Abstract

The European Union (EU) has recently reformed its Common Agricultural Policy (CAP) and, in parallel, has completely abolished the production quotas for milk. These changes will have important consequences for the use of land, of inputs (i.e., water and chemicals) and on the economic performance of rural areas. It is of interest to evaluate the integrated impact of these modifications and of climate change (CC), since the latter could neutralize or reverse some desired effects of the former. For this purpose, this paper evaluates the potential impact of the abolition of milk quotas, as well as of the reform of the first pillar of CAP in two different climate scenarios (present and near future). A bio-economic model simulates the possible adaptation of various farm types in an agricultural area of Southern Italy to these changes, given the available technological options and current market conditions. The main results show that the considered policy changes have small positive impacts on economic and environmental factors of the study area. However, some farm types are more affected. CC can effectively attenuate or reverse several of those effects, especially in some farm types. These results can inform the planning of future changes to the CAP, which will have to act in the context of deeper climate alteration.

Keywords: Agricultural Policy; Climate Change; Bio-economic model; Integrated Assessment

1. Introduction

The European Union (EU) has recently reformed its Common Agricultural Policy (CAP) and, in parallel, has completely abolished the production quotas for milk. These changes will have important consequences for the use of land, of inputs (i.e., water and chemicals) and on the economic performance of rural areas in a context where farmers already cope with great uncertainty due to climate change.

To achieve the sustainability objective, the CAP 2014-2020 changed the basic tool of its first pillar, integrating the basic payment with additional allowances that farmers receive only when applying certain *agricultural practices beneficial for the climate and the environment*. This funding of EU-wide mandatory *green* standards through direct payments (*greening*) requires, among others, crop diversification and the maintenance of existing pastureland (Matthews, 2013). In addition, the CAP reform allocates part of the financial resources to coupled payments and provides *convergence* of the farm-based unitary entitlements to national average, which increases the basic payment to some farms and decreases it for others.

Many studies have been conducted to assess the impacts of the direct payment changes, especially using mathematical programming models. In the following section, a literature review has been conducted. Among the most recent, Cortignani et al (2017), Gocht et al (2017) and Louhichi et al (2017) show that greening has limited impacts, that coupled payments result in more significant changes to gain environmental benefits and that the largest economic impact is due to convergence.

From February to May 2017, the European Commission held a public consultation on modernizing and simplifying the CAP (European Commission, 2017). Open to all interested EU organizations and citizens, it asked a series of questions about principles and priorities for the future CAP to inform a Commission Communication on the CAP post 2020, due in spring 2018. The results of the public consultation clearly demonstrate the important role the CAP is seen as playing and must continue to play with regard to maintaining and enhancing the environment in rural areas generally and on agricultural land specifically. Climate issues are also flagged as an area where the CAP should do more in the future, although views differ on where the focus of policy intervention should lie. The challenge now for the Commission is to develop proposals for a modernized and, in some sense, simplified CAP for the post 2020 era that champions these environmental and climate objectives as part of a package of measures that promote an economically robust and sustainable agricultural sector for the future.

Climate change (CC) affects agricultural land use and the economic performance of farms (Blanco et al., 2017). Many recent studies highlight these potential effects in different parts of Europe. Dono et al (2016) showed that a greater use and availability of water is vital for adapting to CC in Italian Mediterranean agriculture. Nunes et al (2017) studied an agricultural area of Portugal and reach the same conclusion about the role of water availability for the resilience of the farming sector to CC. Steidl et al (2015) evaluated the impact of CC on hydrologic conditions and the agro-economy of an area in north-eastern Germany. They showed that a possible future increase of irrigation needs and water deficits for the entire area and for specific crops might limit the profitability of irrigation. Schönhart et al (2016) showed that CC could increase productivity and the economic performance of the Austrian agriculture but could deteriorate the environmental conditions in rural areas. Mittenzwei et al (2017) determined the combined effects of policy and climate uncertainty in Norway. They note that the uncertainty of CC and the policy may affect the performance of the farming sector, with repercussions for production, land use, income and social welfare. Finally, the CAP reform itself recognizes the relevance of these impacts when it defines sustainable growth in relation to CC mitigation and adaptation as an objective (European Commission, 2010; European Commission, 2011).

The purpose of this study is to assess the potential impact of the milk quota abolition and the reform of the CAP first pillar integrated with the potential effects of CC. The impact of these changes is evaluated under two climate scenarios (present and near future), whose outcomes are compared to derive the separated and integrated effects. We chose a relatively near future horizon (2020-2030) because this perspective is of great interest to study the interactions between possible CC, the current policies, and the responses of the existing farming systems. The analysis concerns a study area of central-west Sardinia (Italy), where different farm types operate, and assesses the potential impacts on land use, inputs (water, chemicals, feeds), and economic results. A Discrete Stochastic Programming (DSP) bio-economic model represents the existing productive conditions, specified for the main farm types, with uncertain conditions for crop yields and water requirements. A recent study in this area used a DSP model to evaluate the impact of CC (Dono et al. 2016). The current study modifies various structural aspects of that model, especially relating to livestock activities, allowing for adaptation strategies that modify the consistency of herds and flocks as reactions to policy changes and to CC.

The following overview highlights some major aspects of the reform of the first pillar and milk quota abolition, with a literature review of some recent research. The *Materials and Methods* section describes the study area, along with the climate, agronomic and livestock simulations submitted to the bio-economic model. The *Results* section reports the simulated scenarios and the impacts on the use of land, inputs, and economic results. *Discussion* and *Conclusions* reports critical reflections about this study and presents the policy implications and some policy considerations for the future of the CAP.

2. Overview of the agricultural policy reforms evaluated in this study

2.1 Normative aspects

The Common Agricultural Policy (CAP) provides two pillars; the first relates to direct payments and Common Market Organizations (CMOs), and the second relates to rural development policy. The first pillar has been historically the most financially important; the CAP reform for 2014-2020 redesigned its direct payments system, known as Single Payment Scheme (SPS), into different payments, including the basic payment, *greening* payment and coupled payments.

