Assessing the awareness of climate change as a factor of adaptation in the agricultural sector

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Summary

The paper describes results obtained investigating the problems of adaptation to climate change of Italian agriculture. It specify a choice process that explicitly considers that farmers base their planning on an awareness of the inherent variability in the climatic conditions of their territories. The expectations on climatic variables, and the consequent conditions for crop, are represented under various hypotheses of climate stability, or cognition of a change achieved by observing the current weather conditions, or even in full knowledge of the actual probability distributions of climate events. The choices due to those expectations are simulated with a model of Discrete Stochastic Programming. The results suggest that it may be interesting to better investigate the hypothesis that, even in a relatively short time and, especially, already in the current period, are in place climate changes significant for the agricultural activities, especially when poor of water resource and in marginal areas. Failure to understand these changes can lead farmers to a wrong choices: on one hand, may prevent from taking advantage of existing opportunities for income improvements,; on the other hand, may induce farmers to misconceptions on the way to defend from the negative effects of climate change. This suggests that among the most effective strategies for adapting to climate change, there is support for farmers to improve their ability to assess the new and changing climate framework.

Keywords: discrete stochastic programming; positive mathematical programming; agricultural supply analysis; adaptation to climate change; awareness of climate change

JEL Classification codes: C61, Q10, Q54

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1. INDRODUCTION

The paper describes results obtained under two research projects, Agroscenari (www.Agroscenari.it) and MACSUR (www.MACSUR.eu), investigating the problems of adaptation to climate change of Italian and European agriculture. This study was developed by specifying a choice process that explicitly considers that farmers base their planning activity on an awareness of the inherent variability in the climatic conditions of their territories. Here we assume that this awareness depends on the experience gained over the years and that it generates expectations from which farmers plan their economic activities.

The expectations on climatic variables, and the consequent conditions for crop, are represented with probability distribution functions (PDF) that can be estimated under various hypotheses of climate stability, or cognition of a shift of the probability distributions achieved by observing the current weather conditions, or even in full knowledge of the probability distributions of climate. The choices due to those expectations are simulated with a model of Discrete Stochastic Programming (DSP). This represents the precautionary behaviour of farmers when planning based on assumptions about the PDF of climate events that determine their productive results. In particular, the DSP evaluates the probability to take management decisions (short-term) that prove unsuitable and, in parallel, the opportunity to correct them before arriving at the final result of the production.

Using DSP involves reducing the range of the PDFs in states of nature with representative values and associated probabilities. This study divides the pdf in states of nature with related probability of occurring. Other studies have used the DSP to assess the impact of climate change, identified by its effects of change in the PDF of events. In these cases, the assumption was that farmers recognize the change and assign weather events they attend in the future to a different PDF. In this study the choices of farmers are simulated to estimate the impact of climate change under the hypothesis that not understanding there is an ongoing climate change, farmers perform their planning based on assumptions of climate stability. The analysis proceeds from the finding that since the early 2000s is now an ongoing shift in the PDF of atmospheric phenomena on which on agricultural production depends. Various simulations are performed to estimate the income lost on the assumption that farmers have generated the current land use based on PDFs of atmospheric events that are long past.

First, the climatic aspects that are crucial to the farm management in the study area have been selected. In this regard, that territory has been divided into two zones. A predominantly lowland area, where irrigation water is provided to farms by a Water User Association. The neighbouring area is mostly hilly, has no irrigation infrastructure and agricultural activity is mainly based on extensive farming and pastoralism. The study considers the productive conditions of spring and summer irrigated crops in the area served by the water supply, while considers autumn-winter crops in the hilly rain-fed area. The production of spring-summer crops is influenced by summer temperatures and by resulting irrigation needs. The analysis used the net evapotranspiration, difference of rainfall and evapotranspiration, as an indicator of irrigation needs in the area. Much attention is paid to forage production, given the importance of cow's milk to the local economy. In the not irrigated areas pastoralism is much important, so the focus has mainly gone to the autumnal and winter grasslands and pastures.

