint states of the two variables, including water accumulation (K1, K2, and K3), and irrigation requirements (R1 and R2). The line immediately below gives the expected value of NI + CAPp from the model. Also included in the table are two columns that give the joint probabilities of the states, calculated as the product of the marginal probabilities of the two independent variables shown in Table 1. The next two columns give the income obtained in individual joint states multiplied by the respective probabilities. The sum of these values corresponds to the expected value of NI + CAPp. The last two columns show the percentage weight, i.e., the contribution of income from individual joint states in determining the expected income in the scenario. These values depend on the level of income obtainable in the individual states and on the state's probability of occurrence.

Comparing the values of the last two columns of Table 3 in the two scenarios reveals that the most radical change occurs when the most favorable conditions of the two variables occur concurrently, i.e., K3 and R1. The contribution of this state in determining the expected income is almost 30% of the total in the baseline scenario, but is insignificant in the near-future scenario. This value is reduced not only because the probability of the joint state drops greatly, but also because of the reduction in the level of NI + CAPp achieved in that state (−4.2%, not reported). On the other hand, there is an increase in the contribution of the worst state (K1 and R2) caused by the higher probabil-

Table 2. Gross margin (GM), net income (NI), and NI plus CAP payments (NI + CAPp) per farm type and total area for the baseline scenario, along with the percentage changes of NI + CAPp with CCV compared to the baseline scenario

Farm types	baseline (000 €)			*Δ % over baseline*
	GM	*NI*	*NI + CAP$_P$*	
large dairy cattle	1,306.8	389.3	655.2	-1.4
medium dairy cattle	99.2	40.8	58.4	1.7
large mixed crops	27.5	16.8	26.3	4.9
medium mixed crops	27.5	18.7	22.6	-12.7
small mixed crops	4.2	3.0	3.3	-2.6
medium - large olive groves	13.1	-8.5	40.4	-2.9
small olive groves	1.2	-0.9	3.9	-0.9
medium horticultural	28.5	21.4	26.0	-22.2
small horticultural	5.1	2.7	3.2	-44.8
medium - large sheep	48.7	24.1	29.8	-1.9
small sheep	20.2	9.9	13.0	-2.0
large vineyards	14,447.9	5,778.9	5,778.9	0.0
small - medium vineyards	43.9	26.3	26.5	-0.5
Total Study Area	**47,461**	**24,336**	**32,871**	**-3.6**

Source: DONO et al. (2013b)

Table 3. Single joint states in baseline and near-future scenarios, including NI + CAPp (single and total expected), probabilities, weighted NI + CAPp, and the percentage weight of the single NI + CAPp on expected income

	A) NI + CAPp		B) probability		C = (A * B)		$C_{K,R}$ % weight on expected income	
	R1	R2	R1	R2	R1	R2	R1	R2
Baseline								
K1	**30,722**	**30,579**	0.128	0.043	**3,940**	**1,307**	12.0	4.0
K2	**32,709**	**32,553**	0.338	0.113	**11,064**	**3,670**	33.7	11.2
K3	**34,130**	**34,004**	0.284	0.095	**9,676**	**3,213**	29.3	9.8
Expected		**32,871**		**1.0**		**32,871**		**100.0**
Near future								
	R1	R2	R1	R2	R1	R2	R1	R2
K1	**31,140**	**31,088**	0.355	0.118	**11,047**	**3,676**	34.9	11.6
K2	**32,163**	**32,147**	0.389	0.130	**12,520**	**4,171**	39.5	13.2
K3	**32,696**	**32,663**	0.006	0.002	**196**	**65**	0.6	0.2
Expected		**31,675**		**1.0**		**31,675**		**100.0**

Source: our elaboration on the results of DONO et al. (2013b)

ity of that state, and also by the increase in income (1.4%, not reported). A comparison of income under baseline and near-future scenarios reveals a significant reduction in income variability due to the decrease in the highest values under the best weather conditions, and also the increase of the lowest values under the worst conditions.

