CAP reform and GHG emissions: policy assessment using a PMP agent-based model

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Contributed Paper prepared for presentation at the 97th Annual Conference of the Agricultural Economics Society, University of Warwick, United Kingdom

27 – 29 March 2023

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This research was funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 816078 for the AGRICORE Project

Abstract

The aim of this research work is to assess the likelihood of dairy farmers to accept predefined policy scenarios that implies different level of CO_2 taxation on GHG emissions produced by the livestock sector. It uses an agent-based model (ABM) and it follows the positive mathematical programming (PMP) approach. ABMs allow to evaluate agricultural policies and farmers' level of acceptance simulating interaction between farmers, taking territorial specificity and farm heterogeneity into account. The PMP methodology enables to add social and cultural perspective to the economical drivers. The Least Square method, applied to the PMP methodology, allows to overcome shortage in data availability. The model is calibrated on FADN data for the Emilia Romagna region (Italy), year 2020. Results show that farmers take decisions based on economic profitability but also on social and cultural background. Farmers opt for more efficient agricultural management practices if economically convenient, however the possibility to exchange production factors can contribute to the optimisation of their utility function.

Keywords: CAP Reform, CO_2 Taxation, Agent Base Model,

JEL code: C61; Q15; Q18; Q52

1. Introduction

Food demand is expected to increase in the next few years and the need for a more sustainable livestock sector can no longer be ignored. Livestock worldwide is responsible for 16.5 % of all anthropogenic GHG emissions, mainly in the form of methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O) and ammonia (NH_3), derived from fodder cultivation, enteric fermentation, manure management, nitrogen deposition and application (Reisinger e Clark 2018; Twine 2021). Livestock activities require an extensive amount of land, both for accommodating animals and for fodder cultivation. This generally translates in deforestation, leading to emissions of carbon previously stored in biomass and in soil. Furthermore, livestock sector is a great cause of water wastage and water pollution, contaminated by animal excreta, antibiotics and hormones, fertilizers and pesticides used in forage production, and runoff from pasture. (Dopelt, Radon, e Davidovitch 2019). Water quality degradation, eutrophication and hypoxia in surface water bodies are mainly due to nitrogen and phosphorous input derived from livestock manure management and fertilizers (Selman e Greenhalgh 2009).

In 2020, Italian livestock sector contributed with 271.051 thousand tonnes of ammonia and 19,759.77 thousand tonnes of CO_2eq, of which 68% (13,534.95 thousand tonnes) are related to cattle enteric fermentation and cattle manure management. National animal production value (in current value) accounted for 15.5 billion € (EUROSTAT 2020).

Since the MacSharry Reform in 1992, the European Common Agricultural Policy is gradually evolving to ensure food security through more sustainable agricultural practices (Cunha e Swinbank 2011). Eco-schemes (ES) and Agriculture Environmental Schemes (AES), have been introduced as new policy tools with the post 2020 CAP reform, to align the CAP objectives to the European Green Deal targets of reaching climate neutrality by 2050, and halving fertilizer application and nutrient loss by 2030 (European Commission 2020).

In the last decades, the European Union has also been developing a carbon pricing system to reduce emissions of greenhouse gases and mitigating climate change. The two main carbon pricing mechanisms, so far implemented, are the Emissions Trading Systems (ETS), and carbon taxes. ETS was set up in 2005 (Directive 2003/87/EC), as a cap and trade approach for activities, which are required to have allowances equivalent to their emissions. However agricultural activities are not yet included in these carbon pricing mechanisms (Ottinger, Robinson, e Tafur 2005). So far, however, policy makers have been reluctant to do so, partly because of the lack of political will, and partly because of the difficulty of measuring emissions and emission reductions at farm level (Verschuuren 2021).

Carbon taxes, on the other hand, directly set a price on carbon emissions, with the aim to incentivize activities to reduce their emissions. Finland was the first EU Country to apply a carbon tax in 1990. Carbon taxes are not compulsory for Member States, and the amount applied can vary widely: from more than 100 €/tCO_2eq in the Northern countries, to less than 1 € in Poland and Ukraine (Asen 2021).

In Italy, a carbon tax was introduced in 1999 (L 448/1998) on the consumption in energy plants of coal, petroleum and coke with a tax rate initially fixed on 1,000 £/t of product (around 0.52 €/t), but it was in force only for that year. After 1999, the reintroduction of the carbon tax in Italy has been discussed but not reimplemented (Mongelli, Tassielli, e Notarnicola 2009).