2. MATERIALS AND METHODS

2.1. Study area and data

The study area is located in central-west Sardinia (Italy), and covers about 54,000 ha of agricultural land. The Land Reclamation and Irrigation of Oristano (WUA) constructed, operates, and maintains the drainage systems in this region, and provides irrigation water. Since the mid-2000s, WUA has operated the Eleonora d’Arborea dam, which holds approximately 450 million m3 (Mm3) of water, 120–130 Mm3 of which is available for farming. This water is distributed to 36,000 ha comprising 26 irrigation districts, which are clustered into four categories according to the technological characteristics of the irrigation network. The first category includes districts where the farms receive water under high pressure. However, the model divides these districts into two sub-categories to specifically differentiate the productivity and irrigation issues of dairying farms in the Arborea zone. Another category uses a similar system, but provides the farms with low-pressure water. In the districts of the fourth category, the water resource is located at a higher altitude than the area it serves, and water is transported to farms through open channels under gravity. The remaining 18,000 ha are rain-fed and not served by the irrigation facilities of the WUA.

The major cropping systems are based on cereals (particularly wheat and corn) and forage (particularly alfalfa, clover, and ryegrass). In addition, large areas are devoted to vegetable crops (particularly artichoke, watermelon, and tomatoes); rice, fruit (especially citrus), olives, and vineyards are also very important. Farming in the rain-fed area is predominantly non-irrigated, but in limited areas some crops are irrigated using farm wells. Of the total land outside the WUA, 55% is dedicated to pastures, tares, woods, and set-aside. With respect to the livestock industry, cattle breeding for dairy milk production is very important in the Arborea region, which has an organized local system for collection, processing, and packaging of milk. The sheep milk sector is also an important component of the economy of the area, and involves almost 372,000 sheep and a number of milk processing plants.

The agricultural production of the area was reconstructed with reference to the situation in 2010 when data from the sixth General Census of Agriculture were available. These data were integrated with FADN data, and data from the records of the WUA. The production conditions for the various crops and livestock were defined on the basis of interviews with farmers and agronomists from private and public institutions, and from information from cooperatives in the area. The phases of cultivation were reconstructed, and data were collected on the use of chemicals, crop irrigation requirements, and production. Similarly, the feed requirements of the various categories of livestock were specified, the feeding rations, and the products obtained. The prices of inputs and products were also reconstructed.

2.2. Climate and model scenarios

The potential climatic forcing acting on the area and the related changes due to CO_2 future scenarios are evaluated by means of a regional modelling strategy that generates calibrated atmospheric time series of temperature and precipitation. In particular a regional numerical model (Regional Atmospheric Modelling System – RAMS) with a complete physical description of atmospheric mechanisms and a full non-hydrostatic treatment of fluid dynamics (Pielke et al., 1992, Meneguzzo et al., 2004), has been nested into a full coupled atmosphere – ocean global simulation model. This global model system is based on the ECHAM 5.4 model developed and managed by the Euro - Mediterranean Centre for Climate Change (CMCC - www.cmcc.it). It is full atmosphere-ocean coupled model with two peculiar components: OPA-ORCA2 for all ocean areas and a high resolution NEMO-MEDIT model specifically for the Mediterranean basin (Scoccimarro et al., 2010). The scenario of greenhouse gas emissions forcing chosen is A1B, for two different time periods: 2000 – 2010, as representative of present climate, and 2020 - 2030 as representative of a near future. These global simulations belong to a specific suite developed, by CMCC, within EU project - Circe (http://www.circeproject.eu). The more detailed physical description provided by RAMS model is applied to downscale original global simulation by increasing the representation of atmospheric small scale mechanisms over the Mediterranean basin.

2.3. EPIC and agronomic data

The EPIC (Environmental Policy Integrated Climate, v 0810. Williams 1995) model was used to estimate the influence of temperature, rainfall and atmospheric CO_2 concentration on the yield of irrigated (silage maize, Italian ryegrass, alfalfa) and rain-fed (grasslands, hay-crops) cropping systems. EPIC is widely tested and used for several purposes like simulate crops yields (Balkovic et al., 2013; Wang et al., 2005) and assess the impact of climate change (Strauss et al., 2012; Niu et al. 2009). EPIC was calibrated on the basis of available crop, soil and weather datasets obtained by field experiments or through interviews with farmers. The silage maize growing season goes from end of June till September/October, the ryegrass cultivation goes from mid-October to May. The simulation was based on fixed sowing dates for both crops while the harvest was scheduled according to heat units accumulation: so, maize forage and ryegrass hay were harvested at about 90% and 60% of total heat unit required for maturity respectively. Irrigated crops were simulated with no water and nitrogen stress, by setting automatic irrigation on soil water content and automatic fertilization on N plant stress. In the case of rainfed crops, automatic N fertilization was only for hay crops, grasslands were not fertilized. Initialization of soil characteristics was adopted and soil characteristics were reset each year to eliminate trends related to soil dynamics and draw attention to the effect of climate.