The basic payment has the same characteristics and functions of the SPS but with fewer financial resources. In fact, part of the national ceiling also funds the *greening* and coupled payments[1]. In addition, in the Member States that apply the historical SPS (e.g., Italy), the value of farm-based

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[1] Italy has allocated the following financial resources to first pillar payments: basic payments (58%), greening payments (30%), coupled payments (11%), payments for young farmers (1%).

unitary entitlements will move towards the national average of the basic payment. This mechanism, referred to as *convergence,* will either increase or decrease the unitary entitlement of single farms. Italy decided to apply the Irish model of *convergence,* which creates a single region at the national level and provides a smooth transition from the pre-reform level of basic payments towards more homogeneous levels by 2019, but not a uniform value.

The coupled payment provision concern the sectors or regions where specific farm types or agricultural sectors are of particular importance for the economic, social, and environmental objectives. Coupled payments can have a significant impact on farmers' land allocation decisions, influence the use of other resources and thus have an impact on the environment. In the interested area, and in the rest of Italy, coupled payments occur for durum wheat, processed tomatoes and rice crops[2]. Furthermore, coupled payments cover the livestock sector and affects dairy cows and ewe lambs.

The *greening* payment provision only affects farms that apply agricultural practices deemed beneficial for the climate and the environment in addition to respecting the cross-compliance constraints. The requirements of the *greening* practices aim to protect the necessary environmental conditions for agriculture and include three basic elements:

a. diversifying cultivation by growing at least two crops on farms where the arable land exceeds 10 ha (and at least three crops where arable land exceeds 30 ha) and by limiting the main crop to 75% of the arable land (and the two main crops to 95% of the arable land where arable land exceeds 30 ha);
b. maintaining permanent grassland at the national, regional, or farm level;
c. maintaining Ecological Focus Areas (EFA) on at least 5% of the arable land of the farms larger than 15 ha. The EFA may be fallow land, terraces, landscape features, buffer strips, hectares of agro-forestry, strips of eligible hectares along forest edges, areas with short-rotation coppice, afforested, with catch crops or green cover, or areas with nitrogen-fixing crops.

The mid-term review of the CAP 2014-2020 (*Omnibus* Regulation) will determine some changes to direct payments, especially for greening and coupled payments. The European Parliament has dealt mainly with simplifying some commitments to beneficiaries and to controllers that had become difficult to sustain. The *Omnibus* Regulation will come into force on 1th January 2018, and in the coming months, the Member States will define the implementing laws at a national level.

The abolition of milk quotas has acted on a policy that has been in place since 1984. In that year, the European Union (EU) applied a supply quota for milk to prevent the overproduction that

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[2] Northern Italy also introduced a payment for soya, while other parts of Italy now offer payments for cereals (durum wheat), oilseeds (rapeseed and sunflower), and legumes (grain and fodder).

resulted from milk price supports. These price supports for milk were subject to critique, as they distort global trade. In the 1990s, the World Trade Organization urged the EU to abolish its system of price supports, in response to which the EU decided to gradually liberalize its dairy policy. Since 2003, the support prices were reduced, and the supply quotas were enlarged in steps. In recent years, world market prices for dairy products increased strongly, decreasing the gap between EU prices and world market prices. Therefore, the EU decided to completely abolish the milk quotas since April 1, 2015.

2.2 Literature review

The policy changes illustrated above will affect the use of land and inputs as well as the economic performance of rural areas. Numerous studies have been recently conducted to assess these impacts. According to Wąs et al. (2014) many Polish farms are already compliant with the *greening* requirements, and the adjustment of most of the remaining requirements should only slightly change the cropping patterns, with minor impacts on income. Ahmadi et al (2015) claim that the *greening* should have no major negative income repercussions on most Scottish livestock farms, while the regionalization of farm payments should have large negative impacts. Solazzo et al. (2015) argue that in Emilia-Romagna (Northern Italy), the *greening* should favour the substitution of maize and durum wheat with nitrogen-fixing crops; the redistribution of direct payments should instead prevail in terms of economic impact. Cortignani and Dono (2015) conclude that the *greening* should restrict the use of nitrogen in Southern Italy, while direct payment reform should negatively affect farm income since the increase of coupled payments does not compensate for the loss of decoupled payments. Solazzo and Pierangeli (2016) show that the overall impact of *greening* on land use and income on Northern Italian farms might be low, and given the weakening of the measures during negotiations, the related payments and sanctions are strong incentives for farmers to fully comply with these practices. Solazzo et al. (2016) argue that the *greening* constraints produce a modest abatement of the total emission of greenhouse gases in the analysed area. They also conclude that the process of “lightening” that affected the greening during the CAP negotiation has inevitably resulted in a missed opportunity to introduce a significant positive change in line with the expectations and needs of society for EU agriculture as a provider of public goods.

The results of Cortignani et al. (2017) showed that while the impact of the greening practice is limited in terms of land use, there were positive effects on environmental indicators. Coupled payments, along with greening practices, have a large impact and are effective in achieving environmental goals. Moreover, the system for reducing green payments and levying administrative penalties in cases of non-compliance is effective and ensures compliance with practices in almost all farms. Gocht et al. (2017) analysed the economic and environmental impacts of CAP greening introduced by the 2013 CAP reform using the CAPRI model. Their results show that the greening will lead simultaneously to a small increase in prices and a small decrease in production. Farm income slightly increases because the price effects offset the production decline. Similar to the economic effects, the environmental impacts of greening are small, although some regions may see greater effects than others. Louhichi et al (2017), using a EU-wide individual farm level model, show that the effects of the crop diversification practice on the EU farming sector are rather small. At the aggregate EU level, the proportion of the area that was reallocated due to the diversification measure represents less than 1% of the total agricultural area, and the crop production and income declines by less than 0.5%. At the individual farm level, the impacts could be more pronounced, although the number of farms affected by the measure remains small.

The abolition of milk production quotas since April 1, 2015 is another reform that should greatly affect the use of European farm resources. Styles et al. (2015) postulate that land use will intensify, with a potential worsening of international carbon leakage due to feed production displacement. Groeneveld et al. (2016) confirm that milk production and breeding intensity should increase in some countries and report that the Dutch government, concerned by the related environmental impact, introduced measures to condition the growth of intensive dairy farms to land availability. According to Samson et al. (2016), specialized and intensive farms are more likely to expand milk production if enough land is available.