On July 14, 2021, the Commission published the "Ready for 55 %" package, COM (2021) 550 final (European Commission 2021) according to the Green New Deal, which includes the revision of the ETS Directive, and the introduction of the Carbon Border Adjustment Mechanism (CBAM) to prevent carbon leakage and to encourage a global move towards net zero carbon emissions in line with the Paris Agreement. The CBAM regulation was approved by the Council in March 2022 (Council of the European Union 2022).

Applying measures to decrease the GHG emissions of the Agricultural sector could significantly reduce the ecological footprint of agriculture but could also affects negatively farms' competitiveness and farmers' incomes (DG AGRI 2022). This effect could be mitigated considering the possibility of exchanging production factors among farmers operating in the same context, in order to reduce single farm inefficiencies.

The aim of this research is to assess ex-ante how farmers could react when facing the possibility of applying to the eco-schemes to make up for potential revenue losses, in an environment where they can reduce their inefficiency by exchanging production factors such as land and pollution quota. The effect of progressive carbon taxes (20, 50, 100, 150 €/tCO_2eq) is evaluated, to simulate farmers' responses in terms of changing the production plan and their resources allocation.

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To reproduce a complex environment at farm scale, in which farmers can interact with each other while maximizing the farm utility function, a Dairy Farm-Agent Based Model (DF-ABM) based on Positive Mathematical Programming (PMP) has been developed and applied.

ABMs allow to evaluate agricultural policies and farmers' level of acceptance simulating interaction between farmers, taking territorial specificity, usually subregion, and farm heterogeneity into account, while the PMP methodology enables to add social and cultural perspective to the economic drivers (Kremmydas, Athanasiadis, e Rozakis 2018; Matthews 2021).

The integration of an ABM and the PMP approach, allows to optimize every farm cost function of the sample, taking into account individual farmer's behavior and characteristics, starting from the observed optimal situation to simulate structural changes, such as changes in farm dimensions or possible abandonment of the farm activity. The model can estimate this choice by simulating the exchange of resources, as well as the introduction of new activities and changes in the agricultural management practices. The aggregation of regional results can provide a useful and solid insight on the general trend of the agricultural sector also at national, and international level.

The paper is organized as follows: section 2 presents the characteristics of the Agent Based model developed through a Positive Mathematical Programming approach; section 3 presents the sample data used for the simulation and the policy scenarios; section 4 presents the obtained results while section 5 concludes and propose paths for future research.

2. Methodology

2.1 ABM and PMP

Since 2013 and the introduction of the Greening measures, researchers have been increasingly focusing on farm models. These models are designed to depict individual farmers' behavior in reacting to market evolution scenarios, agricultural policies, changes in technology sets and climate change. According to recent studies (Kremmydas, Athanasiadis, e Rozakis 2018; Reidsma et al. 2018; Berger e Troost 2014) ABMs seem better suited to fulfil the challenge of assessing policies holistically, considering agricultural but also environmental and social aspects, while delivering substantial innovations to mathematical programming (MP) tools addressed to evaluate agricultural policies.

Likewise the MP farm models, ABMs can represent agents' behavior regarding their production choices: what products to market, what technologies to adopt, what production factors to use and in which quantities (land, labor, water, etc.). In addition, ABMs can represent farm heterogeneity, in terms of farms' structure and production strategies. They can capture interactions among farms in the use of scarce resources and evaluate structural changes under the assumption of not-fully rational production choices, maximizing the utility function rather than the profit function (Kremmydas, Athanasiadis, e Rozakis 2018; Nolan et al. 2009). Farmers are not just individual entrepreneurs but farm-householders, leaving room in the decision-making process for mediation between family members, which may generate economic inefficiencies. Agents decide based on factors endowment, level of technological knowledge and the individual perception of economic and technical risks. These decisions represent the agents' optimal economic choice. ABM farm models should (i) consider the individual farms and farm-households heterogeneity, (ii) reproduce the production choices based on the observed activities, (iii) depict the production specializations and (iv) the technologies used. Literature provides some attempts to measure the effect of the CAP measures through models with an ABM setting, such as AgriPoliS (Happe, Balmann, e Kellermann 2004), MP-MAS (Schreinemachers e Berger 2011), LUDAS (Le et al. 2008), RegMAS (Lobianco e Esposti 2010) and SWISSland (Möhring et al. 2016).

Normative MP models are not appropriate to represent agents as described above, as they assume fully rational farmers' behavior, hence they do not correctly estimate all explicit and implicit costs faced by the agents. Empirical evidence show that solutions obtained in the normative MP model calibration phase differ from the observed data (Godard et al. 2008; Cristoiu, Ratinger, e Gomez y Paloma 2007; Baranger et al. 2008).