Table 4 extends various aspects of this analysis to representative farm types in the area by considering three groups of data. Firstly, the percentage differences between the worst NI + CAPp and the expected under baseline and near-future climate scenarios. Secondly, the percentage differences between baseline and near-future climate scenarios for the worst, the best and the expected incomes. Thirdly, the percentage differences of the worst compared to the best income under the baseline and near-future climate scenarios. The first two columns show that, under the

Table 4. Percentage differences of worst over expected (NI + CAPp) income under baseline and near-future scenarios; the worst, expected and best (NI + CAPp) in the near-future scenario compared to the baseline scenario; and the worst over best incomes in baseline and near-future scenarios

	Worst over expected income		**Near future over baseline**			**Worst over best income**	
	Baseline	Near Future	Worst	Expected	Best	Baseline	Near Future
Small horticultural	-50.2	-5.0	5.3	-44.8	-48.0	-55.1	-9.1
Medium horticultural	-32.5	-3.2	11.7	-22.2	-29.4	-44.4	-12.1
Medium mixed crops	-18.3	-4.7	1.8	-12.7	-17.0	-25.4	-8.5
Medium-large olive groves	-9.7	-7.0	0.0	-2.9	2.8	-12.0	-14.4
Large dairy cattle	-7.7	-1.2	5.6	-1.4	-3.1	-9.7	-1.5
Medium dairy cattle	-7.6	-3.8	5.8	1.7	-1.2	-12.7	-6.6
Total area	***-7.0***	***-1.9***	***1.7***	***-3.6***	***-4.2***	***-10.4***	***-4.9***
Medium-large sheep	-5.5	-1.5	2.3	-1.9	-2.8	-6.8	-1.9
Small sheep	-4.4	-1.0	1.4	-2.0	-2.7	-5.5	-1.5
Large mixed crops	-4.0	-6.5	2.2	4.9	11.6	-9.2	-16.8
Small mixed crops	-2.8	-1.9	-1.7	-2.6	-2.8	-4.9	-3.8
Small-medium vineyard	-1.2	-0.8	0.0	-0.5	0.0	-1.5	-1.4
Small olive groves	-0.7	-0.6	-0.7	-0.9	-1.0	-1.4	-1.2
Large vineyard	-0.02	-0.01	0.00	-0.01	-0.01	-0.03	-0.02

Source: our elaboration on the results of DONO et al. (2013b) baseline scenario, horticultural farms may assume that the most adverse weather events will cause income reductions of more than 30%, which is consistent with the activation of the IST. This outcome has a 4.3% probability (Table 3). Other types of farms, such as medium mixed crops, can expect an appreciable reduction in income, but this may not be sufficient to activate the IST. The second column shows that the situation changes in the near-future scenario, in which even under the worst weather conditions, no farm type could expect income drops at a level that would activate the IST. The three central columns of Table 4 explicitly show the change in the near future scenario compared to the baseline scenario. This shows that in most farm types, the decrease in the average income is due to the deterioration of income in more favorable weather conditions (Best NI + CAPp). Conversely, income in the worst weather conditions is higher than in the baseline scenario under similar conditions. The last two columns show that the deterioration of results for the most favorable state, and the simultaneous increase in income in the more adverse states, will augment the degree of homogeneity in economic performance in the near future. In particular, horticultural farms can expect that, while income under more adverse weather situations in the baseline is 45%-55% lower than under more favourable conditions, it will only be 9%-12% lower in near-future. A similar change occurs for large mixed-crops farms which stray far from the 30% difference between the best and worst income which allows applying the IST. This change is shared by most of the other farm types, except the large mixed-crops farms and the medium-large olive grows.

4 Discussion

This work has focussed on variables whose states of nature are relevant to farmers' decision-making in an irrigated area of the western Mediterranean prone to water scarcity and significant irrigation requirements for spring-summer crops. This water scarcity could worsen with the reduction in autumn-winter rainfall and the increase in summer temperatures predicted by climate change analyses for the area. This could result in appreciable reductions in expected income, ranging from 13% to 45% for horticultural and arable crop farms. These conditions are not natural disasters or catastrophes, and it could be argued that the IST is just the tool to be applied, since the fall of income for some types of farms is higher than 30% of the mean value. Nevertheless, the interesting comparison is not between the expected income of the two climatic conditions, but among the possible incomes within each of them, and in particular within the new expected climate.