2.4. Structure of the economic model

The economic model is a supply territorial farm-type model, and represents the productive system of the area with 13 types of farms obtained averaging the FADN sample by technical economic order. For the specialist dairying, mixed cropping and specialist sheep types the type was obtained with the cluster analysis. Table 1 lists the farm types with their main technical and economic characteristics. Five types are in the rain-fed area, eight in the irrigated districts. Not all the farms types operate in all those areas, and 25 macro farms types result as representing the whole territory. Identified the representative farms, their number in the various irrigation districts categories of the WUA (high pressure, low pressure, gravity, no WAU facilities) was considered[1].

Table 1. Farm types, land, labor, and income.

	Represented farms (n)	Farm land (ha)	Family Labour (units)	Net Income (€ 000)
Under the WUA facilities				
Specialist rice	24	115	2.0	134
Specialist citrus fruits	68	13	1.7	39
Specialist dairying A	130	31	4.4	207
Specialist dairying B	40	32	6.3	177
Specialist market garden vegetables under glass	46	13	3.5	29
Mixed cropping - Vegetables	562	22	1.7	36
Mixed cropping - Rice	55	146	1.2	89
Mixed cropping - Field crops and permanent crops	100	6	2	12
Rainfed area				
Mixed cropping - Vegetables and permanent crops	100	4	1.7	11
Mixed cropping - Field crops	94	25	1.2	30
Specialist sheep A	45	87	2.1	53
Specialist sheep B	188	41	1.5	10
Specialist sheep C	129	62	1.6	30

2.5. Discrete Stochastic Programming model

The Discrete Stochastic Programming (DSP) model considers various uncertainty elements about the crops yields and the water requirements and can be formalised as follows:

$$\max_{x, za_s, zy_s} z_{dsp} = \sum_s P_s * (GI_s * x - Cza * za_s - Czy * zy_s)$$

subject to

$$A * x \leq B$$

$$A_s * x \leq B + za_s \quad \forall\ s \qquad (1)$$

$$N * y_s * x + zy_s \geq R \quad \forall\ s$$

$$x \geq 0, \quad za_s \geq 0 \text{ and } zy_s \geq 0 \quad \forall\ s$$

where z_{dsp} is the expected total gross income; P_s are the probabilities of the s states of nature; GI_s are the gross incomes for each activities and s states of nature; x are the cropping activities; Cza and Czy are the costs associated to each za_s and zy_s adaptation actions defined for each s states of nature (e.g. pump water from the private wells, feed purchase); A is the matrix of the technical coefficients and B are the resources availabilities (land and labor); A_s is the matrix of the technical coefficients for each s states of nature (water requirements); N is the matrix relative to the nutritional content of each feed; y_s are the yields of the forage crops for each s states of nature; R are the nutrients requirements.

[1] For the mathematical formulation of the economic model see the papers by Giraldo et al (2014) and Cortignani and Dono (2014).

In our model we considered six types of states of nature. The first and second regard respectively the pasture and grazed herbage yields in the autumnal period. The third referees to pasture yields in the spring period. The fourth regard the herbage hay yields. The fifth interests the water requirements of the ryegrass with relative influence on the yields. The last type referees to the ETN event on the June – August period and affects the water requirements of the summer crops and the alfalfa and corn silage yields.

2.6. Model calibration

The PMP methodology was implemented to calibrate the (1) model to the observed situation then a first calibration and validation procedure (Ittersum et al, 2008; Louhichi et al, 2010). In recent years, the PMP methodology has been applied in various research areas, and improved to consider many relevant aspects. Heckelei et al. (2012) recently reviewed the more important PMP models that have been development and used. Röhm and Dabbert (2003) proposed a different modeling approach, to take account of the greater elasticity of substitution among crop variants than among different crops. In this approach an additional slope parameter common to all variants of the same crop is considered other than the specific slope parameter for each crop. The Röhm and Dabbert approach can also be used for similar crops, to allow for greater elasticity of substitution among closely related activities defining groups of similar crops (Blanco et al., 2008).

In our model the nutritional requirements of animals were also met by feeds purchased on the market. In the calibration phase this may result in very high dual values for forage crops produced on the farms and used for animal feed, because the market value of the binding nutrient is also considered. In the standard PMP approach this could result in very different cost parameter levels that do not reflect the real characteristics of the crops, considering the very different production of the forage crops observed for the baseline year. The Röhm and Dabbert approach can be used for the forage crops produced on farms and used as animal feed, as the additional slope parameter specifically captures the opportunity cost due market value of the binding nutrient that is common to all forage. The specific slope parameter takes into account the specificities and characteristics of crops, particularly in terms of production costs.

