ECOWHEATALY

Evaluation of policies for enhancing sustainable wheat production in Italy

Work Package 3: Green policies in tranquil times

Deliverable D2

Green policies in tranquil times

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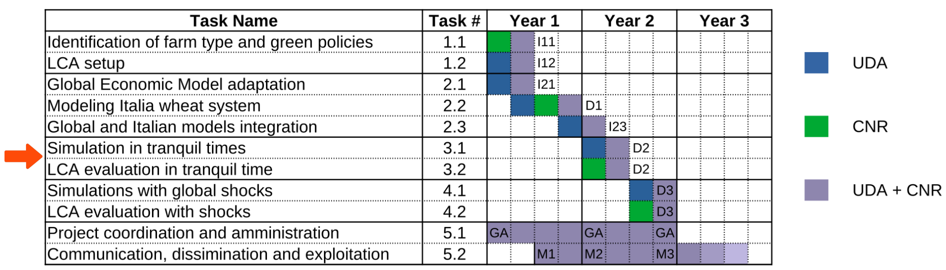

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DISCLAIMER

Green policies in tranquil times

Contents

Executive Summary

This report presents the results of Task 3 of the ECOWHEATALY project, which focuses on the simulation of the economic and environmental impacts of green agricultural policies and external shocks affecting the wheat production system. The simulations are conducted using the integrated modelling framework developed in the previous tasks of the project, which combines a global wheat market model, a farm-level representation of the Italian wheat sector, and an environmental assessment module based on Life Cycle Assessment.

The objective of this task is to analyse how environmental policy instruments and global market disturbances influence wheat production, farm behaviour, market outcomes, and environmental impacts. In particular, the simulations focus on policy measures implemented within the Common Agricultural Policy (CAP), such as Eco-scheme 4 and agri-environmental measures SRA19 and SRA20, which aim to reduce the environmental footprint of agricultural production through crop diversification, reduced pesticide use, and lower input intensity.

The model simulates the behaviour of heterogeneous farms that make production and input decisions in response to market signals and policy incentives. These decisions influence aggregate production, which in turn affects price formation in the global wheat market. At the same time, environmental indicators associated with agricultural inputs are calculated using the Life Cycle Assessment framework developed in earlier tasks.

A series of simulation scenarios is used to explore the interaction between policy interventions and market dynamics. These scenarios include the introduction of green policy measures as well as external shocks affecting global wheat supply and trade. The simulations allow the analysis of how such shocks propagate through international markets and affect domestic production decisions in Italy.

The results illustrate the complex interaction between environmental policies, farm-level production decisions, and global market dynamics. While green policy instruments may contribute to reducing environmental pressures associated with agricultural inputs, their economic effects depend on market conditions and on the behavioural responses of farmers.

Overall, Task 3 demonstrates the potential of the integrated ECOWHEATALY modelling framework as a tool for analysing the economic and environmental implications of agricultural policies in a global market context.

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1 Simulating in tranquil times

1.1 Price Sensitivity, Trade Networks, and Shock-Induced Reallocation

International trade flows are embedded in persistent bilateral networks shaped by sunk entry costs, search frictions, and relational capital. In stable macroeconomic environments, these network structures generate inertia: established exporter–importer links are maintained even in the presence of moderate price differentials, as firms internalize switching costs and relationship-specific investments Melitz (2003); Chaney (2008); Eaton et al. (2016). Consequently, adjustments predominantly occur along the intensive margin, while the topology of the trade network remains relatively stable.

Recent contributions in the trade-network literature emphasize that international trade is characterized by highly structured and persistent network linkages, where relational stability plays a central role in shaping aggregate trade patterns Bernard et al. (2018); Acemoglu et al. (2012). In such environments, relational capital and network embeddedness dampen the short-run elasticity of trade flows with respect to relative prices.