3. Materials and methods

3.1 Study area and farm types

The study area is a 54,000 ha farming district located in the central west area of Sardinia (Italy). The agricultural system was reconstructed 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 dell'Oristanese,* that supplies irrigation water to part of the area.

The study area can be divided in two sub-zones depending on the availability of irrigation water (irrigated sub-zone and rain-fed sub-zone). In the irrigated sub-zone, the WUA supplies water from the *Eleonora d'Arborea* dam, with a reservoir of some 450 Mm3, of which 120 Mm3 are made available annually to potentially irrigate 36,000 ha. The main irrigated cropping systems are based on cereals, especially silage maize and rice, and other forage crops, such as alfalfa and Italian ryegrass, but also includes horticultural crops such as artichokes, watermelon, tomatoes, citrus orchards, olive trees, vineyards, durum wheat and barley. The breeding of dairy cattle in Sardinia is largely concentrated in the irrigated 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 a limited amount of water is occasionally 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 the rest of the land. The dairy sheep industry is largely present in this sub-zone and involves some 372,000 sheep and a number of small sheep's milk processing plants.

The structural and economic characteristics of this agricultural system have been represented in a regional economic model composed of blocks that identify the representative farm types of the area. The latter were obtained using data on FADN farms present in that geographic region: specialist rice, specialist citrus fruits, specialist dairy cattle, specialist vegetables grown under greenhouses, mixed cropping, and specialist sheep. Additional analyses and elaboration were carried out to capture differences among farms of the same types. For the specialist dairy cattle, mixed cropping, and specialist sheep farm types, a cluster analysis was carried out to subdivide farms of these three types into more homogeneous groups considering some structural, economic and managerial aspects. Specifically, a hierarchical cluster analysis was first performed based on average linkage between groups, which involves the measurement of intervals with Euclidean squared distances for selected characteristics of the population. This resulted in a more preferable number of groups. The number of groups was calculated with a non-hierarchical clustering k-means method to aggregate the FADN farms by maximizing the internal similarity of the groups.

For the specialist dairy cattle farms, the total FADN sample was divided into two groups with a better-performing group (*Cattle A*), which has more economically efficient feeding and a shorter calving interval compared to the *Cattle B* group. Similarly, specialized FADN sheep farms were clustered into three groups (*Sheep A*, *Sheep B*, *Sheep C*), largely depending on the availability of irrigation to produce the forage[3]. The mixed cropping type farms were divided into five homogeneous groups that differed according to cropping patterns, structural characteristics, and location (in irrigated zone: *Vegetables–Cereals*, *Cereals–Forages*, *Tree-arable crops*; in rain-fed zone: *Vegetables–Fruit*, *Cereals–Forages*).

All thirteen farm types are representative of the average of the various characteristics within the FADN sample. Representativeness was ensured using the FADN database and other local sources to confirm accurate reflections of resource use and economic results in the study area. Each farm type was multiplied by the proportion of farms in the study area it was estimated to represent.

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[3] The clustering variables used are return on equity, gross margin over milk, illness score and reproductive capacity for the specialist dairying; return on equity, gross margin, percentage of arable land and irrigated area for mixed-cropping and specialist sheep.

3.2 Bio-economic model: relationship between climate variability and agricultural activity

The bio-economic model used in this study to assess the impacts of policy and CC is based on the integration of climatological, agronomic, zootechnical, statistical and economic analyses. Details of individual analyses and their integration are shown in Dono et al (2016). In this sub-section, the salient elements are reported.

The potential climate forces acting on the study area and the changes due to future expected CO2 concentrations were evaluated with a downscaling strategy to produce calibrated time series of rainfall and temperature over the study region already developed for the AGROSCENARI project (www.agroscenari.it). This strategy builds a modelling chain describing with a high level of reliability the main atmospheric variability that acts on the area, from large scale to local scale, and considering the change in the concentration of greenhouse gases. It applies a coupled model of general circulation to estimate large-scale atmospheric and ocean response to future SRES-A1B (Nakicenovic and Swart, 2000) emission scenarios as described in Scoccimarro et al. (2011). We selected two periods of 11 years: 2000–2010 to represent current climate conditions and 2020–2030 as conditions of the near future. For the near future time range, the CO2 concentration of the SRES-A1B emission scenario do not differ significantly compared to the more recent Representative Concentration Pathways (Moss et al., 2010) and compared to the corresponding radiative forcing computed from global models. This is because the structural differences among the two emission scenario ensembles are more evident beyond 2050 when their uncertainty is also higher. The adopted global simulations belong to a specific set developed by the Euro-Mediterranean Center on Climate Change (www.cmcc.it) in the EU project Circe (http://www.circeproject.eu). The general circulation model drives the Regional Atmospheric Modelling System (RAMS) applied to the study area to increase the physical description of mechanisms acting at a local scale and to better represent local variability (Pielke et al., 1992). The proposed RAMS model configuration follows the numerical weather forecast settings of other studies (Meneguzzo et al., 2004). Finally, the statistical representativeness of the calibrated 11 years for each scenario created with RAMS were extended to 150 years of daily data by means of the weather generator WXGEN (Nicks et al., 1990), hereinafter called “150 synthetic years”.

Two crop models were used to estimate the influence of temperature, rainfall and atmospheric CO2 concentration on the main crops of the study area in the two climate scenarios: the EPIC model (Environmental Policy Integrated Climate, v 0810; Williams, 1995) and the DSSAT model (Decision Support System for Agrotechnology Transfer v 4.6; Jones et al., 2003; Hoogenboom et al., 2012). The EPIC model has been applied to simulate alfalfa, a silage corn-Italian ryegrass double cropping system based on two corn hybrids with different earliness, and has been widely used in the irrigated sub-area served by the WUA. Additionally, it has been used for rain-fed hay crops and grasslands and is very common in the rain-fed sub-area. The DSSAT model has been applied to simulate the systems of irrigated rice paddies and rain-fed winter cereals. The calibration of the two agronomic models is based on local crop datasets, surveys, interviews, observations, sample analysis, and from data systematically collected by private farms.

