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Winners and losers from climate change in agriculture: Insights from a case study in the Mediterranean basin

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ABSTRACT

The Mediterranean region has always shown a marked inter-annual variability in seasonal weather, creating uncertainty in decisional processes of cultivation and livestock breeding that should not be neglected when modeling farmers' adaptive responses. This is especially relevant when assessing the impact of climate change (CC), which modifies the atmospheric variability and generates new uncertainty conditions, and the possibility of adaptation of agriculture. Our analysis examines this aspect reconstructing the effects of inter-annual climate variability in a diversified farming district that well represents a wide range of rainfed and irrigated agricultural systems in the Mediterranean area. We used a Regional Atmospheric Modelling System and a weather generator to generate 150 stochastic years of the present and near future climate. Then, we implemented calibrated crop and livestock models to estimate the corresponding productive responses in the form of probability distribution functions (PDFs) under the two climatic conditions. We assumed these PDFs able to represent the expectations of farmers in a discrete stochastic programming (DSP) model that reproduced their economic behaviour under uncertainty conditions. The comparison of the results in the two scenarios provided an assessment of the impact of CC, also taking into account the possibility of adjustment allowed by present technologies and price regimes. The DSP model is built in blocks that represent the farm typologies operating in the study area, each one with its own resource endowment, decisional constraints and economic response. Under this latter aspect, major differences emerged among farm typologies and sub-zones of the study area. A crucial element of differentiation was water availability, since only irrigated C3 crops took full advantage from the fertilization effect of increasing atmospheric CO_2 concentration. Rainfed crop production was depressed by the expected reduction of spring rainfall associated to the higher temperatures. So, a dualism emerges between the smaller impact on crop production in the irrigated plain sub-zone, equipped with collective water networks and abundant irrigation resources, and the major negative impact in the hilly area, where these facilities and resources are absent. However intensive dairy farming was also negatively affected in terms of milk production and quality, and cattle mortality because of the increasing summer temperatures. This provides explicit guidance for addressing strategic adaptation policies and for framing farmers' perception of CC, in order to help them to develop an awareness of the phenomena that are already in progress, which is a prerequisite for effective adaptation responses.

1. Introduction

In analyzing the meteorological conditions of a climatic zone on decennial time periods, it is always found in its sub-areas a significant inter-annual variability that also applies in periods when the climate is perceived as in a stable condition. This variability is generated by the combination of different mechanisms. High frequency mechanisms due to atmospheric dynamics dominate the local climate variability in each month and season. A smaller amount of variability is due to multi-annual and decadal low frequency mechanisms mainly driven by the ocean dynamics. Finally, there is a long term trend induced by global warming: in recent decades this has accelerated, acting both as incremental component, either by modifying the mechanisms of high and low frequency, and the variability that induce. This paper presents the results of an integrated study which assesses the effects of climate variability on crop and livestock production, and farm management of a diversified Mediterranean agricultural district. The results of the

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analysis are used to assess the economic impact of climate change (CC) at farm typology level, including the effect of changing the variability of atmospheric conditions.

The inherent variability of the Mediterranean climate is mentioned and explained by many studies highlighting the determinants and expressions of climatic variables in the different sections of this region (Navarra and Tubiana, 2013). It was shown that the atmospheric circulation in the Atlantic Ocean determines the variability of rainfall in the autumn period (Delitala et al., 2000; Altava-Ortiz et al., 2011). Similarly, it was shown that heat waves are a frequent feature of the Mediterranean summer (Colacino and Conte, 1995; Matzarakis and Mayer, 1997; Gaetani et al., 2012), and several anomalous warm summers have occurred in the Mediterranean and in southern Europe over the last 60 years, with hot events of different intensities and lengths (Baldi et al., 2006; Segnalini et al., 2011).

The influence of climate variability on crop production and livestock is also extensively treated in the scientific literature. Many researches made use of specific mathematical and statistical models to investigate the relationships between variability in the climatic conditions and livestock production (Johnson, 1987; Hahn, 1999; Vitali et al., 2009; Bertocchi et al., 2014; Bernabucci et al., 2014). Other analyses relied on models providing a rich characterization of optimal growth and represent the response of crops production under different climatic conditions (Brown et al., 2000; Liu and Tao, 2013; Dono et al., 2013a,b, 2014). In various studies these models are used to assess the impact of CC by comparing crop yield or the requirement of inputs under conditions of current and future climate (Eckersten et al., 2001; Semenov and Shewry, 2011; Rötter et al., 2012; Olesen et al., 2011; Palosuo et al., 2011; Reidsma et al., 2010; Iglesias et al., 2009). There is also growing recognition of the importance of assessing the effects of climate change, and possible adaptation strategies at the agricultural system or farm household level (Claessens et al., 2012), rather than focusing on aggregated results that can conceal large amount of variability.