However, large exogenous shocks—such as geopolitical disruptions, embargoes, or major supply interruptions—alter the stability of the trade network. When uncertainty increases and the probability of disruption rises, the expected value of maintaining existing links declines, lowering the effective switching threshold. Network rewiring becomes more likely, and firms re-optimize their sourcing decisions more aggressively. The literature on production and trade networks shows that shocks can propagate through existing links but can also induce endogenous network reconfiguration, amplifying the role of price differentials in determining trade flows Barrot and Sauvagnat (2016); Carvalho (2010).

In this framework, the elasticity of bilateral trade with respect to relative prices is state-dependent. Under stable macroeconomic conditions, network persistence dampens price sensitivity. Under large shocks, relational frictions weaken and reallocation along the extensive margin intensifies, increasing the responsiveness of trade flows to relative cost differences. In the context of global wheat markets, the blockade of Ukrainian exports during the Russia–Ukraine war represents a systemic negative supply shock that disrupted established trade links and triggered reconfiguration across importing countries. Our simulations capture this mechanism by contrasting a stable regime characterized by network persistence with a shock regime in which heightened uncertainty and logistical disruptions amplify price-driven reallocation.

1.2 Link to the ECOWHEATALY model

1.2.1 Eliminating Initialization Bias and Stabilizing the Trade Network

Agent-based models are inherently path-dependent and may exhibit strong sensitivity to initial conditions. A standard concern in simulation-based research is the presence of initialization bias, whereby early-period dynamics reflect arbitrary starting configurations rather than structural properties of the model Gilbert and Troitzsch (2005); Tesfatsion and Judd (2006). To ensure that our results reflect the endogenous dynamics of the system rather than transient artifacts, we first allow the model to evolve under conditions of frictionless trade, high commodity mobility, and zero transaction costs.

Under these assumptions, wheat flows freely across regions and agents adjust purely according to relative prices. Consistent with the law of one price in competitive equilibrium theory, the model converges toward a single global price level. In our simulations, this convergence occurs around period 50, indicating that initial heterogeneity in prices and trade flows has been fully absorbed by arbitrage dynamics.

We then gradually introduce positive transportation costs, which generate spatial price dispersion and reduce the intensity of arbitrage. As predicted by spatial equilibrium models Fujita et al. (1999), trade costs induce wedges between regional prices and produce greater volatility in bilateral quantities. This phase allows the network structure to adapt to realistic frictions while maintaining macroeconomic stability.

Finally, under the assumption of stable macroeconomic conditions, we progressively reduce commodity mobility by lowering the share of wheat requests reallocated across partners. This mechanism mimics the emergence of persistent trade relationships and stable commercial agreements. Conceptually, this procedure resembles a simulated annealing process Kirkpatrick et al. (1983): the system is initially allowed to explore the state space under high mobility (high "temperature"), and is then gradually cooled by increasing relational stickiness, enabling convergence toward a stable network configuration. This approach ensures that observed trade patterns reflect endogenous relational persistence rather than artifacts of arbitrary initialization.

1.2.2 Approach to the steady state

Hereafter, we show how we obtain the benchmark setting in tranquil times, i.e., a setting characterized by steady-state prices and positive transport costs. In our model, transport costs are computed in the simplest way:

$$Cost = v \times d$$

where v is the unit cost per ton per kilometer and d is the distance in kilometers.

Moreover, the share of quantities to be moved from the expensive to the cheap market is:

$$\alpha_b(R_b) \;=\; \frac{\alpha_{\max}}{1 + \exp[-0.748\,(R_b - 8.0)]}. \tag{1}$$

where α_{max} is the maximum percentage of demand that can be moved from one month to the next, and R_b is the difference between the prices in the international markets. We first set $v = 0$ and $\alpha_{\max} = 0.05$. That is, there are no transport costs, and a considerable amount of demand (5%) can be moved at each time step. These conditions are kept for 50 time steps. From Figure 1, we observe that, after some periods of relevant changes, the system settles down to a one-price steady state. Afterwards, we start a gradual increase in transport costs. v is increased every 2 time steps for 5 times by 0.0001. This occurs at time steps 50, 52, 54, 56, and 58, when v reaches 0.0005. After this, in period 60, we started the annealing phase, where the $\alpha_{\max}$ parameter is driven down using an autoregressive process of speed ϕ:

$$\alpha_{\max} \leftarrow (1-\phi)\alpha_{\max}$$

The annealing phase is a crucial device for approaching a new steady state, and it mimics the slowing of arbitrage activity in favor of more stable relationships that gradually establish themselves in tranquil times. In Figure 1 the annealing speed is set at $\phi = 0.04$

