How Milk Quotas and the CAP Affect GI Systems: The Case of Parmigiano Reggiano PDO

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Abstract

This article investigates the application of the milk quota system to Geographical Indications (GIs), using the Parmigiano Reggiano PDO cheese as a case study. Firstly, an overview on the empirical context focuses on the evolution of cheese production under the rules set by the GI-Group. Afterwards, an ex-ante analysis evaluates the impacts of the milk quota rules under the CAP 2023-2030 scheme on the Parmigiano Reggiano PDO production system. The latter assessment is addressed through an Agent-Based Model based on the Positive Mathematical Programming approach. The results indicate that the quota system leads to a concentration of production in larger dairy farms, with environmental and social effects that negatively impact the sustainable rural development model advocated by the Common Agricultural Policy.

Keywords: Agent-Based Modeling, Positive Mathematical Programming, Agricultural policy, Milk Quota, Geographical Indication

JEL Codes: Q12, R11, R58

1 Introduction

In 1984, the European Union (EU) introduced the milk quotas regime to curb the overproduction of milk, which had placed a large financial strain on the European Agricultural Guarantee Fund (Petit, 1987). This policy represented one of the most controversial decisions in the Common Agricultural Policy (CAP 2023-2030), and it has contributed to justify the later reforms (Barbero et al., 1984; Oskam et al., 2010). EU milk quotas were gradually loosened until their final abolishment starting from April 1, 2015, in order to give farmers a higher flexibility in responding to the growing demand for milk and dairy products in the European market (Jongeneel et al., 2023). This policy decision made the EU dairy sector more competitive by increasing exports, but it also introduced additional volatility in milk prices and, consequently, in farmers' incomes. However, this provision didn't completely eliminate production quotas, but a new scheme tailored to Geographical Indication (GI) production groups was created instead. More precisely, for GI dairy products (e.g. Parmigiano Reggiano, Comté, Roquefort) there was no continuation of the old EU quotas, but many GI Groups and Producer Organizations introduced their own private or collective supply management rules (sometimes called self-regulation or consortium-based production controls). Differently from the old centralized system, these schemes constitute consortium-agreed market regulation measures or planning mechanisms to balance supply with demand, maintain quality, and stabilize prices.

This article aims to offer a novel contribute to the existing literature by addressing milk quotas under the modified policy framework concerning GI products, specifically with reference to the Parmigiano Reggiano (PR) PDO cheese value chain, which was chosen because of its high economic relevance at regional level (the area of production represents 18% of all the milk produced in Italy (CLAL, 2025a)) and the availability of rich and updated data. The importance of this type of case study is supported by Donati et al. (2020), who demonstrated that GI products make a significantly higher contribution to the local economy compared to their standard counterparts.

The assessment of the quota policy is elaborated by employing an Agent-Based modelling approach which allows to evaluate comprehensively the three dimensions of sustainability: i) the economic performance, assessed through the gross margin generation, ii) the social impacts (referred to the effects on less profitable activities, *i.e.* the structural changes in the production system), and iii) the environmental outcomes in terms of greenhouse gases emissions. The objective is to answer to the following research question: how do milk quotas affect the sustainability of the PR PDO rural system? Different simulation scenarios will be compared to assess whether the scheme has positive or negative impacts and to identify potential trade-offs across the aforementioned dimensions. To make the analysis closer to reality, it also includes one of the CAP 2023-2030 greening measures, so that the results will account for environmental constraints and European subsidies too, likewise in the real market, where farmers not only must respect the rules established by their own GI Consortium with regard to inputs and processes, but they are also subject to the greening constraints that affect productive structures, costs, and revenues.

The paper is structured as follows: Section 2 focuses on the legislative background and relevant literature, and the description of the evolution of the PR PDO quota system according to the rules of the PR-GI Group. Section 3 describes the methodology of the Agent-Based model. Section 4 presents the results, while Section 5 discusses them and draws the conclusions of the study.

2 Contextual Background

2.1 The Legislative Framework

The removal of milk quotas was performed gradually to avoid market setbacks. A significant milestone is represented by the Regulation (EU) 261/2012 on contractual relationships in the milk and dairy sector, that sought to prepare the dairy market for the new context following the CAP 2023-2030 shift from the enforcement of direct market instruments to indirect interventions with the objective of stabilizing agricultural prices and ensuring stable incomes for farmers (Pieri and Rama, 2017; Chiodini, 2016). Specifically, the abolishment of milk quotas in 2015 was first announced in the Regulation (EU) 72/2009, whereas Regulation 8, which at the same time deferred a discussion on the consequences of this decision for PDO cheese producers (Art. 4, Amendment 36 to Regulation (EC) 1234/2007). The Regulation (EU) 261/2012, Article 17, stated that Member States should be authorized to establish production control measures for GI cheeses, because of their importance (especially for vulnerable areas) and to guarantee their quality and value added. The Italian Government applied this provision through the Decree of 12 October 2012 (Art. 5, par. 1), which recognizes the GI Producer Groups' Authority to regulate their cheese supply and establish the procedures and conditions for submitting production control plans.

After these reforms, the current EU no longer enforces quotas on milk and dairy products, thus granting

Producers Organizations (POs), Interbranch Organizations (IOs), and other groups (as defined under the Regulation (EU) 1151/2012) the freedom to autonomously regulate production based on their specific performances and characteristics. The Regulation (EU) 261/2012 was issued in connection with the Regulation (EU) 1151/2012 (repealed by the Regulation (EU) 1143/2024), establishing the GI system (Protected Designation of Origin, Protected Geographical Indication, and Traditional Specialty Guaranteed, commonly referred to as PDOs, PGIs, and TSGs) to ensure fair remuneration for producers, consistent protection of product names across the EU, and clear consumer information regarding the characteristics that enhance the value of GI products (Regulation (EU) 1151/2012, Art. 4). The latter Regulation also defined POs and IOs as entities responsible for ensuring product quality, reputation, and legal protection, as well as promoting value-added attributes (Regulation (EU) 1151/2012, Art. 45). However, the innovative provisions of this policy framework, intended to enhance market efficiency, appeared to be incomplete as they did not permit all GIs to adjust supply in response to changing market demand. Notably, only GIs in dairy, fruit, and vegetable sectors were authorized to manage production volumes (Regulations (EU) 261/2012 and (EC) 1234/2007). Only recently, the Regulation (EU) 1143/2024 expanded this right to almost all food products recognized as GIs (Art. 33, par. 3, let. c).