The estimated relationship between climate variability and agricultural activity can be included in mathematical models simulating economic choices of farms in the context of production risks (Matthews et al., 2013). One of those models, discrete stochastic programming (DSP) (Hardaker et al., 2004), was used to represent the economic impact of many agricultural uncertainties: availability of irrigation water (Calatrava and Garrido, 2005a,b), productive results of technologies (Coulibaly et al., 2011), weather risks (Mosnier et al., 2009), and change in climate variability (Dono and Mazzapicchio, 2010). Dono et al. (2013a,b, 2014) assessed the impact of CC with a three-stage DSP model in which uncertainty is about irrigation water requirements of crops and availability of irrigation water. They compared the results of the model executed with the probability distribution functions (PDFs) of those variables under current and future climate: current PDFs were estimated on climate data of the last three decades, future PDFs were estimated by extrapolating data from climate observations of the last decade.

In this paper we propose a significant knowledge step-forward to what was previously proposed in analyzing CC impacts on agricultural systems (Dono et al., 2013a,b, 2014). Advancements concerns in particular (i) the way present and future climate scenarios were generated; and (ii) the choice of combining climate, cropping systems, livestock and economic models to improve the understanding on how CC can generate losers and winners in different farming systems located in the same district, ultimately resulting into changes in the agricultural land use and/or management. This modeling chain provides an integrated assessment of the expected shifts in terms of probability distribution of climate variability and then of crop and livestock system economic performance.

The interdisciplinary approach was applied to the Regional Pilot case study FACCE MACSUR Knowledge hub.[1] It is located in an agricultural district characterized by a variety of farming systems covering a wide range of situations under both irrigated and rainfed Mediterranean conditions. Therefore, a diversity of issues generated by the interaction of CC seasonal impacts on different cropping and livestock systems were deeply explored and analyzed.

Our hypothesis is that the represented farming systems, and the results obtained by the proposed approach can provide a relevant support for the development of contextualized effective and strategic adaptive responses far beyond the analyzed local context, in the transition to future climate in the Mediterranean region. This also justifies the short-term time horizon chosen for the analysis, which addresses the changes in climate variability that can be immediately relevant for the development of strategic adaptation policies in the context of rural development.

2. Materials and methods

2.1. Study area, data sources and agricultural uncertainties from climate variability

The study area is a 54,000 ha farming district located in the center-west of Sardinia (Italy). The agricultural system was reconstructed with reference to the situation of the year 2010, using the data of the Italian 6th General Agricultural Census, of the Farm Accountancy Data Network (FADN), and of a Water User Association (WUA), Consorzio di Bonifica e Irrigazione dell'Oristanese, that supplies irrigation water to part of the area. The productive conditions of crops and livestock in this area were derived from interviews to farmers, agronomists, leaders of the regional administration and of the local agricultural cooperatives. The requirements of labor, chemicals, and water were defined for the various stages of production of the crops, including yields. Similarly, the feed requirements of the various categories of livestock were specified, with the actual food rations and the products obtained. The prices of the production factors were also collected.

The agricultural district under study can be divided in two sub-zones depending on the availability of irrigation water. In the irrigated sub-zone, the WUA supplies water from the Eleonora d'Arborea dam, with a reservoir of some 450 Mm^3, of which 120 Mm^3 are yearly made available to potentially irrigate 36,000 ha. The main irrigated cropping systems are based on cereals, mainly silage maize and rice, and other forage crops, mainly alfalfa and Italian ryegrass, but includes also horticultural crops such as artichokes, watermelon and tomatoes, citrus orchards, olive trees, vineyards, durum wheat and barley. The breeding of dairy cattle of Sardinia is largely concentrated in the WUA sub-zone (Arborea district), with a well-organized cooperative system for production, processing and marketing of cow's milk. The rain-fed sub-zone covers some 18,000 ha where occasionally a limited amount of water is available, taken from wells in some farms. In this sub-zone 55% of the agricultural land is made of pastures, tares, woods or set-aside fields; durum wheat and barley predominate on the rest of land. The dairy sheep industry is largely present in this sub-zone and involves some 372,000 sheep and a number of small sheep milk processing plants.

Structural and economic features of the farms of this area were represented in the economic model by 13 farm typologies, identified on the basis of data from the FADN and the Agricultural Census.

Climate variability generates uncertainty for the various crop and livestock activities in the study area. Sheep farming in the rain-fed zone is constrained by the inter-annual instability of pasture and hay-crop yields, which is closely dependent on climatic factors particularly in the autumn and spring. The pasture growing season which starts with season's rainfall break in the autumn, is constrained by low temperature and radiation in the winter and reaches its maximum in the spring, to decrease sharply in quantity and quality at the onset of the summer, in which soil humidity reaches a minimum. The dairy sheep farming system is adjusted to concentrate lambing in October-

[1] http://macsur.eu/index.php/regional-case-studies.