The relationships between climate and animal production in the current and future scenarios were estimated on the basis of the results of studies carried out in the Holstein breed, which is widely prevalent in the local dairy district. Attention was focused on the relationships between temperature and humidity, condensed in the temperature humidity index (THI), the mortality of cattle, and the quantity and quality of milk produced. The links between THI and mortality were studied using the Bovine Spongiform Encephalopathy database provided by the Italian Reference Centre for Animal Encephalopathies (Vitali et al., 2009). The relationships between THI and milk yield were studied on 596,515 test-day records from 484 dairy farms located throughout Italy and dated from 2001 through 2007 (Bernabucci et al., 2014). The THI-somatic cells relationship study (Bertocchi et al., 2014) was conducted on 508,613 bulk milk tests recorded monthly during the period of 2003-2009 in 3,328 dairy farms located in the Po Valley. Finally, the relationships between THI, cow mortality, milk yield and SCS were established by a 2-phase linear regression procedure (Nickerson et al., 1989) to detect an inflection point, if one exists, in the relationship between the independent variable (THI) and the dependent variable (mortality, milk yield and SCS).

The effects of climate variability on farmer’s choices can be represented by a Discrete Stochastic Programming (DSP) model (Cocks, 1968; Rae, 1971; Mccarl and Spreen, 1997; Hardaker et al., 2004; Calatrava and Garrido, 2005; Dono et al, 2013; Dono et al, 2016). The model assumes that farmers formulate a probability distribution of some uncertain parameters and, more precisely, discretize the Probability Distribution Function (PDF) into main states, expressed as representative values and related probabilities. Farmers are assumed to conceive the production process as a succession of stages in which some parameters are uncertain. Planning is therefore based on the probability of the various states, with the possibility of correcting their potentially unfavourable results but at a cost. The state that generates the highest expected income determines the various farm activities. The resulting management is different than it would be with a perfect advance knowledge of all the parameters; in fact, considering that unfavourable states may occur, farmers take precautions that depress the income level that could have been potentially achieved. This cost of uncertainty may increase if CC modifies the climate variability, changing the probability distributions of almost every parameter and hence the representative values of the various states and the possibility to correct the occurrence of unfavourable conditions.

Therefore, the economic impact of CC can be evaluated by comparing the results of the DSP model under present and future climate conditions, which would result in a shift in the probability of occurrence of the states of the different parameters.

Several case studies consider DSP models with different numbers of stages, states, variables and constraints. For instance, in modelling water management, Calatrava and Garrido (2005) consider the uncertainty of the resource availability in a dam at the beginning of the irrigation season and divide the allocation of land in two stages with states involving different levels of water availability. Dono et al. (2014) consider three stages also with uncertainty of the irrigation needs. In this study, uncertainty concerns the watering needs of irrigated crops and the crop yields.

3.3 Bio-economic model: mathematical formulation

The mathematical representation of the bio-economic model can be compactly defined as follows[4]:

$$\max_{X_1^L, X_{n_s}^R, X^A} z = GI\, X_1^L + VE\, NE - \sum_{n=2}^{N} \sum_{s=1}^{S} Pr_s\, Cr\, X_{n_s}^R + Pm\, Qm \quad (1)$$

subject to

$$GI = P\, Y + S - C \quad (2)$$

$$Qm = Ym\, X^A \quad (3)$$

$$A\, X_1^L \leq B \quad (4)$$

$$A_s\, X_1^L \leq B + \sum_{n=2}^{N} X_{n_s}^R \qquad \forall\, s \quad (5)$$

$$F\, Y_s\, X_1^L + \sum_{n=2}^{N} X_{n_s}^R \geq R\, X^A \qquad \forall\, s \quad (6)$$

$$X_1^L \geq 0 \; and \;\; X^A \;\; \geq 0 \quad (7)$$

$$X_{n_s}^R \geq 0 \qquad \forall\, s \quad (8)$$

where n is the number of stages of the decision making, s are the states of nature, X_1^L refer to the land allocation of which occurs in the first stage, and $X_{n_s}^R$ are the corrective actions performed in the subsequent states (*n*= *2,...,N*) on the actual occurrence of one of the states (*s*). These actions modify

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[4] The mathematical formulation uses matrix notation with explicit definition of the sets that characterize the DSP model: stages (*n*) and states of nature (*s*). Three types of variables (*X*) are considered: the first refers to the land allocation (superscript *L*), the second refers to the additional resources (superscript *R*) and the last refers to the animal number (superscript *A*).

some available resources, i.e., water and feeds, by water pumping and purchase of feeds and fodder, determining a cost (Cr) to the farms.

Equation (1) is the objective function (z) that sums different components: gross income (GI) of the activities chosen in the first stage (X_1), number (NE) and unit value (VE) of entitlements related to the Single Payment Scheme of the CAP ante-2014 (decoupled payments) and costs (Cr) of the corrective actions XR_{n_s}. In this latter case, the values of the uncertain activities in the states of nature are weighted with their probabilities (Pr_s) and summed over N stages. Finally, the objective function sums the revenues of milk based on the price (Pm) and the total quantity (Qm).

Equation (2) defines the gross income of the cropping activities, where P are the output prices, Y are the yields, S are CAP coupled payments and C are the unitary costs per hectare related to production costs (seeds, fertilizers, herbicides, etc.).

Equation (3) defines the milk total quantity (Qm), where Ym is the milk unitary production, and the X^A variables refer to animal number[5].

Constraints (4) refer to land and labour resources: A is the matrix of technical constraints, and B is the quantity of available resources. Constraints (5) refer to the water resource and show that uncertainty affects A_s, i.e., watering needs of irrigated crops, and that choices involve corrective actions, $X^R_{n_s}$, in stages (n) for each state (s). Constraints (6) refer to animal feeding: F are the unitary contributions of nutritional elements of the forage crops, and R are the unitary nutritional needs of livestock categories. The uncertainty affects Y_s, i.e., yields of forage crops and that choices involve corrective actions, $X^R_{n_s}$, in stages (n) for each state (s).