Such regulatory framework causes the coexistence of two parallel production systems: the non-GI market, where milk is traded without constraints, and the GI market, where it can be indirectly regulated by imposing a threshold on the final product volumes. In other words, the aforementioned evolution finally led to a surreptitious reintroduction of the abolished system of milk quotas, which is intended to secure higher prices for producers, but that also establishes a system of asset capitalization in milk production, thus transforming it into an exclusive right that generates barriers to entry and rent-seeking effects. However, unlike the previous quotas regime, the current policy is markedly different as each GI Group can adopt a tailored scheme for the governed PDO/PGI. Regarding the Italian context, the two most reputable "PDO grana cheeses" (Parmigiano Reggiano and Grana Padano PDO) have two different quota systems: the rules of Parmigiano Reggiano PDO assign the milk quotas to farmers in the form of milk volumes (tons), while the rules for Grana

Padano PDO assign the quotas to dairies in the number of cheese wheels (Dongo, 2022; PRG, 2014). As highlighted by Pieri and Rama (2017) and Carletti and Giangiulio (1998), the system governing the allocation of production rights exhibited rent-seeking dynamics that facilitated the concentration of milk production among larger farms, with significant implications for both rural development and farm management. In terms of rural development, the monetization of quotas by farmers who exited the sector altered the regional development trajectory by removing smaller producers from the supply chain. From a farm management perspective, the consolidation of production among remaining dairy farms often necessitated the assumption of debt, thereby exacerbating financial and operational pressures. This, in turn, undermined the competitiveness and resilience of these farms. The Parmigiano Reggiano Cheese Consortium indicates a growing proportion of farms experiencing economic losses between 2019 and 2023, a trend partly attributable to the inherent complexity of implementing effective management control systems in agriculture, which constrains operational efficiency (Campiotti, 2024).

2.2 Impacts of milk quotas in Europe: evidence from the literature

There is an extensive stream of literature analyzing the effects of milk quotas both at national and regional levels in the EU context, but it only addresses the old European regime, especially regarding the potential implications of its abolition. Before delving into the discussion, it is essential to emphasize that the present study will refer to two distinct types of "efficiency": i) economic efficiency (or profitability), which is the ability to maximize profits and thereby generate a higher gross margin, and ii) productive efficiency (or productivity), understood as the ability to produce a greater amount of output given the same input level.

With respect to the policy outcomes, the article by Corbett (1992) argues that the quota scheme discouraged production efficiency and competitiveness, led to market polarization (large producers becoming larger and small farms increasing in number), and caused a stagnation of the dairy industry across the whole European level. However, Baldock et al. (2008) highlighted how milk quotas had a positive impact on maintaining production in Italian Less Favored Areas (LFAs), primarily through the redistribution of unused quotas, thus mitigating the ongoing phenomenon of concentration of production from mountainous LFAs to more profitable farms (registered from 1995 to 2004); this came with positive environmental effects, as the maintenance of agricultural activities in less productive, marginal regions is essential for the preservation of soil, biodiversity, and landscape.

Regarding the scenarios of quotas abolition, Lips and Rieder (2005) estimated how milk output and price would have changed in the EU at the country level. In particular, it was found through a Computable General Equilibrium model that raw milk prices decreased on average by 22% and those of dairy products by 12.6%, in response to modest average output increases of 2.9% and 1.8%, respectively. This led to the conclusion that the removal of quotas would have overall minor effects on the European milk production, even though the output changes are heterogeneous for each country. Baptiste et al. (2012), using a bioeconomic model based on Positive Mathematical Programming, found that, without quotas, milk production in Western France is expected to increase and to concentrate in more competitive regions, thus altering the geographical distribution of supply. The predictions presented in the study by Markus et al. (2011) for the removal of quotas, made through the CAPRI model, indicate an overall increase in milk production by 4.4% and a reduction in price by 1.6%, while agricultural income is expected to register a total loss of 2% (nearly 4.7 billion €). As dairy herds are simulated to increase, nitrogen emissions are estimated to grow accordingly, even though the increase is relatively moderate (0.66-1.41%). On the other hand, no considerable changes in arable land use were found. Boere et al. (2015) focused on farm dynamics in terms of land use changes in the Netherlands. Their results show that quotas hamper land expansion for milk production, which becomes faster towards the time period in which they are removed, while land decreases are faster in the presence of quotas because they can be sold (thus making it easier for farms to exit dairy farming). Moreover, the model adds to the analysis various socio-economic characteristics of farm holders: a higher education is correlated with more substantial marginal changes in both increases and decreases of land, having successors makes land expansion faster and its reduction slower, full-time labor involvement reduces land changes, and older farm operators are less inclined to alter land use too. More recently, Philippidis and Waschik (2019) applied the monopolistic Melitz model to simulate the changes in the EU milk market from 2020 to 2030 in two scenarios: the baseline, where quotas remain, and the abolition case. The authors found that in the baseline, under the hypothesis of perfect competition, milk prices are expected to increase on average by 31.9 index points by 2030, and dairy prices, due to price transmission effects, by 11.5 index points; meanwhile, downstream dairy production remains static. When quotas are removed, both milk and dairy prices fall (respectively by 39.1 and 10.9 index points) while production volumes grow (more or less markedly depending on the country). An imperfect competition experiment reveals similar results, but it gives additional information about the supply-chain structure, where a "shake-out" of small farms occur as production concentrates into fewer, larger farms. Madau et al. (2017) and Bórawski et al. (2020) found that the removal of milk quotas fostered the expansion of production, higher efficiency in the use of inputs, and an increase of milk yields. The same phenomenon was confirmed by Náglova et al. (2021), who presented several cases in Northern Europe where the abolition of quotas was correlated with greater milk productive efficiency; notably, EU milk production grew steadily between 2014 and 2018, while experiencing a reduction of about 900,000 cows in 22 EU countries (particularly in Germany, France, and Italy). From the environmental point of view, Läpple et al. (2022) found that the absence of milk quotas promotes increased greenhouse gases (GHG) and nitrogen emissions, exacerbating environmental degradation and contributing to climate change; conversely, quotas can help limit GHG emissions but may lead to the concentration of nitrate production on larger farms.