Positive mathematical programming (PMP) models, on the other hand, are based on the assumption that the observed production level, reproduced in the calibration phase, is the result of the optimal agent choices. However, one critical aspect of the PMP is represented by the estimation of explicit variable costs per crop with only the total variable costs per farm available. The generalized least square (LS) method, used in this study to estimate the cost function, enables calibration by overcoming criticisms done to the Paris' three-step approach. This LS method, based on two steps, has the advantage of avoiding the unsolved problems of the arbitrary use of support values needed in the Maximum Entropy procedure (Golan, Judge, e Karp 1996; de Frahan et al. 2007) while using econometry to correctly estimate the cost function, even in absence of exogenous accounting costs. The cost function, so estimated, allows to differentiate the total variable costs of each crop between the explicit and the implicit costs, related to the agent's choice of what to produce and how. The calibration phase is followed by the simulation phase that reproduces the farm's behavior triggered by new market and agricultural policy scenarios. The possibility to estimate an unambiguous cost function for each agent allows the representation of farms' heterogeneity.

The PMP approach developed according to the seminal work of Paris (Paris 2011) and revised using the generalized LS method (Arfini et al. 2016) introduces the following elements: (i) farmers' heterogeneity, addressed through the development of an individual cost function for each farm in the sample; (ii) calibration performed for each farm reproducing its observed activities using the so called "self-selection", which allows to represent the "willingness" of each agent to adopt those activities that satisfy its family strategy, while being aware of alternative available processes; (iii) the exchange of resources (land, labour, water, etc.) between agents made possible by constraints linking farms one another; (iv) technology transfer between agents simulated by using the common cost function matrix that, in the event of changes in market or policy scenarios, provides farmers with the economic and technological information related to those activities not included in their production plan but that could be added or could replace the existing one.

2.2 The model structure

To simulate the effects on farmers' gross margin and structural changes, due to the introduction of carbon taxes as well as other environmental constraints, agents (farm-holders) are initialized with socio-economic characteristics (e.g. farmer age, family composition) and farm structure. The model is implemented in GAMS (GAMS 2016) and its structure is two-stage: the calibration phase, which represents the "positive" component and the simulation phase which represent the "normative" component of the model.

The calibration phase is performed using the LS technique on a sample of N farms. For each farm information on the production plan, prices and technical coefficients (the quantity of factors used to obtain one unit of product) are known. Only one limiting factor $\boldsymbol{b_n}$, available land at the farm level, (n=1,…,N), is considered. Unlike in other ABMs based on the PMP (e.g. SWISSland), the $\boldsymbol{Q}$ matrix composing the quadratic cost function is a full symmetric positive semi-definite matrix, ensured through the Cholesky factorization.

$$\mathbf{Q} = \mathbf{LDL'} \ \ (\mathbf{1})$$

where L is a unit lower triangular matrix, L' is its transpose, and D is a diagonal matrix whose elements are non negative. The coefficients, estimated in the quadratic cost function, provide flexibility to the model's responses towards farm simulations and information on the substitution and complementarity among agricultural activities (Paris and Howitt, 1998).

The PMP-ABM model integrates the first and the second phase of the standard PMP approach using the PMP dual properties, avoiding the explicit inclusion of the calibrating constraints. Moreover, this method allows to fill the data gap of Farm Accountancy Data Network, the most widely used database of agricultural information, that does not collect data about the variable costs per activity, $\boldsymbol{c}$, but only provides the total variable cost of the farm (DG AGRI 2020). The problem of implementing a PMP model without knowing $\boldsymbol{c}$ relates to the fact that the calibration constraints generates at least one associated shadow value equal to zero; otherwise, the shadow price for the structural constraint (land) will be equal to zero and an observed activity will be missed out in the **Q** matrix (Paris e Howitt 1998).

In the simulation phase, the model maximizes the farm gross margin using the quadratic cost function (**Q**) estimated in the calibration phase. The model, therefore, appears as follows:

$$\max_{\mathbf{x}\geq 0} GM = \mathbf{p}'\mathbf{x} - \left\{ \frac{1}{2}\mathbf{x}'\hat{\mathbf{Q}}\mathbf{x} + \hat{\mathbf{u}}'\mathbf{x} \right\} - (t\mathbf{x})'\mathbf{e} \quad (2)$$

Subject to

$$\mathbf{Ax} \leq \mathbf{b} \quad (3)$$

Where the unknown levels of production for each farm are indicated by the vector **x**, the output market prices are represented by the vector **p**, **Q** is the symmetric positive semi-definite matrix, and **u** is the vector of marginal cost deviations per farm **A** is the matrix of the technical coefficients and **b** is the vector of resources (land). The **Q** matrix is not representing the technology itself, but the technology costs related to the production choices. *t* and **e** represent respectively the CO_2 taxation and the vector of the emission factors.

