Productive and economic adaptation of Mediterranean agriculture to climate change

Produktive und wirtschaftliche Anpassung der mediterranen Landwirtschaft an den Klimawandel

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Abstract

Farmers plan annual activities taking into account the effects of the inherent variability of climate on plant and animal production. This variability is here represented by probability distributions of plant and animal production. A stochastic programming model associates the decision-making mechanisms of agricultural supply in an area of the Mediterranean basin to the variability of production due to climatic conditions. The analysis is carried out under the conditions of both present and near future climate. The results show that the transition to the future climate has different effects on different types of farms and the various production areas, particularly between irrigated and non-irrigated regions. This requires specific and different adaptation strategies for the various cases.
Keywords: adaptation of agriculture to climate change; discrete stochastic programming; change of climate variability; interdisciplinary modelling of farm and agricultural territory.

Zusammenfassung

BäuerInnen planen ihre jährlichen Aktivitäten unter Berücksichtigung der Auswirkungen der inhärenten Variabilität des Klimas auf Pflanzen- und Tierproduktion. Diese Variabilität wird hier durch Wahrscheinlichkeitsverteilungen der pflanzlichen und tierischen Pro-

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duktion vertreten. Ein stochastisches Programmierungsmodell verknüpft die Entscheidungsmechanismen der landwirtschaftlichen Versorgung in einem Gebiet des Mittelmeers, um die Variabilität der Produktion aufgrund von klimatischen Bedingungen abzubilden. Die Analyse wird unter den Bedingungen des aktuellen Klimas und eines Szenarios in der Zukunft durchgeführt. Die Ergebnisse zeigen, dass der Übergang zum zukünftigen Klima unterschiedliche Auswirkungen auf die verschiedenen Arten der landwirtschaftlichen Betriebe und die verschiedenen Produktionsbereichen hat. Dies betrifft insbesondere bewässerte und nicht bewässerte Flächen. Daher sind spezifische und unterschiedliche Anpassungsstrategien für die verschiedenen Fälle erforderlich.
Schlagworte: Anpassung der Landwirtschaft an den Klimawandel, diskrete stochastische Programmierung, Änderung der Klimavariabilität, interdisziplinäre Modellierung von Hof und landwirtschaftlichen Territorium

1. Introduction

Farmers base their annual planning on expectations about crop and livestock production that depend on inherent variability of climate. This aspect should be considered when estimating the impact of climate change (CC) on agriculture, especially by considering that farmers will need to change their choices in order to adapt to changes in climate variability (CCV).

An extensive literature on the agricultural impact of CC does not consider this aspect because it is dedicated to investigate an earlier stage of agricultural choices with the modelling of the optimal conditions for growth and production of crops or livestock. Based on this modelling, a first estimate of the economic impact of the CC can also be obtained by examining the changes of yield or of demand of productive factors (RÖTTER et al., 2012). However, in this way it is not considered that farmers may adjust to climate variability of the future by modifying the agronomic techniques or the relative weight of crops and varieties in the agricultural land use. Another approach is provided by Ricardian methods that estimate the econometric relationship between the value of land and weather conditions, by using data from different climatic zones and from the farm typologies working there (MASSETTI and MENDELSOHN, 2012). This relationship should measure the ability of farmers to adapt to different climate conditions, therefore to the CC in the long term. However, it does not indicate how adaptation takes place and, hence, what policies can better support it.

The following interdisciplinary approach seeks to represent this dimension of the decision-making process of farms. For this purpose first the influence of climate variability is synthesized as probability distribution function (pdf) of productive variables under present climate scenario and in the near future. Second, a choice process subject to the uncertainty caused by this variability is simulated, where the pdfs represent farmers' expectations on production in the two climate scenarios. Third, the productive and income results of these scenarios are compared to assess the impact of transit in the future, and identify the types of farms that are more subjected to CC effects.

2. Materials and methods

The study area consists of 54,000 hectares (ha) located in central-western Sardinia, Italy. Some 36,000 hectares of this area are supplied with irrigation water by the Oristanese Water User Association (WUA) that draws from the notable water resources of the Eleonora d'Arborea dam. In the irrigated area cow's milk is a key product and relies on some 6,000 ha of silage corn and other forage crops and on imported feeds. Durum wheat and rice (3,000 ha respectively) are also important, as well as vegetables (e.g. artichoke), citrus, olive trees and vineyards. In the remaining 18,000 rain-fed hectares, dairy sheep grazing systems are very relevant and the corresponding land uses are cultivated rainfed hay-crops (cereals and Italian ryegrass) and grazed fallows. Forests and set-aside agricultural land are also part of the local landscape. Only a small part of the irrigated area relies on farm wells. This use of farm resources has been derived from the results of the 6th Agricultural Census of 2010, the Farm Accountancy Data Network (FADN) system, and information provided by the WUA. Other information was obtained through surveys on the territory, carried out by interviewing farmers, engineers and managers of cooperatives and other private and public institutions that operate in the area.