2.3 The evolution of the milk quotas system for Parmigiano Reggiano PDO

The area of production established by the Product Specification of the Parmigiano Reggiano PDO Group (PRG), considered in this analysis, is strictly limited to the provinces (NUTS 3 level) of Parma, Reggio-Emilia, Modena, Bologna, and Mantua (PRG, 2025a); specifically, milk, cows, and feed must all originate in these areas and respect specific quality criteria. The regulation of milk production by a quota system was first introduced in 2014 to align milk supply and demand, ensuring that overproduction did not result in price reductions, thus destabilizing farmers' incomes. Other objectives, aligned with the Regulation (EU) 1308/2013, include the support to vulnerable areas, quality assurance, and the strengthening of producers' bargaining power (PRG, 2014). The PRG effectively maintained the milk price above that in the non-GI market (Figure 1). The PR Production Plan (PRG, 2014) defines the supply control mechanisms: at the start of every year, the PRG determines a total equilibrium production level and assigns each farmer a milk quota proportional to its production capacity. Milk produced beyond this quota does not lose its suitability for transformation into PR cheese. Still, if at the end of the year the total amount of cheese produced exceeds the equilibrium level, farmers will have to pay an additional contribution proportional to the amount by which they exceeded their quotas. More precisely, this policy is not directly applied to farmers but indirectly, as the contribution is levied on dairies, which then apportion it among farmers who supplied them with milk, based on each farmer's surplus production.

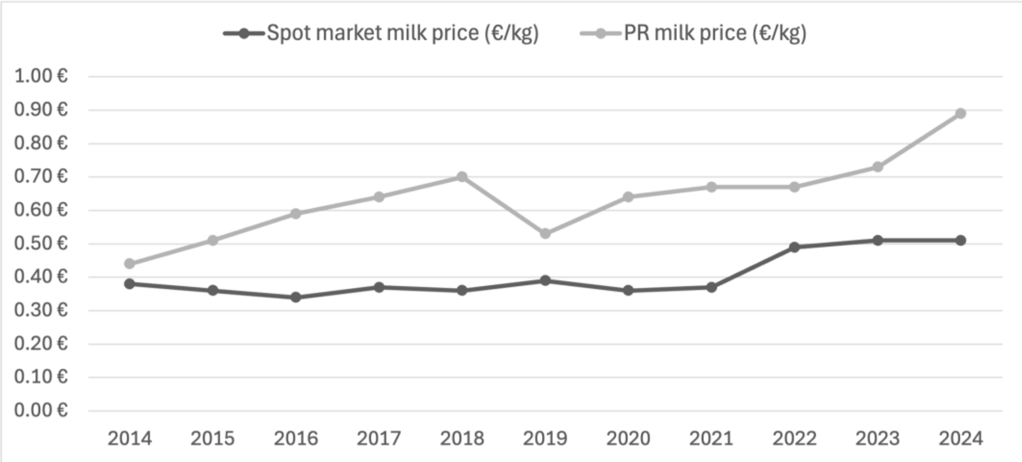

Figure 1: Comparison of milk prices.
Source: own elaboration on CLAL (2025b) and CLAL (2025c).

As a last remark, the Production Plan defines quotas as "intangible assets", meaning that they can also be sold or rented to other farmers; to safeguard farmers producing in LFAs, the quotas located in mountain areas cannot be bought by farmers in plain or hill areas, and vice versa. Moreover, a discount on additional contributions is applied for mountain farms. The cheese equilibrium level, the quantity of assigned quotas, and the amount of extra contributions are revised every year based on market conditions.

Detailed information on the characteristics of farmers supplying milk for PR cheese production is provided in Appendix A. At the macro level, PR cheese production steadily grew from 3,298,000 wheels in 2014 to 4,079,000 in 2024, at an average annual rate of 1.6% (CLAL, 2025a). Conversely, active farms decreased from 3,186 in 2014 to 2,606 in 2020, with a 27% reduction in farms below 800 tons/year of production and a 19% increase in farms above 800 tons/year (PRG, 2022). According to Deserti and Bertolini (2021), this occurred because elderly farmers were unable to keep up with innovations and closed their operations, with the allocation of milk quotas accelerating this trend. Indeed, quotas were transferred from minor to more extensive, competitive dairy farms. In particular, Bertolini and Giovannetti (2020) explained how farmers' innovations increased milk protein content, resulting in better curdling yield, as between 2015 and 2018, the milk needed to produce one cheese wheel was reduced by 5.4%. While a single cow produced, on average, 14 forms/year in 2005, production per cow had increased to 18.5 forms/year by 2021 (PRG, 2023). The quota scheme has a substantial impact, as the production threshold has been exceeded increasingly over the years, thereby burdening farmers with growing contributions to be paid (Figure 2). Moreover, while the additional contribution for surplus production increased, the volumes of exchanged quotas decreased over the years (Figure 3).

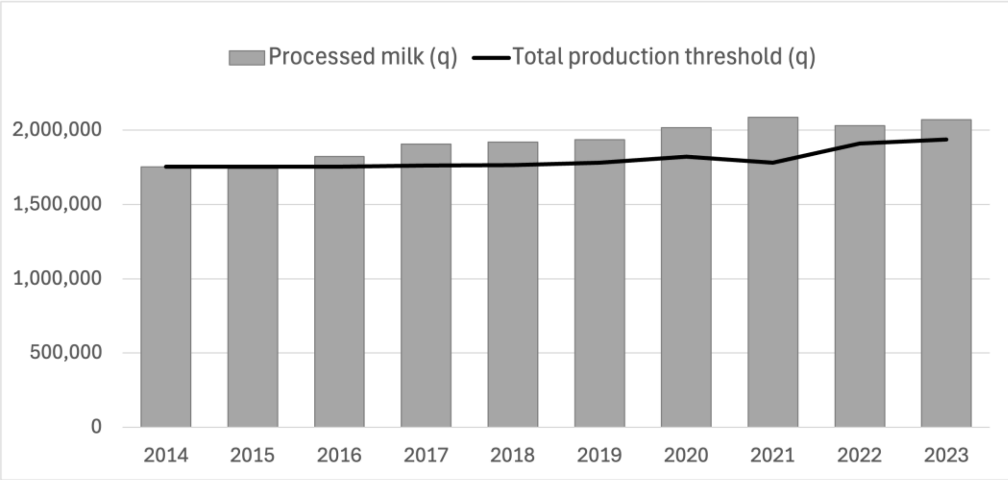

Figure 2: Comparison between milk transformed into PR cheese and the production threshold.
Source: own elaboration on CLAL (2025a) and PRG annual production updates (PRG, 2025b).