Modelling dairy production relies on two main assumptions: i) the milk output price covers the costs of milk production (e.g. forage crops production costs, extra feed purchase costs, cows maintenance costs, etc.), so that milk price is greater than or equal to the milk accounting unit cost, and ii) the livestock is strictly linked to the available land, through the use of fodder crops produced on farm. This is possible by adding the below equation in the simulation:

$$y_{nr} x_{n,milk} - x_{nr} \leq 0 \ \forall n \ \forall r \quad (4)$$

where y_{nr} is the parameter of feed requirement per unit of milk for the farm *n* (*n*=1,…,*N*) and each fodder crop *r* (*r*=1,…,*R*); $x_{n,milk}$ is the variable associated with the production of milk on the n-th farm, and x_{nr} is variable for the production of fodder crops Each farm reemploys all the forage produced to feed the dairy cows. This means that the market price of fodder crops must be equal to 0, as the farm holder is not selling it. In this case, fodder includes: i) meadows and pastures; ii) alfalfa; iii) silage maize; iv) other forages.

As mentioned above, farms can exchange land according to specific agent-based constraints that trace a one-to-one relationship among all the farms included in the sample, in the sense that each farm has the option to rent or rent out land with the other farms, namely:

$$\sum_j \left(A_{nj} x_{nj} \right) \leq b_n + Z_n - V_n \quad \forall n \quad (5)$$

The constraint (5) requires that the total land allocated to the different crops *j* (*j*=1,…,*J*), $\sum_j \left(A_{nj} x_{nj} \right)$, (*j*=1,…,*J*) must be less than or equal to the observed total available land at farm level, b_n, plus the land rented, Z_n, and less the land leased, V_n. The land-exchange rules are designed based on the socio-economic characteristics of the farmers and on the assumption that the land price is the same for every farm and it is exogenously defined.

More specifically, the land rented

$$Z_n = \sum_m ZZ_{nm} \quad \forall n \quad (6)$$

and the land rented out

$$V_m = \sum_n VV_{nm} \quad \forall m \tag{7}$$

Where ZZ_{nm} and VV_{nm} are the matrix tracing the transfer of land for each pair of farms for rent and rent out, respectively. Furthermore, for each pair of farms, the land rented by one farm must be equal to the land leased by the other, as follows:

$$ZZ_{nm} - VV_{nm} = 0 \quad \forall n \forall m \tag{8}$$

To avoid a given farm rents and leases land at the same time, a specific constraint has been added:

$$Z_n V_n = 0 \quad \forall n \tag{9}$$

Finally, to ensure that the exchange of land is consistent with total available land at regional level, we establish that the total land rented must be equal to the total land leased:

$$\sum_n Z_n - \sum_n V_n = 0 \tag{10}$$

Therefore, we assume that the exchanges of land are limited to the farms belonging to the same region.

The behavioral rules used by the DF-ABM is based on the social profile of the farmer, defined for this study, simulates that farmers older than 65 years of age and with no successors are unlikely to rent additional land (Möhring et al. 2016). Renting out the entire property is assimilated to a farm withdrawal.

1. Data and Policies Scenarios

3.1 Sample analysis

The sample investigated is limited to farms located in the ER NUTS-2 region. It refers to the 2020 Italian FADN (RICA) observation that counts 710 farms. The technical-economic orientation and number of farms associated is depicted in Table 1. It is also reported the weighted number of farms, as RICA provides a sample weight for each farm to be representative of the whole universe. Farms having more than 1,000 ha have been then removed from the sample, as not statistically representative.

Farm's technical orientation	Sample	weighted sample
arable crops	310	15233.8
horticulture	8	410.9
permanent crops	160	9083.6
dairy cattle	91	3305.5
other herbivores	24	2307.6
granivores	30	677.5
polyculture	67	3370.5
mixed farming	2	32.6
mixed (crop-livestock)	18	918.8
total	710	35340.9

Table 1: Number of farms in the Emilia Romagna 2020 FADN by farm typology.

Figure 1 and **Errore. L'origine riferimento non è stata trovata.** depict the distribution of farms by altitude and by holders' age.