We perform the same simulations for $\phi = 0.03$ and $\phi = 0.05$. The resulting price dynamics are reported in panels a) and b) of Figure 2, respectively. The final price

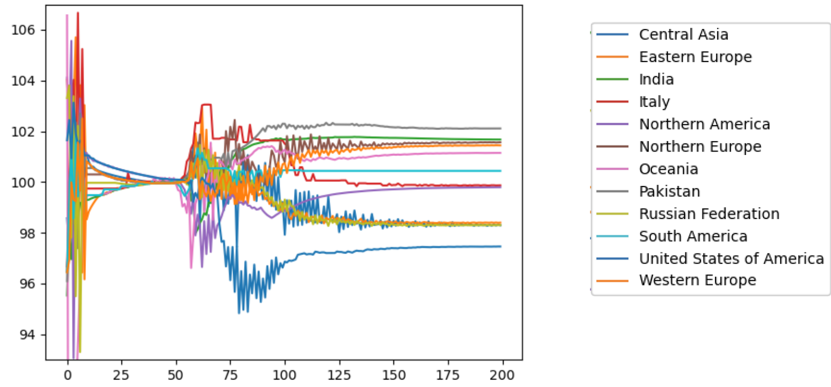
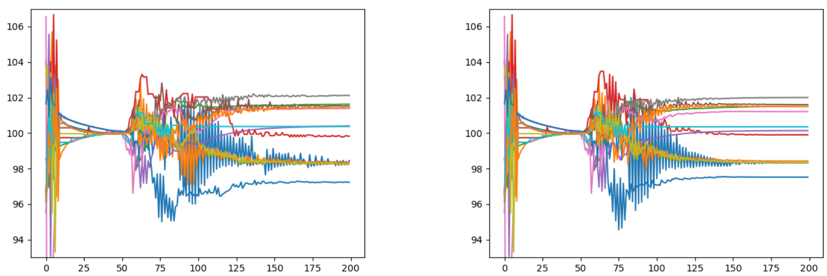


Figure 1: The price dynamics of wheat international prices with increasing costs of transportation and variation in global demand elasticity.

levels in the three cases are reported in Table 1. In general, it should be noted that a higher adjustment speed ϕ leads, in some cases, to a faster convergence to the steady state. However, the effect of the adjustment speed interacts with the change in transport costs achieved in the previous phase, which affects how demand shifts from one market to another and makes the outcome region-specific. Accordingly, in Table 1, we observe different situations depending on the region considered.



(a) (b)

Figure 2: The price dynamics of wheat international prices with increasing costs of transportation and variation in global demand with annealing speed of $\phi = 0.03$ in panel a) and $\phi = 0.05$ in panel b).

Area	$\phi = 0.03$	$\phi = 0.04$	$\phi = 0.05$
United States of America	97.233	97.461	97.521
Russian Federation	98.243	98.303	98.331
Eastern Europe	98.354	98.401	98.433
Central Asia	98.455	98.296	98.34
Italy	99.831	99.871	99.904
South America	100.373	100.441	100.355
Northern America	100.406	99.797	100.140
Oceania	101.400	101.148	101.211
Western Europe	101.412	101.445	101.492
Northern Europe	101.514	101.567	101.605
India	101.624	101.674	101.505
Pakistan	102.121	102.111	102.005

Table 1: The final levels of prices in the three cases of global wheat demand variation with annelaing speed $\phi = 0.03$, $\phi = 0.04$, and $\phi = 0.05$.