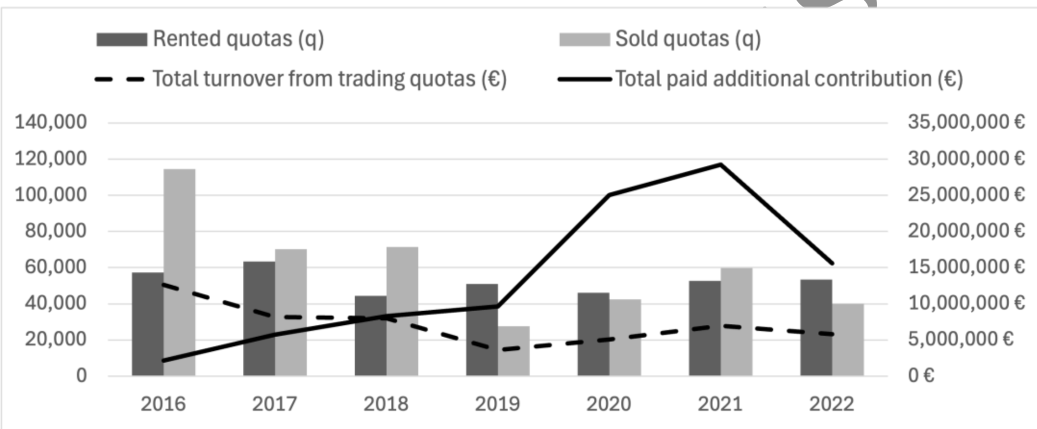

Figure 3: Traded milk quotas and total turnover.
Source: own elaboration on PRG (2025b).

Finally, the elasticity of produced milk with respect to the assigned quotas is almost unitary. In contrast, the price elasticity is lower, suggesting that farmers adjust production more reactively to quotas than to price (Table 1).

Year	Total milk ('000 q)	Total quotas ('000 q)	$\Delta milk/\Delta quotas$	$\Delta milk/\Delta price$
2016	1,823.1	1,824.1	-	-
2017	1,907.1	1,835.5	1.01	0.61
2018	1,919.9	1,843.9	0.97	0.07
2019	1,937.2	1,863.6	0.97	0.04
2020	2,017.4	1,876.2	0.97	0.19
2021	2,086.5	1,899.8	0.94	0.60
2022	2,031.2	1,921.9	0.92	0.49
2023	2,071.4	1,930.0	0.95	0.95

Table 1: Elasticity of processed milk to assigned quotas and to milk price.
Source: own elaboration on CLAL (2025a) and PRG annual production updates (PRG, 2025b).

In summary, the quota scheme has contributed to the renewal of the PR system by concentrating production towards farms with higher capacity and productivity, which represents a relevant structural change in the supply chain. This process occurred despite quota purchases (or leases) and contribution payments, which certainly had an impact on the economic and financial management of farms. Although quotas are not binding, resulting in milk production consistently exceeding the equilibrium threshold, the price guarantee associated with them, coupled with the PRG promotional activity, allowed PR producers to invest in their businesses.

3 The ex-ante assessment of the milk quota system

To address the research questions stated in Section 1, the study enhances the farm-based model AGRISP (*Agricultural Regional Integrated Simulation Package*) to analyze the following aspects: i) how trading quotas impact farmers' economic performance, ii) to what extent this policy favors or hampers marginal farms, and iii) what are the environmental effects in terms of CO_2 emissions.

3.1 Data

The sample counts 79 farms covering the PR cheese production area, extracted from the national Italian 2023 FADN-RICA database and restricted to those specialized in milk production (identified by the farm-type code "450"). Further details on the dataset are provided in Table 2. The FADN database, through the RICA at the Italian level, provides data at the individual farm level including detailed information on land utilization, subsidies paid to farmers, crops prices, and family structure of farms.

Province	< 10 ha	11 - 20 ha	21 - 50 ha	51 - 100 ha	Total
Parma	7	6	4	1	18
Bologna	2	0	1	0	3
Modena	1	2	7	1	11
Reggio-Emilia	5	4	10	0	19
Mantua	8	9	10	1	28
Total	23	21	32	3	79

Table 2: Structure of the sample: # of dairy farms.

Source: RICA database (2023).

It is assumed that farmers maximize their gross margin (GM) subject to constraints related to environmental practices and production quotas, as described in the next paragraph. A comparative statics approach is used: different equilibrium points are compared based on data from a single year and that all agents are simulated simultaneously. In particular, the granularity of the data allows to simulate the exchange of quotas and land, as less efficient farms in terms of GM transfer their quotas to more efficient agents, consequently also changing their sizes (if production levels decrease, the non-utilized land will also be transferred). While economic and sociodemographic data can be directly extracted from the RICA for each farm, additional metrics to measure the emission levels and estimate environmental outcomes are needed. Specifically, nitrogen emissions produced by cows are based on data provided by the national Regulation 15/12/2017 of the Emilia-Romagna Region, which considers 82.8 kg of NO_2 (nitrogen dioxide) per dairy cow and 36.0 kg of NO_2 per rebreeding cow. The amount of emitted CO_2 (carbon dioxide) is also computed for each activity by following the IPCC (Intergovernmental Panel on Climate Change) guidelines (IPCC, 2008; Solazzo et al., 2016); the respective values per hectare of production are showed in Table 3.

3.2 The Model

AGRISP is an Agent-Based Model (ABM) based on Positive Mathematical Programming (PMP), built in GAMS (*General Algebraic Modeling System*)[3], introduced by Arfini et al. (2005) and further developed over the years to include a more detailed representation of farm relationships (Arfini et al., 2008; Gigante et al., 2014), environmental metrics, including CO_2 emissions and water consumption (Donati et al., 2013), and policy scenarios, such as the CAP 2023-2030 greening measures (Solazzo et al., 2014; Baldi et al., 2024).

[3]GAMS is a software used for mathematical programming capable of solving large-scale linear, nonlinear, and mixed-integer optimization problems through computer code.

Cereals		Animal feed		Industrial crops		Dairy milk	
durum wheat	1.33	alfalfa	0.50	beetroot	1.45	milk	5.50
soft wheat	1.55	protein crops	1.04	potato	2.27		
sorghum	1.33	pastures	2.24	tomato	2.24		
rice	8.50	other forages	0.67	soja	0.81		
barley	0.99			oleaginous	0.82		
other cereals	1.33			sunflower	0.82		
				maize	3.52		
				vegetables	2.21		

Table 3: Tons of CO_2 emissions per hectare.

Source: own computations on IPCC guidelines and FADN data, as in Baldi et al. (2023).

The approach underlying the AGRISP model is based on the three elements listed here:

1. development of individual cost functions to address farmers' heterogeneity;
2. calibration for each farm reproducing their observed activity levels using the so called "self-selection", a rule representing the agents' willingness to adopt the activities that satisfy their strategy while being aware of all those available (Paris and Arfini, 2000);
3. introduction of ABM rules to simulate the exchange of resources (here the production quotas) by using the common cost function matrix, which provides farmers with the information on those activities not included in their production plan but that could be adopted.