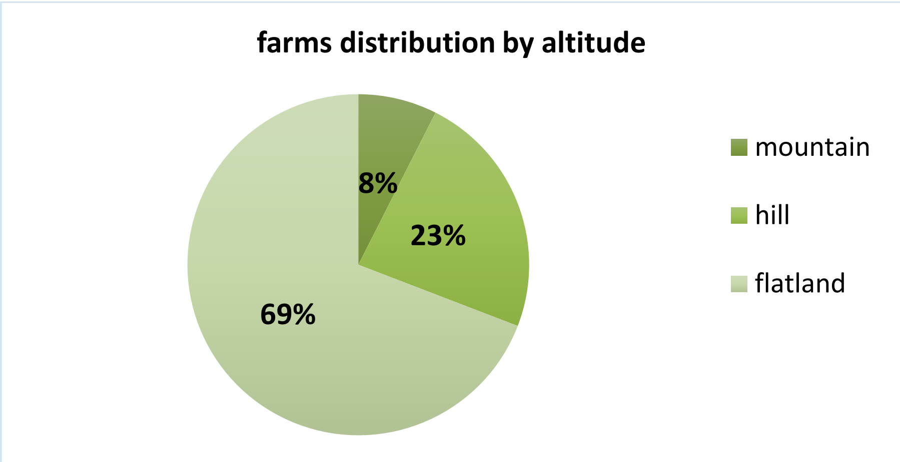

Figure 1. Farms distribution by altitude

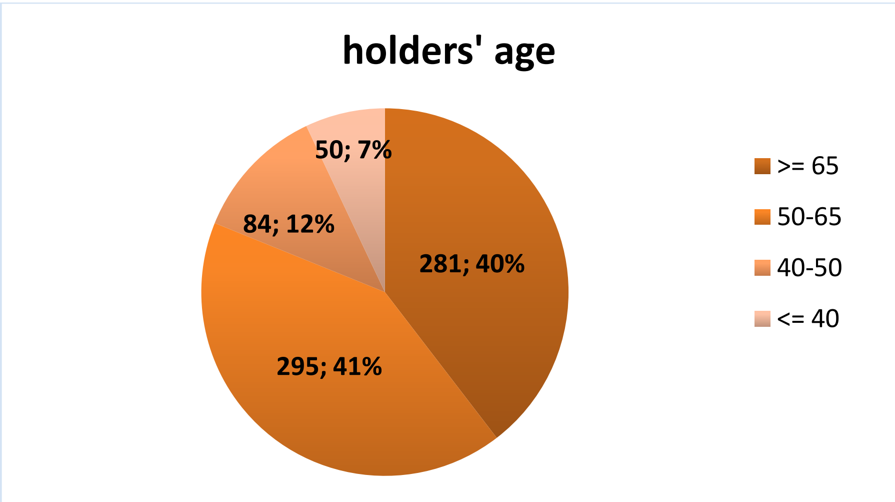

Figure 2: Farms distribution by holder's age.

In 2020, Emilia Romagna accounted for 11.4% of Livestock Units bred in Italy; more specifically 10% bovines, 12% swines, and 18 % poultry, representing 15.2% national animal production value (2,357.297 million €) (EUROSTAT 2020). Emilia Romagna produces also 16% of Italian milk: in 2020 deliveries of cow's milk stood at 2,029,257 tonnes and is the second region for milk production after Lombardia (44%). Cheese production is strongly rooted in the territory: 89.2% of the regional milk was allocated, in 2020, to the production of 140,000 tons of Parmigiano Reggiano, in the area between the Po and Reno rivers, while 325.700 tons of regional milk (0.016%) were used to produce 24,000 tons of Grana Padano (CLAL 2020).

The ER region is responsible for 10.4% of Italian livestock-related GHG emissions (2,059 thousand tonnes) and for 9 % of national ammonia emission (23,114.78 tons of NH_3) (Taurino et al. 2020).

3.2 Scenario description

To assess ex-ante the impacts generated from the introduction of a progressive carbon tax and quotas on nitrogen derived from bovine manure, as well as farmers' responses in changing their production plan and resources allocation, scenarios are configured in the DF-ABM-PMP model as follows.

The amount of CO_2eq emitted per ton of crop is calculated based on the estimated emissions per hectare or per LSU, using the ICAAI methodology (Impronta Carbonica dell'Azienda Agricola Italiana), developed by CREA-PB on the basis of t IPCC guidelines for establishing a national inventory of greenhouse gas emissions (IPCC 2008; Coderoni, Bonati, e Vanino 2013; Solazzo et al. 2016).