2 Policies evaluation

In Task Report 1.1, we discussed and identified some policies that most affect wheat production. For the reader's convenience, we list them hereafter and discuss how they can be simulated in our model in the next section.

- Eco-scheme 4 (crop rotation)
- Measure SRA19 (Sustainable and Reduced Use of Pesticides)
- Measure SRA20 (Sustainable Nutrient Management).

2.1 Eco-scheme 4: rotation constraint (two-year average)

As already discussed in the Task 1.1 report, Eco-scheme 4 introduces a crop rotation requirement within the CAP 2023-2027 to address environmental and agronomic externalities associated with cereal monoculture. While wheat specialization may be privately optimal due to higher expected gross margins, economies of scale, and market liquidity, continuous monoculture generates long-term soil degradation, increased pest pressure, and nutrient imbalances. This creates a divergence between short-run private incentives and long-run social sustainability. Eco-scheme 4 partially internalizes these intertemporal environmental externalities through a per-hectare payment that increases the private return to rotation. The measure also contributes to EU climate and biodiversity objectives by improving soil carbon storage, reducing nitrogen losses, and enhancing agroecosystem resilience.

Quantitative comparison of wheat and rotational crops. Empirical evidence from typical EU cereal systems suggests that rotational crops such as grain legumes often generate lower gross revenue than wheat but also substantially lower variable costs. For example, wheat yields of 6–7 t/ha at prices of 220–260 €/t imply revenues of approximately 1,400–1,700 €/ha, with total variable costs commonly in the range of 600–850 €/ha, resulting in gross margins around 700–800 €/ha. By contrast, grain legumes typically generate revenues of roughly 900–1,300 €/ha but incur significantly lower nitrogen and input costs (350–550 €/ha), producing gross margins that are often 50–150 €/ha below wheat. However, legumes frequently improve soil nitrogen availability and reduce disease pressure for the subsequent wheat crop, generating second-year benefits estimated at 50–120 €/ha. Over a two-year horizon, the effective gross margin differential between monoculture and rotation therefore narrows substantially. In this context, an Eco-scheme 4 payment in the range of 60–110 €/ha is often sufficient to offset the residual private opportunity cost of rotation.

2.1.1 Average input and revenue effects of Eco-scheme 4

Empirical evidence from agronomic and economic literature suggests that crop rotation involving grain legumes or forage crops generates substantial input reductions relative to wheat monoculture, while typically implying a moderate short-run reduction in gross sales revenue. Legumes contribute to biological nitrogen fixation and improve nitrogen-use efficiency in subsequent wheat crops (Drinkwater et al., 1998; Peoples et al., 2009). Meta-analyses for European systems show economically significant pre-crop benefits, including lower fertilizer requirements and improved yield stability (Preissel et al., 2015). Diversification also reduces pest and disease pressure over time (Bullock, 1992; Smith et al., 2008) and enhances agroecosystem resilience (Lin, 2011).

Using representative Italian cereal systems as a reference (baseline wheat nitrogen application $\approx$ 160 kg N/ha), a typical Eco-scheme 4 rotation composed of approximately 70% legumes/forage crops and 30% break crops implies the following average effects:

Variable	Year 1 (Rotation crop)	Year 2 (Wheat after rotation)
Nitrogen application	–60% to –70%	–20% to –30%
Herbicide use	–70% to –75%	–5% to –10%
Insecticide use	$\approx$ –70%	–5% to –15%
Gross sales revenue	–10% to –25%	0% to +5%

Table 2: Average percentage changes relative to wheat monoculture (Italian reference case).

The revenue reduction in the rotation year reflects lower average yields and market values of grain legumes relative to wheat. For typical Italian yield and price conditions, legume revenues are approximately 10–25% below wheat revenues in the rotation year. However, second-year wheat frequently benefits from improved soil fertility and reduced disease pressure, partially offsetting this difference and in some cases slightly increasing gross revenue due to yield stabilization effects (Preissel et al., 2015).