The general objective function to be maximized is defined as follows:

$$\max_{GM} = \sum_j \left(p_{n,j} x_{n,j}\right) - \frac{1}{2} \sum_j \left(x'_{n,j} \hat{Q}_{n,j} x_{n,j} + \hat{u}_{n,j} x_{n,j}\right) \tag{1}$$

subject to:

$$A_n X_n \leq b_n \tag{2}$$

where p represents the market prices for each activity j and farm n, and x is the vector of production levels. Q constitutes the non-linear part of the PMP equation; it is a symmetric positive semi-definite matrix, ensured through the Cholesky factorization, while u is the vector of marginal cost deviations per farm with respect to the frontier cost function Qx. In equation 2, A is the matrix of technical coefficients of limiting production factors (here constituted by land), and b is the vector of their availability. A limitation of the model lies in the $x'Qx$ matrix as, due to computational constraints, the many activities practiced by the agents have to be aggregated into macro-categories (for instance, single crop species are grouped into broader classifications such as "cereals", "oilseeds", and so on); while this reduces the dimensions of the matrix, it may slightly hamper the model accuracy.

Two groups of constraints (equations 3-4, where λ is the vector of differential marginal costs) are introduced to implement the 'self-selection' process, providing the necessary structure to represent farmers' production decisions. This mechanism not only enables the model to distinguish between activated and non-activated practices, but also extends beyond basic PMP by allowing the simulation of farmers' potential access to all available production activities and their choice of those that are most economically convenient from the full set of available options.

$$mc_{n,k}/x_k > 0 : \bar{\lambda}_{n,k} + \bar{c}_{n,k} = Q_k x_n + u_{n,k}\ ,\ k = 1, \ldots, j_n \tag{3}$$

$$mc_{n,k}/x_k = 0 : \bar{\lambda}_k + \bar{c}_k \leq Q_k x_n + u_{n,k}\ ,\ k = 1, \ldots, j - j_n. \tag{4}$$

The first constraint (equation 3) implies that realized productions have a marginal cost (mc) equal to that of all the existing productions j across the frontier. The second one (equation 4) regards the estimation for non-activated productions, based on the relation $mc(x) \equiv \bar{\lambda} + \bar{c} = Q\bar{x}$, where the common element of the cost function for all farms is obtained from the average marginal cost observed in the sample (Arfini et al., 2005). The parameters of the costs matrix Q are estimated through the Maximum Entropy approach, which consists in maximizing the level of uncertainty relative to the probability distribution of each element of the matrix, as explained in detailed in Paris and Howitt (1998). Differently from other methods, like the Least Squares, the Maximum Entropy can be used when variable costs are known - as in this case - and is more consistent with the "inertia" characterizing economic decisions in agricultural businesses (Paris and Howitt, 1998). The ABM is strongly based on this estimation, as the willingness of agents to exchange resources among them depends on their specific marginal costs.

In AGRISP, dairy production relies on the following assumptions: i) milk price covers the costs of production (equation 5) and ii) the livestock is linked to the available land through the produced fodder crops (equation 6, where y is the feed required per unit of milk).

$$p_{n,milk}x_{n,milk} \leq c_{n,milk}x_{n,milk} \tag{5}$$

$$y_{n,fodder}x_{n,milk} - x_{n,fodder} \leq 0 \tag{6}$$

The market price for fodder crops is set equal to 0 as it is assumed that farmers do not sell it, but reuse it entirely for milk production; feed includes pastures, alfalfa, and other forages, while silage maize is excluded as it is prohibited from the PR cheese product specification (PRG, 2025a).

To regulate the mechanisms of quota exchange, the following ABM constraints are developed in GAMS. Firstly, each farmer has the option to either sell or buy production quotas but, as established in the PR Production Plan to protect activities in marginal areas (PRG, 2014), only farmers in the same agrarian regions can interact among them (*i.e.*, quotas in mountain areas cannot be sold to plain and hill areas, and vice-versa). The price of quotas is exogenous and fixed at the average level observed in 2022, which is equal to 130 €/ton (PRG, 2025b). In particular:

$$\sum_{j} x_{n,milk} \leq \bar{x}_{n,milk} + Z_n - V_n \qquad \forall n \tag{7}$$

$$\sum_{n} Z_n - \sum_{n} V_n = 0 \qquad \forall n \tag{8}$$

where it is ensured that the total produced milk ($\sum x_{n,milk}$) does not exceed the initial level of production $\bar{x}$ plus the rented quotas Z_n and minus the sold quotas V_n. Equation 8 ensures that the exchange of quotas is consistent with the available level. To avoid that farmers sell and buy quotas at the same time, the following control point for each agent is introduced:

$$Z_n V_n = 0 \tag{9}$$

meaning that either Z_n, V_n, or both must be equal to zero for each farm, and therefore situations where both have values different from 0 are avoided. Finally, the following constraints are introduced to trace transfers for each pair of farms:

$$Z_n = \sum_{m} ZZ_{n,m} \qquad \forall n \tag{10}$$

$$V_m = \sum_n VV_{n,m} \qquad \forall m \tag{11}$$

$$ZZ_{n,m} - VV_{n,m} = 0 \qquad \forall n \forall m \tag{12}$$

where $ZZ_{n,m}$ and $VV_{n,m}$ are the matrices for pairs of farms n and m respectively buying and selling quotas. Specifically, equation 12 ensures that the quotas bought buy one farm are equal to those sold by the other farm. Finally, it is assumed that farmers older than 65 and with no successors do not participate in the trading of quotas and receive a pension equal to 12,000 €. In fact, it is reasonable to assume that older conductors with no future perspectives for their activity would be less inclined to make investments and significantly change the structure of their farm; this tendency is also confirmed by the analysis of Boere et al. (2015) (Section 2). When a farm reduces its production or exits the market (because production levels become zero), its land has to be transferred to another farm in order to keep the total UAA constant in the model. Consequently, constraints analogous to those written for milk quotas are also imposed on the land factor to enable its exchange among agents (Baldi et al., 2023). This relationship is represented as:

$$\sum_j (A_{n,j} x_{n,j}) \leq b_n + R_n - T_n \qquad \forall n \tag{13}$$

where R and T are respectively the transferred and acquired hectares of land by each farm, subject to the same control points and behavioral rules as those listed above for quotas. Unlike the quota-related constraints, which are activated only in the scenario simulating the scheme, the land-related ones remain active across all scenarios.