Problems due to the change of agro-climatic conditions in this area were analysed, first, by integrating climatological agronomic and livestock models. The model outputs were then treated with statistical methods and included in an economic model that simulates the farm choices.

The present and future climate scenarios of the area were obtained by nesting a Regional Atmospheric Modelling System (RAMS), into an atmosphere-ocean model based on ECHAM 5.4 (SCOCCIMARRO et al., 2011). Greenhouse gas scenario A1B of 2000–2010 denotes present climate, and 2020–2030 was chosen as near future. Ten years generated by the RAMS were considered sufficient to represent the variability inherent in the two scenarios. Errors due to poor geo-morphological description (mountains, land cover) from numerical models were reduced by means of a post-processing procedure based on observed data and on the reconstructed sea surface temperature. The CC raises maximum and minimum summer daily temperature. Also, temperature increases slightly in spring and markedly in fall–winter. Rain variability increases, coupled to a reduced spring rain.

The EPIC (Environmental Policy Integrated Climate) model (WILLIAMS, 1989) was used to simulate the impact of temperature, rainfall and atmospheric CO_2 on yields of irrigated (silage maize, ryegrass, alfalfa) and rain-fed (grasslands, hay-crop) crops (BALKOVIC et al., 2013). Calibration was based on soil, climate and crop management data based on local field experiments farm records and interviews to farmers. The cultivation of silage maize and rye-grass was simulated using fixed sowing dates; harvest was scheduled on the basis of heat units accumulation. Irrigated crops were simulated without water and N stresses. Rain-fed hay-crops were simulated without N stress. Soil characteristics were yearly reset to remove long term soil dynamics and focus on climate effects. The crop models were run under two climate scenarios, each of 150 synthetic years, obtained by transforming the two decades of present and future outputs of the RAMS with the weather generator WXGEN (HAYHOE, 1998). For tree crops only the increased irrigation requirement was estimated, as a proportion of the variation of the ET_N.

The impact of climate on cattle was evaluated using equations derived from the literature on the relationship between temperature humidity index (THI) and mortality (VITALI et al., 2009), the yields of milk and its somatic cell content (BERTOCCHI et al., 2014). These relationships were estimated with linear regression analyses in two phases in Italian areas where the Holstein Friesian is bred as in the study area. Instead, the climate impact on the summer production of sheep milk was neglected, being this already irrelevant in the present.

The numerical outputs of the climatological, crop and livestock models were processed with maximum likelihood methods to estimate the pdfs of the productive variables. The pdfs of the agro-climatic variables were divided in three intervals, with associated probability (low = 25%, intermediate = 50%, high = 25%) and representative value derived as the average of the observations falling in them. These probabilities and representative values were used to represent the expectations of farmers on the occurrence of the agro-climatic variables in a model of discrete stochastic programming (DSP). This model allows to simulate the decision-making process of farmers, given the likelihood of different weather conditions during the season, with their different productive results, and the possibility to correct the choices made when the course of weather that actually occurs is different than expected (DONO et. al., 2013).

The DSP model of agricultural supply in the area is a regional model in blocks that are based on 13 macro-farms representing the typical farms of the zone. Its objective function is the sum of the gross incomes (GI) of these macro-farms. The climatic-driven variability relates to summer water needs of crops, spring yields of pasture and hay from grasslands, autumnal yields of pastures and of grazed grasslands. If unfavourable weather events occur, farmers apply corrective actions, i.e. pump water from wells or buy feeds: this causes sub-optimal results but minimizes the impact of adverse conditions. Instead, the impact of changes in temperature and humidity on milk quality, quantity, and head mortality is an ex post simulation. The prices of inputs and outputs, and the condition of agricultural policy refer to 2010, and the model was calibrated with respect to this framework with the PMP approach of RÖHM and DABBERT (2003). Comparing the results of present and future climate allowed identifying the potential resilience of the system to CC or, inversely, the impact on income difficult to avoid. This comparison detects the possibility of minimizing the impact of income of the CC based on present technologies and resource endowments, without changes in the markets and policies.