The cropping activities were calibrated to the reference year (2010) with the PMP approach of Röhm and Dabbert (2003) that allows modelling the choices between technically similar crops whose mutual substitution elasticity is greater than that relating to other crops[6]. The calibration involved deciding land allocation among crops in the first stage[7].

Compared to the model used by Dono et al. (2016) to analyse the impact of CC in that area, the model in this study presents several changes. Some of these refer to an explicit specification of the

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[5] In the baseline, the production of cattle milk is subject to the quota constraint.

[6] For more details, see Cortignani and Dono (2015).

[7] The PMP approach requires a relatively limited amount of data and can be perfectly calibrated to the reference period. It recovers additional information from observed activity levels, allowing researchers to specify a non-linear objective function such that the resulting nonlinear model exactly reproduces the observed behaviour of farmers and can be used for simulation analyses (Arfini and Paris, 1995; Howitt, 1995; Paris and Howitt, 1998; Heckelei and Wolff, 2003). This method not only automatically and exactly calibrates the model to observed activity levels but also avoids adding ad hoc constraints and over-specialized responses of the model to policy changes (de Frahan, 2016). Heckelei et al. (2012) made a review of the development and utilization of the most important PMP models.

model components involved in the simulations. The first is the explicit definition of the decoupled payments (NE and VE) in the objective function. Furthermore, the equation of the GI gross income calculation is defined to highlight the singular components (prices, yields, costs and coupled payments) that are subject to modifications in the future scenarios.

Other changes are of structural types and relate in particular to livestock activities. The number of bred animals is now defined as a variable and not as a parameter determining a fixed resource requirement. Livestock feeding is instead modelled as in the previous model by meeting the requirements related with milk production under the various climate-weather conditions with the production of fodder on farm and the purchase of feed.

To increase the ability to simulate adjustments following the abolition of milk quotas, the livestock units are defined as variables, and the number of dairy cows is calibrated with the presence of milk quotas in the baseline[8]. Even the sheep units and the tree crops are defined as variables, calibrated with the PMP approach and subject to possible modifications in the future scenarios.

3.4 Bio-economic model: input data, scenarios and potential impacts

The productive conditions of crops and livestock in this area were derived from interviews with farmers, agronomists, and leaders of the regional administration and of the local agricultural cooperatives. The requirements of labour, chemicals, and water were defined for the various stages of production of the crops, including yields and prices. Similarly, the feed requirements of the various categories of livestock were specified with the actual food rations and the products obtained. The output and input prices have been identified through the use of local databases and through interviews. With regard to output prices, the model does not consider the interaction between supply and demand of the various agricultural activities but considers the agricultural supply of a small area where the market price is based on the farm type’s expectations.

The constraints regarding the land, labour, water and their availability have been determined 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 dell’Oristanese*. The nutritional constraints take into account the various nutrient needs of the various livestock categories and such requirements are met by the fodder produced in the farm and the purchase of feeds on the market.

The bio-economic model is static (annual choices) and considers short-term adjustments and impacts. In other words, the productive activities (annual crops, perennial crops, and livestock

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[8] The calibration was carried out in order to avoid interference between the milk quota and calibration constraints as implemented in the CAPRI model (JRC, 2009).

activities) are limited by structural constraints (in particular land and labour). In addition some structural elements were analysed and considered as regards perennial crops and livestock activities

Regarding livestock activities, the model considers that each productive animal (cows, ewes) is linked with a series of non-productive animals (dry cows, dry ewes and young animals). This considers the different lactation stages and the costs necessary to maintain the herd.

In the baseline, fixed capital (stables, installations, machinery) are oversized with respect to herd dimension. Cattle breeders have invested heavily in fixed capital, trying to concentrate all the region's milk production in the *Arborea* region alone. With regard to the sheep farms, in the recent past (compared to baseline) the price of sheep's milk was higher and has determined a dimension of fixed capital that is oversized compared to the animal numbers observed in the baseline.

Verifications carried out in livestock farms have allowed us to confirm that the reduced increments in terms of animals (which will be shown in the *Results* section) would not result in investment in terms of expansion and new capital. These investments could thus be implemented as is done in other static models, e.g., SEAMLESS (Ittersum et al., 2008).

In the case of perennial crops, it was considered that a portion of the surface is in a non-productive phase, which determines costs but does not generate revenue. This proportion is a percentage of the productive area and varies according to the economic life of the tree species considered (olive, vines, and citrus fruits).

Another fundamental characteristic of the bio-economic model concerns the choices made about uncertain conditions: different states of the nature of some parameters (yields and irrigation requirements) and choices made in later stages. The representative values and probabilities of the states of nature for the various crop variables (yields and water requirements) were estimated by executing EPIC, DSSAT, and livestock models using the climate data from the synthetic 150 years. The outcomes were used to estimate the PDFs of the yields, current and future, of pastures and grasslands in the rain-fed zone, of irrigation needs, and of relative yields of maize, ryegrass and alfalfa in the irrigated zone. The irrigation needs of the other crops were estimated based on their present values and the percentage change in net evapotranspiration (ETN) of the future climate relative to the present. All the PDFs were obtained with a maximum likelihood estimator. Chi-square tests were applied to identify the function that best approximates the dataset. Finally, the range of each PDF was divided into three states, with a 25% probability for low and high states, and 50% for intermediate, which constitutes the vector of probability (P) of each uncertain variable. The representative value of the variables in the three states is the average of their values in the synthetic years falling in each state. The model does not consider catastrophic events, such as floods or droughts, that result in the destruction of agricultural production and more. The model considers, through nature states, negative events to the extreme of probability distributions that cause a worsening of production conditions (yields or irrigated needs) and which are more likely to occur in the future scenario.

The first stage of the model provides land allocation; the following stages provide corrective actions on the use of groundwater and the purchase of feeds and fodder. The model also includes activities for which farmers cannot perform corrective actions because the uncertainty concerns the final output and is only resolved at the end of the production cycle. In these cases, only the difference in the average gross income under the climate conditions of the present and future is evaluated. These activities include summer production of cow's milk, whose yields and quality levels decline under the future climate scenario, livestock mortality, which instead increases, and production of crops to sell, such as rice, wheat and barley, with different impacts on yields.