3.2.1 Environmental constraints

In addition to the previous behavioral constraints, also environmental aspects are included in the model. The CAP 2023-2030 greening measures, more specifically the GAEC 7, aims at maintaining soil fertility and biodiversity by encouraging farmers to rotate different crops. In AGRISP, this standard is implemented through requirements on crop diversification and crop rotation on arable land (European Commission, 2013). Crop diversification is developed as follows:

$$S_{n,j} \leq 0.75A \tag{14}$$

$$S_{n,j} + T_{n,j} \leq 0.95A \tag{15}$$

where S is the main crop, which cannot occupy more than 75% of the utilized land if the farm owns more than 10 ha of utilized agricultural area (UAA); in the second constraint, applied to farms with more than 30 ha of UAA, the two main crops (*S* and *T*) cannot occupy more than 95% of the surface. These constraints ensure a diversified use of land as stated by the CAP 2023-2030 greening measures. Crops rotation, which requires changes between botanical groups, is introduced through the following equation:

$$x_{n,alfalfa} + x_{n,proteics} + x_{n,soja} + x_{forages} + x_{n,beet} + x_{n,tomato} = x_{n,wheat} + n_{n,maize} + n_{n,barley} + x_{n,sorgum} \tag{16}$$

Since AGRISP is a static, non-recursive model for comparative static analysis, equation 16 simplifies the condition on annual rotation by assuming that the same share of land is used for wheat, legumes and forages. Similar simplifications are also commonly used in dynamic mathematical programming models, where the farm is divided into roughly equal parts and the acreage of each crop is maintained constant, so that crop rotation is treated as a land-share parameter (Cortignani and Dono, 2020). Finally, greenhouse gas emissions are computed for each activity as described in Solazzo et al. (2016), based on the guidelines provided by the regional legislation and the IPCC (Section 3.1).

3.3 Simulation scenarios

The milk quotas scheme is assessed by simulating four policy scenarios, described in Table 4.

Name	Description
baseline	No quotas policy is applied, and farmers can produce without production constraints.
baseline_price	An increase in milk price by 7% is applied.
quota_trade	The ABM constraints for the exchange of quotas among farmers are introduced and, therefore, the additional costs and revenues from buying and selling are added to the general equation (1).
quota_trade_price	The scenario quota_trade is modified by setting an in- crease in milk price by 7%.

Table 4: Simulated policy scenarios.
Source: own elaborations on simulation results

All simulation scenarios include the CAP 2023-2030 greening constraints and payments, as well as those allowing land transfers, described in Section 3.3. In the following sections, the changes in economic, structural, and environmental performances will be examined by analyzing the outcomes of introducing quotas into a free market (baseline vs. quota_trade), and how farms respond to a price increase under both the free market (baseline vs. baseline_price) and the constrained market (quota_trade vs. quota_trade_price) scenarios. Since AGRISP is a static model, all discussed values are always referred to one year of activity.

4 Results

The simulated impacts of milk quotas are compared with the reference scenario (baseline) and are described in this section. Figure 4 depicts the policy effects on crop production, while Figure 5 presents the changes in milk production.

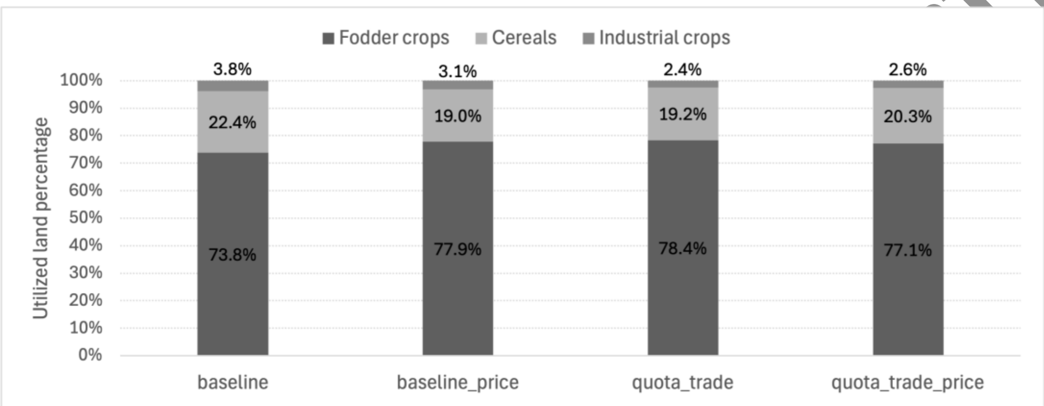

Figure 4: Comparison of changes in land utilization.
Source: own elaborations on simulation results

As expected, the productive structure of farms remains mostly unchanged, as they specialize in milk production and therefore always dedicate most of their land to fodder crops. On the other hand, the policy has more visible impacts on milk production. Compared to the baseline scenario, the implementation of quotas does not limit milk production very effectively.

Figure 5: Comparison of changes in milk production.
Source: own elaborations on simulation results

However, when the milk price rises, production grows less markedly than in the absence of quotas. In particular, production is highly responsive to price in the non-constrained market, as it nearly doubles

(Figure 5); even though its elasticity remains more than proportional to price when quotas are imposed, this reaction – previously more uncontrolled – is now dampened (Table 5).

Compared scenarios	Elasticity
baseline *vs* baseline_price	6.1
quota_trade *vs* quota_trade_price	2.4

Table 5: Elasticity of milk production to price.
Source: own elaborations on simulation results

To illustrate the structural effects of the policy, in Figures 6 and 7 the number of farms is categorized by altimetric areas and UAA classes, respectively. The variations in their numbers reflect the activation and deactivation of sample farms as they expand or contract their land. When farmers' production levels fall to zero, they exit the market. The total number of farms is slightly lower when the policy is not enforced. As shown in Figure 6, between baseline and baseline_price, there is a slight increase in farms across all three areas, whereas when milk prices rise due to the policy's effect, there is an incentive to enter the market only for mountain and hill farms. Figure 7 shows that small producers remain mostly stable across the scenarios, while the activity of medium-large farms (21-50 ha) is more strongly promoted when quotas are applied.

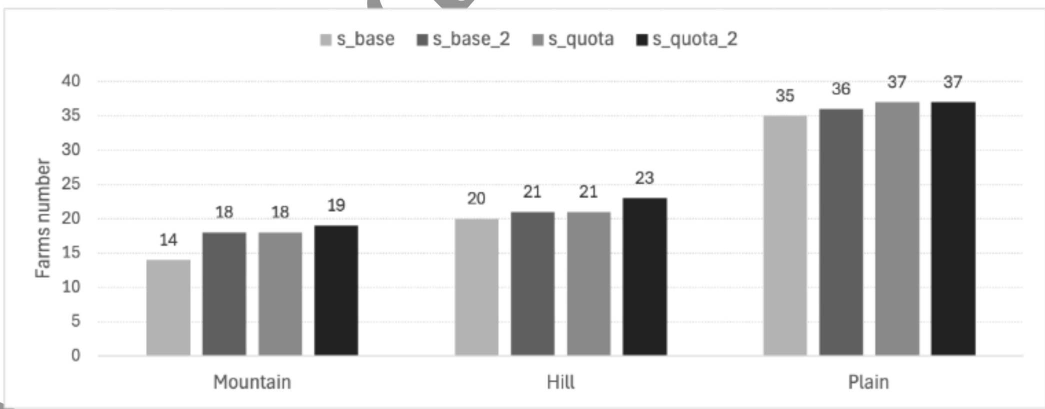

Figure 6: Dynamic number of farms per area and policy scenario.
Source: own elaborations on simulation results