2.7. Simulations with calibrated model

The PMP technique was used to calibrate the DSP model of the Oristano agriculture using three different PDFs of productive results influenced by climatic conditions. First, the distribution based on results obtained under the climatic conditions in the years up to 2000; then, the estimate based on the climate observed up to 2010; finally, the distribution based on climate data generated by the Pasqui model. The first distribution (climate 2000) represents an expectation of stable climate to the conditions known to 2000; the second (climate 2010) is developed by constantly updating observations and, thus, by acquiring the cognition of a shift of the PDFs, estimated with data from the last thirty years available. The third distribution (actual climate) is an expectation based on full knowledge of the PDFs of productive results in 2010.

The PMP calibration of the model under the three sets of PDFs provides three different results with identical land use and different purchases of factors, such as feed, to compensate the different yields of fodder; sales of products, depending on yields; expected net income of the representative farms, and of the entire area. Comparing the results of the three simulations indicates the income gaps between the three expectations hypothesis: this is a first benchmark of the gains that could have been lost by generating the observed result under wrong assumptions on climate conditions. A second indication can be obtained by removing the constraint that ensures the use of resources found in 2010, both in the model with the 2000 climate, and in the 2010 climate, and applying the Pasqui climate. In other words, keeping the dual cost function estimated in the original condition, and estimating the possible adjustment under the productive conditions of the actual climate.

3. RESULTS

3.1. Different climate expectations

Table 2 shows the net income (000 €) of the various types of representative farms, of the areas under the WUA facilities and rain-fed, as well as of the whole region. The incomes are obtained with the use of land of 2010 under the different hypotheses on climate expectations, i.e., 2000 climate, 2010 climate and Pasqui climate. Also, the percentage differences are reported between climate 2000, 2010, and Pasqui; and between climate 2010 and Pasqui.

Table 2. Different climate scenario: Net income (000 €) and percentage differences (Δ%).

	Climate 2000	Climate 2010	Climate Pasqui	Δ % between climate scenarios		
				2000/2010	2000/Pasqui	2010/Pasqui
Specialist rice	3,079	3,081	3,085	-0.2	-0.1	-0.1
Specialist citrus fruits	2,670	2,670	2,670	0.0	0.0	0.0
Specialist dairying A	24,666	25,752	26,302	-6.2	-2.1	-4.2
Specialist dairying B	6,450	6,467	6,666	-3.2	-3.0	-0.3
Specialist market garden vegetables under glass	1,211	1,215	1,231	-1.6	-1.3	-0.3
Mixed cropping - Vegetables	18,503	18,533	18,666	-0.9	-0.7	-0.2
Mixed cropping - Rice	4,791	4,787	4,854	-1.3	-1.4	0.1
Mixed cropping - Field crops and permanent crops	1,165	1,168	1,180	-1.3	-1.1	-0.2
Mixed cropping - Vegetables and permanent crops	1,013	1,013	1,014	0.0	-0.1	0.1
Mixed cropping - Field crops	2,678	2,681	2,691	-0.5	-0.4	-0.1
Specialist sheep A	1,787	1,824	1,897	-5.8	-3.9	-2.0
Specialist sheep B	1,947	1,965	1,894	2.8	3.7	-0.9
Specialist sheep C	4,820	5,083	5,424	-11.1	-6.3	-5.2
Under of the WUA facilities	62,537	63,673	64,653	-3.3	-1.5	-1.8
Rain-fed	12,246	12,566	12,920	-5.2	-2.7	-2.6
Total Area	74,783	76,239	77,573	-3.6	-1.7	-1.9

The income of the entire area is lower under expectations of stable climate at 2000 conditions than under expectations updated at 2010 conditions, and under perfect knowledge of climatic PDFs. The same applies to the comparison between expectations updated to climatic conditions of 2010, and those with perfect knowledge of climatic conditions. In general, the income gap with the expectation based on the perfect knowledge is higher for the hypothesis of stable climate, rather than that of updating based on the observation of the climate. These differences are more pronounced for the zones with rain-fed irrigation than for those supplied of irrigation water from the WUA facilities. There are also substantial disparities between the types of farms, with very high differences for some sheep farm types in rain-fed areas and for dairy cattle farms in irrigated areas. Also for the farms types the differences with the income under perfect knowledge of the climatic PDF are very high when planning assumed climate stability, are generally very minor with an updated framework.