The model considers seven different scenarios.

The first scenario (s_land) give the possibility to exchange arable land by renting or renting out land as consequence of the possibility to determine an optimal use of farm resources. The cost for renting a hectare of arable land is set at 589 € by the Land Market Research of CREA-PB (2020). This setting is associate to the others five scenarios. This scenario is considered as baseline and provides the comparison term with the other six scenarios described below. By contrast, the situation observed at the time of calibration is represented by the scenario "s_cal".

Then four different taxes (20, 50, 100 e 150 €/tCO2eq) are applied, to estimate how this additional cost may influence the farmer production choices and his/her gross margin. Each taxation level corresponds to a different scenario, that are names respectively "s_em20", "s_em50", "s_em100" and "s_em150".

The last scenario, "s_nitrogen", simulate the right to spread manure according to the EU Nitrate Directive 91/676/CEE, which aims at reducing and preventing nitrates water pollution from agricultural sources. The Nitrate Directive requires member States to be responsible for identifying pollution sources, designating "Nitrate Vulnerable Zones" (NVZs) and designing appropriate action programs; moreover, it sets a limit of 170 kg of nitrogen from livestock manure that can be spread annually over one hectare.

The Directive is transposed by the Regional Regulation 15/12/2017 no.3, which identifies NVZs exclusively in the flatlands, and corresponding to the 29.6% of the ER agricultural land. We therefore consider the quantity of nitrogen produced by livestock for each farm, knowing the number of LSU, with a production 82.8 kg of N per dairy cow, and 36 kg of N per rebreeding cow, according to the Regional Regulation mentioned above.

Farm holders under the constraint of 170 kg of N/ha and based on (i) the quantity of nitrogen produced by their livestock and (ii) their Utilized Agricultural Area (UAA), can decide to either reduce the number of cows, or rent more land from non-livestock farms, to spread the exceeding manure.

Dairy farmers can acquire rights to pollute to spread the exceeding manure from non-livestock farms that need nitrogen fertilizers, paying a cost of 150 €/ha. In addition, distribution cost of exceeding manure is set to 69€/ton of nitrogen, based on the average price (80 €/hour) and capacity (4.5 tons of manure) of a manure tank, and the nitrogen content of dairy cow manure (0.42%). The economic convenience will drive the choice. Transportation cost is not considered, as farms are not geolocated within the FADN sample.

All the above scenarios include default policy measures of CAP 2023-2030 such as greening payment, single payment and crops coupled payment, funded through Pillar I, according to 2014-2020 CAP reform (MIPAAF, 2014). Moreover, it has been considered that farmers over 65 and no successors will receive a retirement pension of 1,000€/month,

Besides carbon emissions and nitrogen production, also water consumption is evaluated using water footprint data calculated by Hoekstra e Mekkonnen (Mekonnen e Hoekstra 2010).

4. Results

The exchange land scenario highlights how farmers opt for a more efficient combination of the limiting factor land. As described above, farmers can adopt a structural strategy renting out all their land and abandon the market or renting out just a part of their land and continue farming.

	Dairy farms		Other farms		Total	
Farm dimension	s_cal	s_land	s_cal	s_land	s_cal	s_land
<10 ha	**6**	**7**	**237**	**199**	**243**	**206**
10-20 ha	**11**	**15**	**125**	**115**	**136**	**130**
20-50 ha	**39**	**42**	**151**	**147**	**190**	**189**
50-100 ha	**26**	**20**	**67**	**71**	**93**	**91**
100-300 ha	**9**	**6**	**34**	**37**	**43**	**43**
> 300 ha	**0**	**0**	**5**	**4**	**5**	**4**
tot	**91**	**90**	**619**	**573**	**710**	**663**

Table 2: Number of farms and class of size.

The impact of these strategies in the number of farms is depicted in Table 2. Overall, with respect the observed scenario (s_cal), the number of farms decreases from 710 to 663 (-6.6%), with a bigger impact on the non-dairy farms (-7.4%) than on the dairy ones (-1.1%). The number of farms decreases mostly in size range <10 ha (-37 farms). This result demonstrates how the structural adaptation strategy leads farmers to find new forms of economic efficiency. Considering the land exchange scenario (s_land) as baseline, the assessment of the policies scenarios on all the farms shows a net effect on farms structure (Table 3).