The main features of the baseline and of the other scenarios considered in the simulation phase are

- Baseline: the model was calibrated to the situation observed in 2010 characterized by present climate conditions (2000-2010), presence of milk quotas, prices and direct payments of CAP as in 2010. Regarding the latter, coupled payments were active for rice and for processing tomato, and quality premium for durum wheat.
- Policy scenario: the abolition of the milk quotas and reform of the CAP direct payments are simulated under the present climate (2000-2010). The coupled payments are provided for the livestock (dairy cows and ewe lambs) and for different crops (durum wheat, rice and processing tomato).
- Policy+CC scenario: the abolition of the milk quotas and reform of the CAP direct payments are simulated under the near future climate scenario (2020-2030) that modifies crop yields, irrigation requirements and cattle milk production conditions (quantity and quality milk, mortality), as specified in Dono et al. (2016).

The model (1)-(8) has been modified in order to consider the policy changes: the number (NE) and unit value (VE) of entitlements related to the Single Payment Scheme of the CAP ante-2014 (decoupled payments) have been subdivided in basic payments (NEb and VEb) and greening payments (NEg and VEg); the VEb unit value of basic payments has been subject to a convergence effect; the new coupled payments have been considered; the milk quota constraint has been removed; the constraints related to the greening practices have been added[9].

Several drivers are involved in the various scenarios (Table 1).

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[9] The mathematical formulation of greening constraints and of two (basic and greening) payments has been widely dealt with in the recent literature. For more details refer to Cortignani and Dono (2015), Solazzo and Pierangeli (2016), Cortignani et al. (2017).

Table 1

These drivers directly affect various model elements, resulting in direct impacts. Other impacts (indirect) are a consequence of direct ones. For example, the abolition of milk quotas directly influences the number of dairy cows, resulting in changes in land use, inputs and economic results. The impacts shown in the table are potential but may not necessarily occur.

4. Results

The following results are reported for each scenario: size of the livestock and land use (Table 2), use of main inputs (Table 3), economic results of the total area (Table 4), and net income of each farm type and sub-area (Table 5). Each table shows the absolute value of the baseline and expresses the data of the other scenarios as percentage change compared to the baseline.

4.1 Policy scenario

Changes in livestock number are observed considering the abolition of milk quotas and coupled payments for the ewe lambs (Table 2).

Table 2

Abolishing the milk quotas increases the number of cows (4.4%) suggesting that the quota limited the livestock number. The coupled payments provided for the ewe lambs increase the number of ewes (5.5%).

The changes in livestock number, the coupled payments provided for the crops (durum wheat, rice and processing tomato) and the greening practices determine changes in the land use (Table 2).

The coupled payments provided for the crops increase the surface devoted to the durum wheat (6.3%), rice (0.6%) and processing tomato (7.1%). The three *greening* practices have different effects on various crops and farms. The diversification does not affect silage maize, practised as a secondary crop that follows the main crop (ryegrass) in the same area during the same year. However, this practice affects clover (hay crops), diffusely cultivated in the sheep farms, which has been considered the main crop subject to diversification since 2016. The pasture maintenance is a stringent constraint for one of the sheep farm types (Sheep A). The EFA affects the most intensive types, "*Cattle*" and "*Vegetables–Cereals*", that reduce the arable land in order to respect the constraint. Overall, the forage crops slightly decrease (-0.9%), but with differences for the various crops. In fact, the surface of ryegrass and corn silage increases to feed more cattle (0.7% and 1.6%, respectively). The increase in the ryegrass causes a subsequent decrease in alfalfa (-2.7%). Additionally, the surface area of grasslands increases in order to feed the large number of sheep (0.5%). The surface area of artichokes decreases (-2.0%) due to the increase in tomato cultivation.

Regarding the use of main inputs (Table 3), the overall increase in the livestock number causes a significant increase in the external purchase of feeds (12.4%).

Table 3

Land use changes result in a very limited impact on the use of irrigation water and chemicals, of which nitrogen decreases 0.4%. The decrease in water pumping is greater (-1.4%), as the surface area of some irrigated crops that use water from farm wells (e.g., artichokes) is lower.

Table 4 shows the economic results of the total area.

Table 4

The changes in livestock number and land use result in an increase in animal revenues (4.6%) and crops revenues (3.7%). Overall, the total revenue increases 4.1%. Additionally, variable costs increase (2.5%) caused largely by higher feed costs (12.3%). The overall impact on the net income is slightly positive (0.6%). However, this impact would have been more positive without the convergence effect.

In fact, the convergence of the basic payment determines a reduction in the direct payments of the CAP (-14.1%). Within the study area, decoupled payments are higher than the average, given that activities with highly coupled payments (rice, processing tomatoes, cow's milk, wheat, sugar beet) were practised in the historical reference periods. Hence, the convergence leads to a considerable loss of decoupled payments in favour of other territories, and the level of direct CAP payments decreases. Regarding the various farm types (Table 5), the convergence of the basic payment provides decoupled payments to the "*Citrus specialized*" farm that this type did not receive in the baseline; therefore, its net income increases by 6.6%.

Table 5

In the other farm types, the convergence of the basic payment results in a lowering and, in many cases, a loss of net income. Net income especially decreases in the "*Sheep C*" and "*Cereal-Forages*" types because their decoupled payments, previously higher than the basic national payment, are converge towards this last value. In the other livestock farms (other than "*Sheep C*"), the net income increases because of the higher revenues (increased number of animals and of their products) of coupled payments and because the convergence effect is lower.

Finally, different impacts on net income are observed for the two subzones. In the irrigated zone, the net income increases 0.8%, while in the rain-fed zone, a reduction of 0.7% is observed.