3.2. Adjusting to actual climate PDFs

Table 3 reports the net income obtained by removing the constraint on 2010 land use in models with 2000 and 2010 climate, and applying Pasqui climate. The simulation maintains the dual cost functions obtained for the two models under the expectation hypotheses presented in the previous tabel, and estimates the possible adjustment based on actual climate conditions. The table shows the net income and the percentage differences compared to the corresponding original situations shown in Table 2, as well as with respect to the Pasqui climate.

Table 3. Climate scenario: Net income from adjustment to Pasqui climate and percentage changes (Δ%).

	Climate 2000	Climate 2010	Δ % between climate scenarios			
			2000/2000	2010/2010	2000/Pasqui	2010/Pasqui
Specialist rice	3,092	3,089	0.4	0.3	0.2	0.1
Specialist citrus fruits	2,670	2,670	0.0	0.0	0.0	0.0
Specialist dairying A	25,873	26,858	4.9	4.3	-1.6	2.1
Specialist dairying B	6,924	6,857	7.3	6.0	3.9	2.9
Specialist market garden vegetables under glass	1,227	1,228	1.3	1.1	-0.3	-0.2
Mixed cropping - Vegetables	18,881	18,811	2.0	1.5	1.2	0.8
Mixed cropping - Rice	4,920	4,897	2.7	2.3	1.4	0.9
Mixed cropping - Field crops and permanent crops	1,193	1,186	2.4	1.6	1.1	0.5
Mixed cropping - Vegetables and permanent crops	1,013	1,013	0.0	0.0	0.0	-0.1
Mixed cropping - Field crops	2,707	2,700	1.1	0.7	0.6	0.3
Specialist sheep A	1,891	1,907	5.8	4.5	-0.4	0.5
Specialist sheep B	2,149	2,111	10.4	7.5	13.4	11.4
Specialist sheep C	5,081	5,285	5.4	4.0	-6.3	-2.6
Under of the WUA facilities	64,780	65,597	3.6	3.0	0.2	1.5
Rain-fed	12,842	13,015	4.9	3.6	-0.6	0.7
Total Area	77,622	78,612	3.8	3.1	0.1	1.3

One can notice that there would be substantial increases in income abandoning the hypotheses of expectations based on the stability of the climate, and expectations of updated by continuously observing the trends every year. These two increases for the area as a whole would be very similar to each other. Also here, the increases would be more consistent in rain-fed areas than in irrigated areas. Again, there would be significant differences between the various types, with some who would gain a lot from a perfect assessment of the climatic conditions. Finally, we note that in various types of farms, the adjustment in land use would greatly increase the revenue compared to the 2010 condition generated under the hypothesis of perfect knowledge of climate of the moment. On the contrary, in various types the adjustment appreciably reduces the level of income.

4. Discussion and Conclusions

These results suggest that there are quite different situations among the various types of farms in the study area. For those whose income increases the indication is obtained that the assumption of full knowledge of the climate is wrong, i.e. the use of the land in 2010 was not achieved with that expectation. At the same time, this means that those types of farms, if succeed in better understanding of actual climate conditions, may actually appreciably increase their income by modifying their cropping systems. On the other hand there is the case of various types that appreciably reduce their income, especially assuming that in 2010 they managed their soils considering the actual condition of the climate. More precisely, those types do not improve if it is hypothesized that they had planned at best, i.e. considering the actual climatic condition; instead, they are favoured if it is hypothesized that they had planned for the worst, i.e. considering the climatic stability. So, those types were planning the use of their resources, based on assumptions almost outdated by the worsening in climate conditions relevant to their activities.

These results suggest that it may be interesting to better investigate the hypothesis that, even in a relatively short time and, especially, already in the current period, are in place climate change of a certain importance for agricultural activities, especially those poor of water resource and in marginal areas. Failure to understand these changes can lead to errors of planning: on one hand, by preventing from taking advantage of opportunities for improvement of income, which also exist; on the other hand, may induce farmers to misconceptions about the way in which to defend from the negative effects of climate change. For example, it may lead them to believe that the negative results are the outcome of occasional adversities, while are instead the result of a programming based on an inadequate framework of the climate conditions. Perhaps this may suggest that, in order to better adapt to the change of climate variability that is in progress, one of the most important and effective measures can be to support farmers in better assess the new and changing climate framework in which they operate.

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