Dairy farms	s_land	s_nitrogen	s_em20	s_em50	s_em100	s_em150
<10 ha	7	5	7	8	12	14
10-20 ha	15	19	18	14	16	10
20-50 ha	42	40	39	41	33	35
50-100 ha	20	20	20	19	23	23
100-300 ha	6	6	6	7	5	6
> 300 ha	0	0	0	0	0	0
TOT	90	90	90	89	89	88
Other farms	s_land	s_nitrogen	s_em20	s_em50	s_em100	s_em150
<10 ha	199	199	194	194	193	191
10-20 ha	115	115	116	116	117	115
20-50 ha	147	147	148	148	147	147
50-100 ha	71	71	71	71	70	70
100-300 ha	37	37	37	38	37	37
> 300 ha	4	4	4	3	5	5
TOT	573	573	570	570	569	565
all farms	663	663	660	659	658	653

Table 3: Number of farms per policy scenario and class of size.

Table 3 shows a constant decrease in the number of farms (dairy and non dairy), with 10 farms deciding to abandon the activities when the heaviest CO_2 tax ("s_em150") is introduced. The ones leaving the market are mainly non dairy farms, while in the dairy sector the impact is limited. The number of smaller dairy farms (<10 ha) increases, despite the introduction of the tax. This trend could be explained with the fact that as taxes rise, farmers rent out part of their land to cover their production costs, but still manage to remain in business. The introduction of the Nitrate Directive ("s_nitrogen") has no influence in the number of farms.

Table 4 depicts the influence of policy scenarios on farms' gross margin.

Regional Gross Margin	s_land	s_nitrogen	s_em20	s_em50	s_em100	s_em150
Million €	1050.0	1040.6	1005.1	944.74	860.31	788.36
% variation	-	-0.9	-4.3	-10.0	-18.1	-24.9
GM/ha	**s_land**	**s_nitrogen**	**s_em20**	**s_em50**	**s_em100**	**s_em150**
€/ha	1258	1246.9	1204.4	1132.0	1030.9	944.6

Table 4: Overall regional gross margin and gross margin per hectare.

Gross margin reduces slightly in scenario "s_nitrogen", but the reduction is substantial and increasing along with the with the tax increase (from -4.3% with a tax of 20 €/tCO_2eq, up to -24.9% in "s_em150").

UAA (1000 ha)	s_land	s_nitrogen	s_em20	s_em50	s_em100	s_em150
CEREALS	194.44	195.66	199.36	200.96	206.51	210.73
FORAGES	324.38	326.03	349.76	366.23	377.98	384.29
MAIZE /SILAGE	77.44	74.18	67.62	53.93	40.30	31.15
PROTEIC/OILSEEDS	61.15	61.50	64.54	64.40	64.38	64.73
MEADOWS PASTURES	66.93	66.86	65.97	64.79	64.77	64.75
OTHER	107.15	107.26	84.22	81.10	77.43	75.38
GREENING	3.06	3.06	3.08	3.15	3.18	3.53

Table 5: Land allocation by crop type.

Table 5 and Table 6describe farmers' production plan regarding land allocation and the variation considering "s_land" as baseline scenario.

% variation	s_nitrogen	s_em20	s_em50	s_em100	s_em150
CEREALS	0.6	2.5	3.4	6.2	8.4
FORAGES	0.5	7.8	12.9	16.5	18.5
MAIZE /SILAGE	-4.2	-12.7	-30.4	-48.0	-59.8
PROTEIC/OILSEEDS	0.6	5.5	5.3	5.3	5.9
MEADOWS PASTURES	-0.1	-1.4	-3.2	-3.2	-3.3
OTHER	0.1	-21.4	-24.3	-27.7	-29.7
GREENING	0.0	0.5	2.7	3.8	15.2

Table 6: Percentage variation in land allocation compared to s_land.

The introduction of taxation also generates a significant effect on the farms' productive organisation by modifying land use. The "s-nitrogen" scenario, while not affecting the number of farms, modifies the production organisation by reducing the area allocated to silage for cows outside the Parmigiano Reggiano PDO area. On the other hand, the scenarios that foresee increasing taxation pushes farms towards a more extensive management of crops with less environmental impact. In fact, the most penalized crops by taxation are maize-silage and industrial crops (others), which are reduced by 60% and 30% respectively. Conversely, these crops would be replaced by fodder crops (+18.5%), cereals (+8.4%) and set-aside (+15.2%).

All the policy scenarios introduced shown a decrease in the number of dairy cows (Table 6). The decrease is due to the introduction of nitrogen pollution quotas in "s_nitrogen", both to the introduction of CO_2 taxation that impacts on GHG emissions associated to milk production.