4.2 Policy scenario + CC

As described previously, the percentage changes shown in the tables are reported with respect to the baseline. In the following description, comparisons with the *Policy* scenario will highlight the effect of CC. However, it is also interesting to compare the combined effect of *Policy* and *CC* to the baseline. Various explanations account for the reduction in cow numbers (3.6%) compared to the previous scenario (Table 2). Heat waves in the future climate scenario worsen the productive conditions in cattle dairy farms; high air humidity in the summer reduces the cow milk production and worsens its quality levels, which reduces its price and increases the mortality of cows. In addition, the worsening of fodder cultivation conditions effect all livestock farms, with reduced yields for corn silage, clover, alfalfa, and pasture. Specifically, the combination of these reductions in yields generates a significant increase in the area cultivated with silage maize and ryegrass (double crop) by 11.8% and 7.3%, respectively, given the importance of these crops for the feeding of dairy cattle. This causes a further decrease in the alfalfa (-26.4%). Additionally, a decrease of 4.4% of clover production (hay crops) is observed because of its reduced yields. In contrast, the increase in yields of durum wheat and rice, due to the greater concentration of atmospheric CO2, increases their use of land by 8.6% and 2.9%, respectively (Table 2).

These changes (livestock number and land use) have an impact on the use of inputs (Table 3). An increase in the use of irrigation water and chemicals emerges compared to the baseline. The nitrogen is increased by 1.5%. In parallel, there is an increase in the use of feeds (+12.5%) that especially concerns the sheep farms (not explicitly shown in table), which are particularly affected by the lower productivity of the forage crops in rain-fed conditions.

The economic results are also interestingly affected (Table 4). The total revenues increase by 3.7% with a substitution between the crop revenues and animals compared to the previous scenario. In this scenario, higher revenues from durum wheat and rice, a lower increase in the number of animals, and a decrease in cow's milk production are observed. Variable costs increase by 3.5%.

Compared to the previous scenario, a lower increase in feed costs (+10.1%) and a greater increase in technical means (3.5%) are observed. This is because the increase in the use of feeds, especially in the sheep farms (the feeds are less expensive than those used for dairy cattle) and because of the intensification of land use (larger areas devoted to silage maize, durum wheat and rice). Considering the same negative impact of the convergence, which reduces CAP payments by 14.1%, the changes in revenues and variable costs determine a negative impact on net income of the total area (- 2.0%).

Even in this scenario, the impacts on net income are very different for the various farm types (Table 5). The net income of the "*Rice*" type increases by 9.5% due to higher rice yields. The "*Cattle*" farms lose income (-1.4%, and -0.9%) because of the general worsening of production conditions (heat waves and fodder production). CC also increases the impact of the EFA practices on the income of cattle farms. In fact, the reduction of alfalfa yield in the future climate induces a reduction in its cultivation; since this culture is recognized as EFA, its decrease compels those farms to reduce the arable land to meet the constraint on the EFA elements. Different results also affect "*Sheep*" farms because CC worsens the productive conditions of fodder and raises the purchase costs of livestock feed. Only the "*Sheep A*" shows an increase in the net income, but this was very low compared to the *Policy scenario*. In the other two sheep farm types, the net income decreases by 1.9% and -14.3%, respectively. The overall income impact in the two sub-areas is negative, especially in rain-fed sub-areas (-5.3%) compared to irrigated sub-areas (-1.4%).

5. Discussion

Overall, the results show that the considered policy changes have small positive impacts on economic and environmental factors in the study area. CC can effectively attenuate or even reverse several of those effects, especially in some farm types. Different drivers have been considered in the analysis, and our results confirm those of other recent studies.

Milk quota abolition is likely to generate an expansion in dairy milk production largely supported by feed purchase on the market, which could increase environmental pressures in both milk and feed production areas (Styles et al, 2015; Fradj et al, 2016).

The greening practices have limited impacts on land use and on environmental benefits. The practice that seems to have a greater impact is that which concerns the introduction of EFAs in specialized and/or intensive farms. The coupled payments result in more significant changes, and the greatest economic impact is due to convergence (Cortignani et al., 2017; Gocht et al., 2017; Louhichi et al., 2017). In our case study, the convergence of basic payments has a very high negative impact. In fact, within the study area, decoupled payments are higher than the national average level, the convergence leads to a considerable loss of decoupled payments in favour of other territories, and the level of direct CAP payments decreases. In general, the reallocation of decoupled payments will have a positive impact on the farms situated in hill and mountain areas, where in the past (in the reference period), more extensive crops were practised, and smaller coupled payments were provided at the disadvantage of intensive farms located in plains, such as those in the case study.

CC can generate different alterations of atmospheric conditions that are all relevant for the annual planning of agricultural activities, with repercussions on production, land use, income and the environment (Dono et al., 2016; Schönhart et al., 2016; Nunes et al., 2017; Mittenzwei et al., 2017). Overall, CC causes a worsening of the economic and environmental impacts. In particular, the (animal) production level is lower, but more use of inputs and higher costs are expected. Larger negative impacts would have occurred without the policy, but a part of the effect on income support and the mitigation of impact on the environment is impaired in the new climate conditions.

Therefore, in the specification of the CAP post-2020 the elements/instruments of support to income and environmental protection must be strengthened in order to counteract the worsening effects of CC.

The results of the Commission's recent public consultation on the future of the CAP have reinforced the message that the CAP must do more to deliver for the environment and climate. Biodiversity, soils and water are particularly highlighted. Climate issues are also flagged as an area where the CAP should do more in the future, although views differ on where the focus of policy intervention should lie. There is an urgent need to mitigate the impact of climate change by reducing emissions of greenhouse gases from agriculture while also ensuring that agriculture in different EU regions can adapt to the expected impacts of climate change (European Commission, 2017). Decision-makers can explore the scientific results that are meaningful to them and participate in generating information that becomes actionable, specifically because it has been cooperatively structured to answer their most pressing questions (Forni et al., 2016). Scientific knowledge and insight must be communicated to decision-makers in meaningful ways to ensure they can act upon it. Regarding CC, decision-makers should plan at different scales by enabling regional-scale strategies and embedding tool design in their local planning context to successfully ensure promised goals (Bosomworth et al, 2017; Zandvoort et al., 2017).

6. Conclusions

In this study, we assessed the potential impact of the milk quota abolition, as well as of the reform of the first pillar, in terms of land use, use of inputs (especially water, nitrogen, feeds), and economic impacts. These impacts were evaluated in two different climate scenarios (present and near future) in order to analyse the interactions between the possible impact and adaptation to CC and the reactions to policy changes. We focused on a study area located in the central western area of Sardinia (Italy) where typical farming systems of the Mediterranean area operate. We used a bio-economic model representing the existing production conditions in the main farm types under uncertain conditions for crop yields and water requirements. The results of the study can contribute to the debate on CAP post-2020, which will have to act in deeper climate-altering contexts.