3. Results

Table 1 reports some of the characteristics and results for the 13 farm types that constitute the blocks of the DSP regional model, and for their aggregate in the two sub-areas and the total area. In particular, column 2 shows the average size in hectares of the farms for those types. Column 3 reports the net income (NI) per average farm, while column 4 lists NI per macro-farm, both in the scenario of the present climate[2]. Column 4 contains instead the percentage change of NI by going from the present to the future climatic scenario. Finally, column 5 shows the value of the Finger-Kreinin index (FKI) on the similarity between the use of land in the two conditions[3]. FKI ranges between 0 and 1, with smaller values indicating that more significant changes in the use of land occurred in the transition from present climate to future. The last three rows of the table report all these data for the entire irrigated zone, for the rain-fed zone, and for the whole territory.

The results show that many farm types adapt to the new climate without appreciable reductions of NI. The reduction of the agricultural NI of the area is mainly due to the loss in dairy cattle and sheep farms. In these groups, income losses in the less efficient breeding of dairy cattle (B) are similar to those of the most efficient unit (A); while higher income losses are suffered by sheep farms that are smaller and unable to irrigating fodder (C). The rain-fed zone is more affected than the irrigable zone. The last column shows that these changes are associated to changed use of resources. Smaller values of the FK index testify the possibility that some types of farms have to adapt to the change of climate variability by modifying the relative weight of the different crops and varieties.

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[2] NI subtracts to GI the fixed costs of the farm types, estimated with area's FADN data.

[3] The similarity is assessed as percentage of the various crops and varieties on total land, in the present and future climatic scenarios (FINGER and KREININ, 1979).

Tab. 1: Impact of near future climate scenarios on the average Net Income (NI) per farm and farm typology in the case study area.

Farm typology	Average farm size (ha)	Present (000 €)		% change of future *NI* over Present	FKI
		NI per farm	NI per macro farm		
Rice	115.3	128.5	3,085	0.0	1.00
Citrus fruits	12.6	39.3	2,670	0.0	1.00
Dairy A	30.9	202.8	26,367	-6.6	0.81
Dairy B	31.9	167.2	6,686	-7.8	0.79
Greenhouses	12.9	26.8	1,231	0.4	0.94
Mixed vegetables	22.2	33.2	18,656	-0.8	0.98
Mixed + Rice	146.4	88.6	4,875	0.7	0.98
Mixed + Permanent	5.8	12.1	1,209	0.0	0.99
Veg. + Permanent	4.1	10.1	1,014	0.0	1.00
Mixed field crops	24.5	28.6	2,691	0.0	0.99
Sheep A	86.9	42.2	1,897	-12.2	0.85
Sheep B	41.2	10.1	1,894	-17.6	0.77
Sheep C	62.4	43.6	5,618	-9.1	0.68
Irrigated zone	29.9	63.2	64,779	-3.7	0.93
Rain-fed zone	40.3	23.6	13,115	-8.2	0.80
Total area	33.5	49.2	77,894	-4.4	0.88

FKI … Finger-Kreinin Index

Source: OWN CALCULATION, 2014

4. Discussion and conclusions

The impact of near future climate in the study area mostly depends on the reduction of sales of cow's milk and worsening of its quality in the summer. The model reflects this effect but does not provide adaptation options to dairy farms. Instead, it captures the adaptation to new productive condition of silage corn, by adjusting crop management to recover present climate production. It also captures the reaction to the worse condition of non-irrigated grasslands: sheep farms reduce crops for sale to produce feed or hay, and increase purchase and production of hay. This reduces revenues and increases costs. The NI decline in the irrigated zone is smaller as water availability in the WUA meets the increased demand of future. In addition, the water pricing, based on fixed fees per hectare, prevents the increase of payments: volumetric systems would have completely different impacts, notably penalizing tree crops and vegetables farms, based on their appreciable increase in water uses.

This approach based on modelling the choices of farmers under uncertainty by climate variability, extends the findings of crop and animal production models. In this way, it better specifies the impact of the CC by considering the adaptation options in farm management. In particular, it indicates options on how adaptation can take place in several different farm typologies: this is of help in identifying the economic agents to whom the different adaptation policies should be targeted. Consequently, this approach allows to identifying the way in which the adaptation policies can be effectively specified and used. Finally, since the area that has been examined represents a wide variety of Mediterranean agricultural productive situations, it may be assumed that the findings of the study may be relevant to many other farming areas of the Mediterranean.

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