In this regard, the results show that in the baseline scenario the IST could be really useful for horticultural farms which, according to the DSP approach, are aware that in some years their income could drop even more than 30%. These farm types could therefore consider applying for the IST, and even more so if this is supported by financial incentives. The position of mixed-medium crop farms that are exposed to an appreciable drop in income is interesting, as the expected income decline is less than 30%, and so should not induce those farms to activate the IST.

The probability distribution of the two uncertain variables simulated for the near-future scenario is very different to the baseline scenario. In that case, the most important climatic variations occur in states that are most favourable for cultivation rather than for the most adverse states. Not only is the occurrence probability of favourable states reduced respect the analogous in the baseline, but also the income associated with them is decreased. Conversely, the income generated in less favourable conditions tends to slightly grow, both for farms that are most affected by the CCV and for the average value of the entire area. In other words, especially for farm types most affected by the CCV, the lower income expectation is primarily due to lower probability of favourable weather conditions, and to lower levels of income that may be obtained when these conditions occur. This result decreases the range of income that farmers can expect to obtain once they adapt to the CCV, given known technology, resource availability, and price regimes; and not even the gap between worst income and best generates conditions for applying the IST.

In this context, the IST and the set of tools to insure against adversity and catastrophic events may not be considered by farmers as suitable devices to deal with the future variability of the two climatic variables considered in this study. These tools are, in fact, activated only when the negative impact of climate conditions becomes explosive compared to a reference condition. Instead, the near-future climate scenario adopted in this study generates greater homogeneity between the income levels for different climatic states, even if the expected income is appreciably lower than in the baseline. In this case, the challenge is to sustain agricultural productivity under these new conditions.

5 Conclusions

The DSP outlines a broad set of factors that are relevant for farmers in assessing environmental conditions that will arise from climate change. The DSP model presented in this study assumes that farmers esteem the pdfs of the uncertain variables on the basis of meteorological observations from the past, and evaluate them by discretizing in relevant states of nature. The use of resources is based on the state of nature that maximizes the expected income, i.e., the average of all the obtainable results. Studying the contribution of possible states of nature to the expected income, i.e., expectations on the income effects of various climatic conditions, may provide useful insights on farmers' interest for insurance-type instruments coping with income variability caused by atmospheric instability.

This study considered two variables influenced by climate; the availability of water in the reservoir, and the watering requirements of crops, which can affect irrigation management and lead to income effects that are relevant to the application of IST in the Mediterranean. Other variables, not considered by the study, are equally important and require further investigation. These variables include the climate-driven dispersion of pests, and the change in quality of products, which are both very important for the horticultural farms. These farms were identified as the most affected by the simulated climate events. Other important variables are weather conditions, such as frost, storms and hail, ice, heavy rain, or severe drought. These conditions constitute natural disasters, which the EU regulation on the RDP explicitly considers for the application of insurance-type tools. Insurance companies offer frost, hail, ice insurance with no support of government in most countries in the EU. However, it is difficult to estimate the pdf of these variables, and the change with the CCV, in the Mediterranean climate given its complex interactions of large-scale atmospheric patterns, the Mediterranean-Ocean, and orographic factors, and the limited knowledge of past climate, which is a particular problem with respect to the occurrence of extreme events (KNIPPERTZ et al., 2012).

A focus of future work will be to assess whether future climatic conditions will increase farmers' interest in using of insurance instruments as tools to facilitate adaptation to climate change. For the variables examined in this study, we show that the near-future climate scenario may be perceived by farmers as an indication of lower overall variability in expected incomes, but with a general trend to lower incomes. This may cause farmers to discount insurance tools that intervene only when there are extreme drops in income compared to an expected value. This could result in public resources (diverted from other RDP measures) dedicated to the activation of these tools being unused.

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