Overall, Eco-scheme 4 generates a pronounced reduction in nitrogen and pesticide use in the rotation year, followed by persistent but smaller input reductions in the subsequent wheat year. The short-run trade-off consists of a temporary reduction in gross sales revenue that is partly compensated by lower input costs and, under the policy, by the per-hectare Eco-scheme payment. These magnitudes are consistent with the agronomic literature on rotational benefits and nitrogen dynamics in European cereal systems.

Although a simple two-year accounting exercise may suggest that Eco-scheme 4 renders rotation privately profitable on average, adoption remains heterogeneous. First, the agronomic benefits of rotation—including reduced nitrogen requirements and improved wheat performance in the subsequent period—are uncertain. If rotation increases income variance or introduces yield volatility, risk-averse farmers may prefer monoculture even when expected profits are higher. Second, part of the economic gain from rotation materializes in the following production cycle, while the potential margin reduction occurs immediately. In the presence of liquidity constraints, annual debt obligations, or limited access to credit, farmers may prioritize short-run cash flow over intertemporal profit maximization. Third, switching crops may entail adjustment and transaction costs, including new machinery requirements, contractual uncertainty, learning costs, or administrative compliance burdens.

Recalling the nomenclature used in paragraph 5.2.2 of the Task 1.1 report, formally, the adoption of Eco-scheme 4 requires that

$$E[GM_r] + S - K + \beta E[futurebenefit] - \frac{1}{2}\gamma \Delta Var(\pi) \geq GM_w,$$

where GM_r and GM_w represent the gross margin for the rotation crop e for wheat, respectively, K denotes switching costs, β the discount factor, and γ the degree of risk aversion. If switching costs are substantial, discounting is strong, or risk premia are large, the Eco-scheme payment may not fully offset the private opportunity cost of rotation. Consequently, incomplete adoption of Eco-scheme 4 is consistent with rational profit-maximizing behavior under uncertainty and financial constraints.

2.1.2 Implementation in ECOWHEATALY

In practice, farmers adopt the Eco-scheme 4 measure by subdividing their fields into two parts: one for wheat cultivation and the other for the rotation crop. In this framework, we assume that only farms with a total acreage at least twice their wheat acreage can join Eco-scheme 4. Farms satisfying this requirement proceed as follows.

Let us consider the revenue from two years of wheat cropping as in Equation 2.

$$GM_{2w} = \underbrace{p_w\hat{y} - p_N\hat{x}_N - p_h\hat{x}_h - p_i\hat{x}_i}_{wheat\ in\ year\ 1} + \rho(\underbrace{p_w\hat{y} - p_N\hat{x}_N - p_h\hat{x}_h - p_i\hat{x}_i}_{wheat\ in\ year\ 2}) \tag{2}$$

where p_N, p_h, and p_i are the prices of nitrogen, herbicide, and insecticide, respectively, x_N, x_h, and x_i the corresponding quantities. Besides, ρ is the farmer's discount factor.

Under the rotation sequence *alternative crop* $\rightarrow$ *wheat*, we can compute the gross margin of two years through Equation 3.

$$\begin{aligned} GM_{rw} = & \underbrace{p_r\hat{y}_r - p_N(1-\beta_{N,1})\hat{x}_N - p_h(1-\beta_{h,1})\hat{x}_h - p_i(1-\beta_{i,1})\hat{x}_i}_{alternative\ crop\ in\ year\ 1} \\ & + \rho(\underbrace{p_w\hat{y} - p_N(1-\beta_{N,2})\hat{x}_N - p_h(1-\beta_{h,2})\hat{x}_h - p_i(1-\beta_{i,2})\hat{x}_i}_{wheat\ in\ year\ 2}) \end{aligned} \tag{3}$$

where β is the percentage reduction in the specific input used in wheat cropping when it is part of a rotation system. This occurs because leguminous crops promote a decrease in the use of nitrogen and other chemical inputs in the subsequent wheat crop.