Greening practices should be revised because they do not involve significant environmental benefits. One possibility could be to integrate greening practices into the second pillar of the CAP and, in particular, in the agri-environment-climate measures (Aecm). With proper support and well-defined practices, this could result in wide participation in the measures and greater environmental benefits.

The greening practices could be planned in such a way as to encourage possible adaptation strategies to CC. For example, irrigation deficit techniques could be recognized as EFA in order to incentivize a more sustainable use of the irrigation water. Specific actions in the new Aecm of the second pillar could be envisaged to encourage the adoption of irrigation deficit techniques.

In contrast to greening practices, coupled payments can result in more significant changes also in order to gain environmental benefits, as specific payments for protein crops and nitrogen fixing are provided. In the CAP post-2020, a part of coupled payments could be geared towards adopting to climate change adaptation with strategies such as promoting the use of production activities more resistant to adverse weather conditions.

Concerning the convergence of decoupled payments, the situation illustrated in this study seems inevitable for all other similar areas and farms. Levelling the decoupled payment leads to income loss for some farms compared to the situation before 2014. To recover this loss, farms should make more market-oriented choices and try to implement technological developments also through the incentives of the 2nd pillar measures of CAP.

With regard to market conditions and technological development, an improvement on the current study might be to consider other drivers such as output prices, input and technological improvements. New technologies could mitigate the negative impacts and determine more sustainable production. On the other hand, changes in the ratios between commodity and factor prices could interact with political changes in different CC scenarios, in some cases balancing its impacts, and in other cases accentuating them.

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Tables

Table 1. Types of impacts (Direct [D] and Indirect [I]) of the various drivers on livestock number (cows and ewes), land use, use of inputs (feeds, water, chemical) and economic results and the farm types mainly involved.

	Number of		Use of		Economic	Farm types
Scenarios / Drivers	cows	ewes	land	inputs	results	
Policy scenario						
abolition of milk quota	D		I	I	I	Cattle
coupled payments - livestock	D	D	I	I	D	Sheep
coupled payments - crops	I	I	D	I	D	Rice, Mixed
greening practices	I	I	D	I	I	Cattle, Mixed, Sheep
convergence of basic payment					D	All
CC scenario						
crop yields	I	I	D	I	D	All
irrigation requirements	I	I	D	D	I	All
milk production	D		I	I	D	Cattle

Table 2. Dairy livestock number and land use in the baseline (absolute values) and simulated scenarios (percentage changes over baseline [%Δ]): total area.

	Baseline	Policy scenario	Policy scenario + CC
Dairy livestock number			
Cows	18,440	4.4	3.6
Ewes	17,292	5.5	5.5
Land use			
Grain cereals	13,533	2.2	4.4
Durum wheat	*8,335*	*6.3*	*8.6*
Rice	*2,700*	*0.6*	*2.9*
Forage crops	32,478	-0.9	-1.3
Grasslands	*11,394*	*0.5*	*-0.6*
Hay crops	*9,523*	*-3.6*	*-4.4*
Silage maize forage	*4,265*	*0.7*	*11.8*
Silage maize other	*1,446*	*-3.0*	*-12.5*
Italian ryegrass	*3,582*	*1.6*	*7.3*
Alfalfa	*1,978*	*-2.7*	*-26.4*
Field horticultural crops	6,022	0.7	1.3
Processing tomato	*1,935*	*7.1*	*7.3*
Artichoke	*1,919*	*-2.0*	*-1.8*
Greenhouse crops	177	*0.0*	*-0.9*
Tree crops	1,702	*0.6*	*0.6*

Table 3.Use of main inputs in the baseline (absolute values) and simulated scenarios (percentage changes over baseline [%Δ]): total area.

	Baseline	Policy scenario	Policy scenario + CC
Total water	121,586	-0.1	2.0
WUA water	114,590	0.0	2.1
Water pumping	6,996	-1.4	-0.6
Nitrogen	9,828	-0.4	1.5
Phosphorus	4,993	0.1	1.8
Potassium	6,562	-1.1	-0.8
Feeds	1,100	12.4	12.5

Table 4. Economic results in the baseline (absolute values) and simulated scenarios (percentage changes over baseline [%Δ]): total area.

	Baseline	Policy scenario	Policy scenario + CC
Total revenues	203,391	4.1	3.7
crops	113,610	3.7	4.3
animal	89,781	4.6	2.9
Direct payments CAP	31,647	-14.1	-14.1
Variables costs	128,181	2.5	3.5
Technical means	52,926	0.6	1.8
Feed	22,441	12.3	10.1
Extra-farm labour	6,735	-0.5	-1.0
Payments to the WUA	2,143	0.0	0.8
Water pumping from farm wells	278	-1.2	-0.2
Gross margin	106,858	0.5	-1.3
Net income	78,571	0.6	-2.0

Table 5. Net income in the baseline (absolute values) and simulated scenarios (percentage changes over baseline [%Δ]): farm types and sub-zones.

	Baseline	Policy scenario	Policy scenario + CC
Irrigated sub-zone			
Rice	4,345	-1.2	9.5
Citrus	2,734	6.6	6.6
Cattle A	27,115	4.2	-1.4
Cattle B	6,597	5.4	-0.9
Greenhouse	1,203	0.4	0.5
Vegetables - Cereals	19,155	-2.0	-2.8
Cereals - Forages	4,772	-15.4	-12.7
Tree and arable crops	1,075	1.2	1.3
Rain-fed sub-zone			
Vegetables - Fruit	1,039	-1.1	-1.1
Cereals - Forages	2,738	-2.6	-2.7
Sheep A	2,288	6.3	1.7
Sheep B	1,798	9.5	-1.9
Sheep C	3,711	-8.3	-14.3
Irrigated sub-zone	66,997	0.8	-1.4
Rain-fed sub-zone	11,574	-0.7	-5.3
Total area	78,571	0.6	-2.0