LIVESTOCK UNTS	s_land	s_nitrogen	s_em20	s_em50	s_em100	s_em150
n. of dairy cows	228130	209050	202020	158510	109120	77914
% variation	-	-8.4	-11.4	-30.5	-52.2	-65.8

Table 6. Variation in number of dairy cows

Table 7 and Table 8 show variation in carbon emission

CO2 EMISSION (1000 tCO2eq)	s_land	s_nitrogen	s_em20	s_em50	s_em100	s_em150
CEREALS	334.6	337.8	326.0	318.7	313.4	305.5
FORAGES	164.9	165.9	180.7	189.2	195.4	198.4
MAIZE /SILAGE	227.4	217.3	194.5	156.2	113.9	85.4
PROTEIC/OILSEEDS	52.7	52.9	54.8	54.4	54.2	54.5
MEADOWS PASTURES	149.9	149.7	147.8	145.1	145.1	145.0
OTHER	175.0	173.5	138.5	132.1	124.9	121.2
DAIRY COWS	1254.7	1149.8	1111.1	871.8	600.2	428.5
TOTAL	**2359.3**	**2246.9**	**2153.5**	**1867.5**	**1547.0**	**1338.6**

Table 7. Carbon emissions in thousand tons of CO2equvalent

% variation	s_nitrogen	s_em20	s_em50	s_em100	s_em150
CEREALS	0.9	-2.6	-4.8	-6.4	-8.7
FORAGES	0.6	9.6	14.8	18.5	20.3
MAIZE /SILAGE	-4.5	-14.5	-31.3	-49.9	-62.4
PROTEIC/OILSEEDS	0.4	4.0	3.2	2.8	3.4
MEADOWS PASTURES	-0.1	-1.4	-3.2	-3.2	-3.3
OTHER	-0.9	-20.8	-24.5	-28.6	-30.7
DAIRY COWS	-8.4	-11.4	-30.5	-52.2	-65.8
TOT	**-4.8**	**-8.7**	**-20.8**	**-34.4**	**-43.3**

Table 8. Percentage variation in carbon emission compared to s_land

Compared to s_land, in s_nitrogen carbon emissions decrease by -4.8%. The products most impacted are dairy milk (-8.4%) and maize/silage (-4.5%). Emissions related to cereals e forages slightly increase.
In the CO_2 taxation scenarios, overall CO_2 emissions drop down respectively by -8.7%, -20.8%; -34.4% and -43.3%. Decreasing in dairy products, maize and silage, other crops and cereals. Forages emission increases.

5. Discussion and conclusion

The environmental policy tools, developed through the post 2020 reform, represent a new phase of the European Common Agricultural policy. The need for models capable of assessing policies' goals ex-ante by simulating agents' behaviors based on their socio-economic characteristics and their relationship with the geographical context becomes a must. These micro-based farm models can evaluate price-cost market dynamics, farmers' aptitude to change production plans under economic, market, technological and environmental scenarios, as well as the ability of farmers to deal with critical environmental variables.
Supply-side farm models, while accurately representing the entrepreneur's strategies, have the limitation of assuming the farm as a "close" production system whose decisions consider only the available production resources. In the real word, farmers exchange production factors, in particular land, as possible strategy to adapt to changes in their marginal value. The effect is that some entrepreneurs rent-out land to more productive farmers who instead expand their activity by pursuing economies of scale and scope. Thus, the assessment of the CAP's impact on the environment must use new analytical tools capable of capturing the interactions between farmers, and the interaction between farmers and the surrounding socio-economic and natural environment. ABMs proved to be particularly effective in this context, also because they allow researchers to consider specific social farms households' attributes.
The repercussion of CO_2 taxation on farms' structure and rural regions, reveled through the use of agent-based models, is significant. If output prices are assumed to remain unvaried, CO_2 taxation will impact the most polluting processes (intensive crops and dairy cows) and the more intensive farms that will then opt for new production strategies to become more environmentally sustainable. Increased environmental sustainability is due to (i) reduced soil pressure (fewer animals per hectare), (ii) use of more sustainable fodder and (iii) the possibility of redistributing nitrate quotas to non-livestock farms. However, the possibility of exchanging land favours the most efficient farms, which increase their size at detriment of inefficient farms, with consequent economic and social impact.
The Emilia Romagna case is emblematic as wealth and welfare, generated by PDO cheeses such as Parmigiano Reggiano, led over time to increasing environmental pollution and creeping structural reform pushing small scale farms to leave the market. While environmental pollution can be countered with targeted policies, such as effluent taxation, the effect on the socio-

economic structure requires the use of more complex set of interventions that the Rural Development Plan must address.

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