Many of the involved elements are farm-specific. To have an easy-to-handle problem, we pack all the idiosyncratic factors into one using the following devices. First, we move the advantages of the second year in the rotation case to the first period by setting $\beta_{*,2} = 0$ and considering modified β coefficients in the first period (denoted with $\tilde{\beta}$). Therefore, in computing the difference $GM_{2w} - GM_{rw}$, the second terms of the previous expressions cancel out and the difference of gross margin for one year becomes:

$$\begin{aligned} GM_w - GM_r =& GM_{2w} - GM_{rw} = \\ =& \underbrace{p_w\hat{y} - p_N\hat{x}_N - p_h\hat{x}_h - p_i\hat{x}_i}_{wheat\ in\ year\ 1} \\ &- \left(\underbrace{p_r\hat{y}_r - p_N(1-\tilde{\beta}_N)\hat{x}_N - p_h(1-\tilde{\beta}_h)\hat{x}_h - p_i(1-\tilde{\beta}_i)\hat{x}_i}_{alternative\ crop\ in\ year\ 1}\right) \end{aligned}$$

Second, we put all the $\tilde{\beta}_*$s at the same level $\tilde{\beta}$. Third, we put $p_r\hat{y}_r = p_w\hat{y}_w(1-\tilde{\beta})$. Under these simplifications, we have:

$$\begin{aligned} GM_w - GM_r =& \underbrace{p_w\hat{y} - p_N\hat{x}_N - p_h\hat{x}_h - p_i\hat{x}_i}_{wheat\ in\ year\ 1} \\ &- \left(\underbrace{(1-\tilde{\beta})(p_w\hat{y} - p_N\hat{x}_N - p_h\hat{x}_h - p_i\hat{x}_i)}_{alternative\ crop\ in\ year\ 1}\right) \end{aligned}$$

Defining $p_w\hat{y} - p_N\hat{x}_N - p_h\hat{x}_h - p_i\hat{x}_i = \hat{\pi}_w$ we can write

$$GM_w - GM_r = \hat{\pi}_w - (1-\tilde{\beta})\hat{\pi}_w$$

and therefore

$$GM_w - GM_r = \tilde{\beta}\hat{\pi}_w$$

where $\tilde{\beta}$ gathers all the idiosyncratic elements, such as the quality of the farm's soil, for example (ability to keep nitrogen, of being improved by the rotation); the farmer's personality, such as her/his discount factor; the volatility of the output prices, and so on.

Now we include in our reasoning the benefit from Eco-scheme 4 adoption, denoted by S, and the additional bureaucratic and switching costs required to obtain this benefit, denoted by K. We assume that K is a fixed cost; therefore, we divide it by the acreage A to obtain the per-hectare cost. This implies that larger farms are more likely to have employees or agronomists who can easily apply for the benefit.

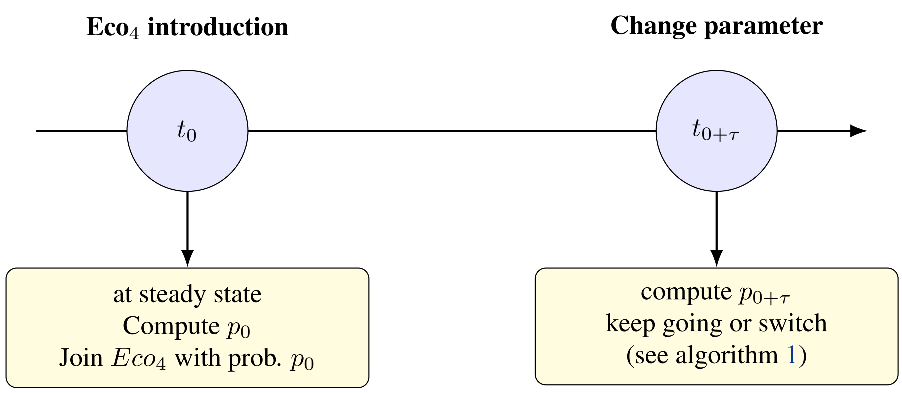
We define the probability of joining Eco-scheme 4 as proportional to $S - \tilde{\beta}\hat{\pi} - K/A$:

$$p(Eco_4) \propto S - \tilde{\beta}\hat{\pi} - \frac{K}{A}.$$

Note that there are constants, such as K, aggregate dynamics, and farm-specific variables entering in this expression. A, for example, is a farm-specific variable (acreage) as well as the $\tilde{\beta}$. The province features (the ss, λs, $\bar{y}s$), affect $\hat{\pi}$ as well as p_w which is an aggregate dynamic variable. Furthermore, S could be modeled as a constant or as a variable that varies year by year, depending on the number of farmers adopting the Eco-scheme. In practice, the total amount at the national level may be divided by the total acreage enrolled in the Eco-scheme.

Timeline of simulation in tranquil time. When the model reaches a steady state, say at t_0, we introduce the possibility of evaluating adoption and the corresponding environmental impact.

Timeline of Eco_4 introduction and switching



Subsequently, say in $t_{0+\tau}$, we change a parameter to perform comparative static analysis. At that time, we computed the new probability of adoption. Let p_0 denote the probability of adoption when the policy was introduced, and $p_{0+\tau}$ the new computed probability. The change in adoption is computed as follows:

Algorithm 1: Eco-scheme switch adoption Decision Rule

Draw r from uniform distribution;
Whenever evaluating a change in Eco-scheme, compute p;
if *farm is running Eco-scheme* **then**
  if $p < r$ **then**
    Switch off;
else
  if $p > r$ **then**
    Switch on;

Recall that we allow rotation only on farms with total acreage at least twice the wheat acreage. The idea is that, in the case of rotation, wheat alternates between two land parcels of equal size. It means that a parcel producing wheat is active in each production year. Therefore, farms that joined the scheme compute the inputs as shown in the second column of Table 2: nitrogen is reduced by 25%, herbicides by 7.5%, and insecticides by 10%.

2.1.3 Results of Eco-scheme 4 adoption

Table 3 summarizes the parameters we use to simulate the Eco-scheme 4 using our agent-based model. The table translates policy measures into quantitative parameters that affect the farmer's decision problem. Each policy is characterized by its duration, the annual per-hectare payment, potential administrative costs, and the expected effects on profit, production, and input use.

In particular, the table specifies how each policy modifies the optimal use of nitrogen, herbicides, and insecticides. For some interventions, the reduction in input use is represented as optional adjustments, reflecting the fact that the policy may influence farmers' practices without imposing strict quantitative limits. The parameter values are broadly consistent with the economic incentives and environmental objectives of the Italian CAP Strategic Plan.

We simulate two cases with different profit levels in the second year following measure adoption: case A, with parameters set according to Table 3, and case B, with parameters set according to Table 4. Both experiments are consistent with the assumptions in Table 2. It is useful to clarify that the *Profit* parameter is defined based on the change in gross sales revenue in year 1 (0.15 means that we allow for a decrease of 15%), whereas the *Product* parameter reflects the corresponding change in year 2 (0.00 means that the production does not decrease).

Name	eco4
Duration	2
Payment/ha	70
Profit reduction	0.15
Product reduction	0.00
Nitrogen	optional|0.2
Herbicide	optional|0.3
Insecticide	optional|0.15
Admin costs	10

Table 3: Calibration of Italian Eco-scheme 4 incentive derived from CAP 2023-2027 environmental policies: case A.

Simulation of case A. The timing of the policy introduction requires some clarification. In the first 50 periods of the simulation, the system evolves under conditions of zero transport costs. This initial phase allows the model to converge towards a one-price configuration across regions (see Section 1.2.1).