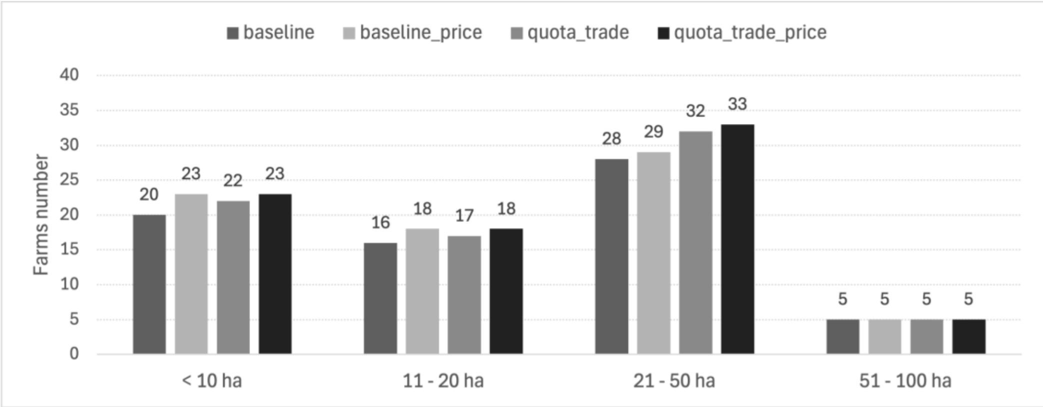

Figure 7: Dynamic number of farms per UAA class and policy scenario.
Source: own elaborations on simulation results

The economic impacts are shown in Figure 8, where the average Gross Saleable Product (GSP) and the Gross Margin (GM) per farm are plotted. While production volumes grow by 14% without quotas and by 4% with them in place, profits increase by 4% and 6%, respectively. In Table 6, farm dimensions and their productivity (average milk production level per cow) are compared. Even though milk production (and consequently the GSP) is higher in the quota_trade scenario than in the baseline, the GM is slightly worse. Conversely, when milk price rises (in quota_trade_price), there is an improvement in quota_trade, but the GM is always lower than in the scenario where price increases without quotas being enforced (baseline_price). On the other hand, Table 6 highlights how in both quota scenarios there are more cows but concentrated in less farms. The quota trading mechanism fosters productivity, albeit not to a greater extent than the increase in milk price alone, simulated in baseline_price.

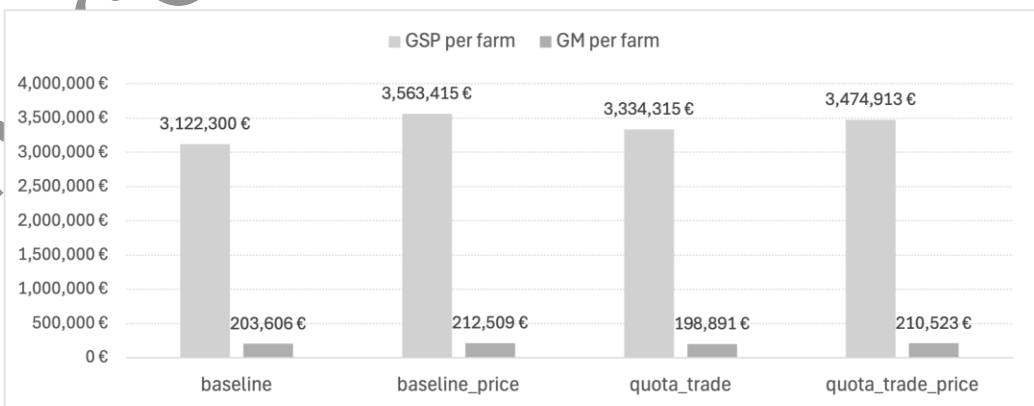

Figure 8: Economic results per policy scenario.
Source: own elaborations on simulation results

Scenarios	Cows number	Cows per farm	Tons of milk per cow
baseline	2,346	34	5.01
baseline_price	3,111	41	5.38
quota_trade	2,832	37	5.19
quota_trade_price	3,214	41	5.35

Table 6: Farms productivity per policy scenario.
Source: own elaborations on simulation results

Environmental outcomes are displayed in Figure 9. Results show that the policy is not very effective in reducing total greenhouse gases (GHG) emissions. However, when milk price rises, emissions increase by a lower degree than in the absence of quotas.

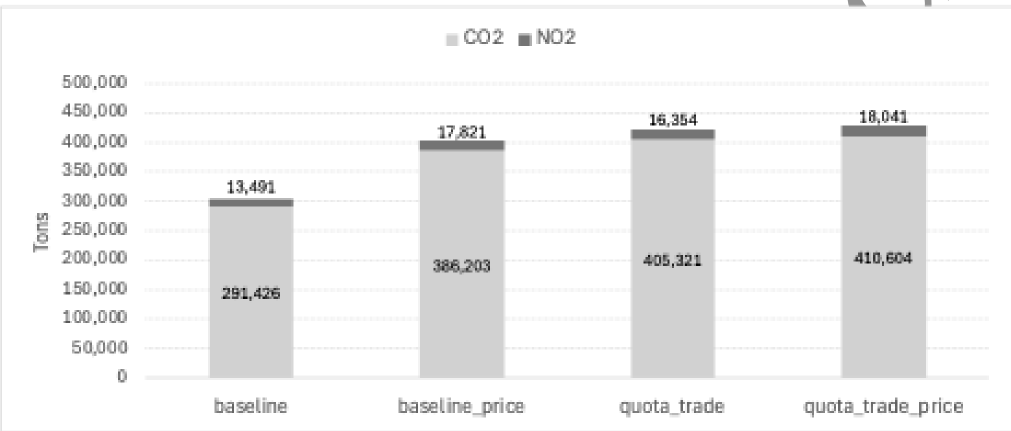

Figure 9: GHG emission levels (CO_2 and NO_2) per policy scenario.
Source: own elaborations on simulation results

5 Discussion

After analyzing the key findings on the implementation of the PR production plan, this study aims to evaluate the actual economic, structural, and environmental impacts of milk supply management under the policy framework implemented by the PRG.

From a policy perspective, the main concern is the establishment of new farm assets associated with the right to produce milk for PR cheese, which expanded farms' production capacity and economic dimensions (Table 6). The quotas policy fostered the conditions for production growth; in fact, it is not strictly binding, but farms can exceed their allocated production threshold and pursue economies of scale by trading milk quotas. In the scenarios, while a higher milk production is incentivized in all areas (mountain, hill, and plain) when quotas are in place, the market becomes much less reactive to price changes (Figure 5 and Table 5). Moreover, this mechanism does not constitute a strong entry barrier, as there are more farms in the market than the baseline scenarios (Figure 7); additionally, the rule establishing that quotas cannot be traded between different agrarian regions prevents plain and hill farms – characterized by a much higher production capacity – from competing with mountain farms, thus supporting production and development in such LFAs. However, since quotas represent an additional cost for farmers who want to expand their production, an increase in productivity is not followed by an improved economic efficiency: although farms intensify their production in an attempt to cover their costs (Table 6), thereby also generating a higher GSP, gross margins in absolute terms remain on average lower compared to those generated in the free market (Figure 8). This aligns with Bouamra-Mechemache et al. (2008), where it is stated how production quotas are attributable to decreases in farmers' gross margins (which are even stronger when production grows). This means that gains from higher production quantities are not able to fully compensate for investments in quotas, and further price increases would be needed to achieve the same profits. Indeed, in quota_trade_price they rise by a slightly greater extent in percentage terms, but the result is still worse than in baseline_price. While the existing literature agrees on the positive effects of quotas on profitability, here it is highlighted how, in a supply chain with different and stricter cost structures typical of GI products, enhanced productivity does not necessarily come with better economic results. On the contrary, the expansion of costs generated by the quotas scheme is not offset by the current price premium guaranteed to farmers. Bigger farms, with stronger capital bases, may absorb these costs more easily, while smaller activities might experience sharper constraints, which in the long term could reinforce structural inequalities within the sector. Therefore, even if quotas do not seem to stop farmers from entering the market, they can hamper competitiveness when economic margins are systematically eroded. Indeed, looking at the social dimension, even though both small farms and activities in marginal areas are preserved as they do not exit the market, there is a slight tendency to concentrate production towards larger farms when quotas are traded (Table 6). A limitation of the model lies in the absence of dynamic elements, which prevents us from considering how this dimension would evolve across multiple years. However, the empirical evidence (Appendix A) confirms that the concentration observed in the simulations, when comparing the baseline and quota_trade scenarios, is bound to become increasingly exacerbated. While this may represent an advantage when it strengthens farmers' ability to invest in more efficient production technologies, it simultaneously undermines social sustainability, as it excludes small farmers from the supply chain – those very actors that GIs are, by definition, meant to support.

At the same time, the policy does not improve the environmental outcomes, since GHG emissions are at the lowest level in the baseline scenario (Figure 9). This stems from the fact that, as mentioned above, the quotas are not strictly binding and an expansion in land allocated to forage production and livestock is observed, so that environmental impacts are not curbed either. On the other hand, accordingly to the analysis of Baldock et al. (2008), the policy as implemented by the PR Consortium is actually effective in preserving marginal mountain areas, which, in an overly competitive context, would otherwise be abandoned with negative consequences for soil and ecosystems. In this regard, the environmental issue is particularly relevant in light of the Art. 7 of Regulation (EU) 1143/2024, allowing GI groups to draft sustainability reports on their production system.

6 Conclusions of the study

From a methodological perspective, the PMP approach is employed to calibrate model parameters and assess production costs, replicating observed practices and outcomes. ABMs complement this approach by enabling the social characterization of individual agents and their interactions within the economic environment through rule-based asset exchanges. The integration of PMP and ABM enables broader, more realistic scenario simulations by accounting for economic and non-economic parameters. The overall result is a more detailed analysis of impacts, ranging from sectoral to regional scales, and an improved understanding of the phenomena observed as individual policy measures vary.

In summary, with respect to the research question stated in the study's introduction, the findings suggest that milk quotas have mixed effects on the sustainability dimensions of the PR cheese rural system, thereby allowing for the evaluation of both the pros and cons of the policy. In particular: i) farmers' profits (economic aspect) are slightly eroded, ii) activities in marginal areas (social aspect) are preserved, but there is a general tendency of polarization towards larger farms, and iii) GHG emission levels (environmental aspect) are not reduced, but the increased number of farms operating in mountain areas has a positive role on the preservation of ecosystems and landscapes.

When drawing conclusions, it has to be acknowledged that PMP and ABMs, like any other economic modelling approach, imply simplifications and assumptions on agents' behaviors and market dynamics. In the first place, even though the behavioral assumptions are realistic and supported by the literature, they remain quite simplistic with respect to reality; the decision on whether to participate or not in quotas investments may depend not only on age and future business prospects, but also on risk aversion, "myopic" or long term planning, access to market information, and volatility of milk price.

However, such data cannot be incorporated into the model because it is not currently available in either national or regional databases. Thus, future research may improve the model by enriching it with additional elements from behavioral economics theories. Further studies may also focus on creating recursive structures capable of modelling individual agents for several years, with the aim of studying the evolution of the system at a high level of detail over time.

As a closing remark, the supply control system for EU GIs is a significant tool for safeguarding farmers' incomes; nevertheless, its application extends beyond PDO and PGI systems' management, influencing rural development dynamics toward selecting commercial activities based on market competitiveness and impacting the relationship between agriculture and the environment. Therefore, it is crucial to understand the effects of these supply chain management tools and transform them into effective tools for production, social and environmental planning at the territorial level. This development should occur through collaborations between local stakeholders in coordination with the Rural Development Program.

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Appendix A

Milk tons per farm	2014	2015	2016	2017	2018	2019	2020	2021	2022
0 - 200	1,086	1,070	949	812	801	712	598	548	497
200 - 400	840	797	774	756	717	673	652	600	572
400 - 800	654	637	647	660	618	614	632	629	609
800 - 2.000	476	479	495	501	514	520	517	533	516
2.000 - 4.000	100	103	115	134	138	144	156	166	159
> 4.000	30	26	33	37	40	43	51	56	57
Total	3,186	3,112	3,013	2,900	2,828	2,706	2,606	2,532	2,410

Table 7: Number of farms by production class.
Source: PRG (2022).

Altimetric area	2016	2017	2018	2019	2020	2021	2022	2023	2024
Mountain	1,085	1,044	1,018	975	940	912	865	825	800
Plain and hill	1,928	1,865	1,810	1,734	1,670	1,620	1,544	1,466	1,421
Total	3,013	2,900	2,828	2,709	2,610	2,532	2,413	2,291	2,221

Table 8: Number of farms by geographical distribution.
Source: AllevaWEB (2025).