After period 50, transport costs are gradually introduced and increased, allowing the system to transition towards a more realistic equilibrium characterized by spatial price heterogeneity. The model eventually converges to a new steady state under these conditions. This steady state is reached around period 140. Introducing the policy at that time ensures that transitional dynamics do not influence the observed effects; rather, they reflect the policy's impact on a stable economic environment. Thus, we introduce Eco-scheme 4 in period 140, with a payment of 70 euros per hectare.

First, we present the results of case A. We report in Figure 3, 4, and 5 a series of charts arranged in two columns. The left-hand panels show the effects of increasing the Eco-scheme 4 payment to 80 euros per hectare, introduced in period 170. The right-hand panels instead show the effects of reducing the payment to 60 euros per hectare during the same period. These experiments allow us to assess the system's sensitivity to changes in the level of policy support.

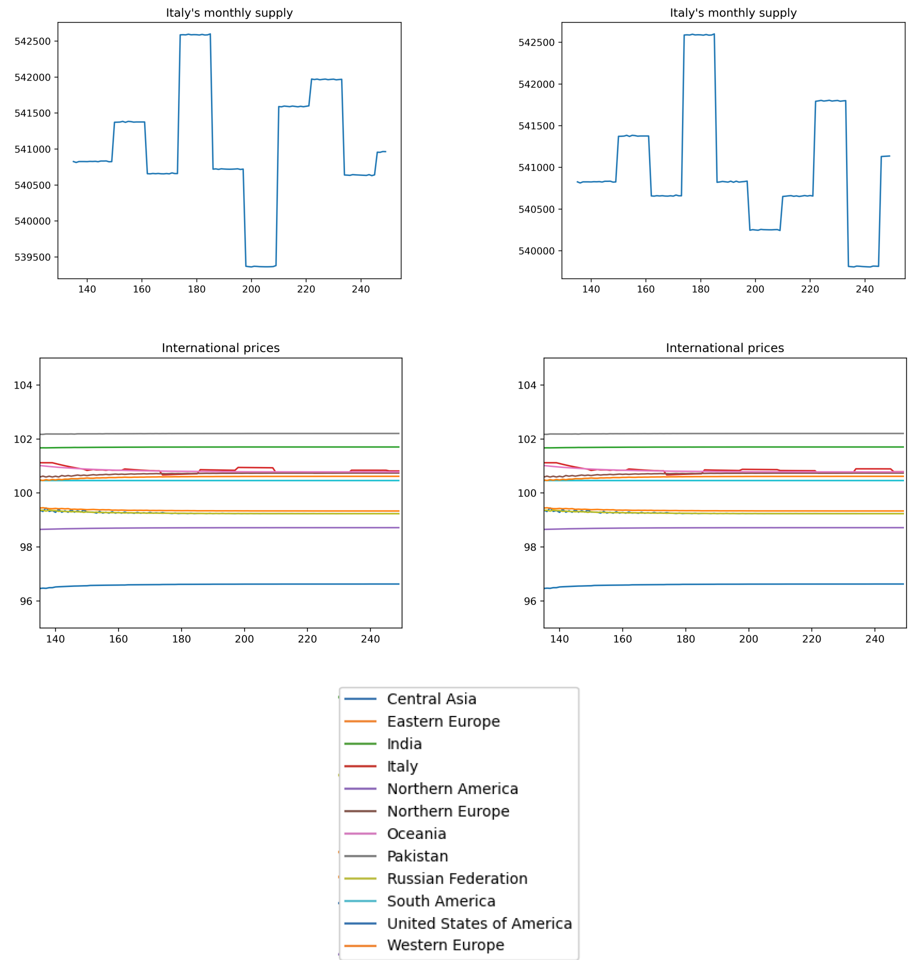


Figure 3: Case A. Effects on Italy's supply and international prices of wheat after the adoption of Eco-scheme 4 (introduced at time 140). Left side panel: payment set to 80 euros. Right-hand panel: payment set to 60 euros.

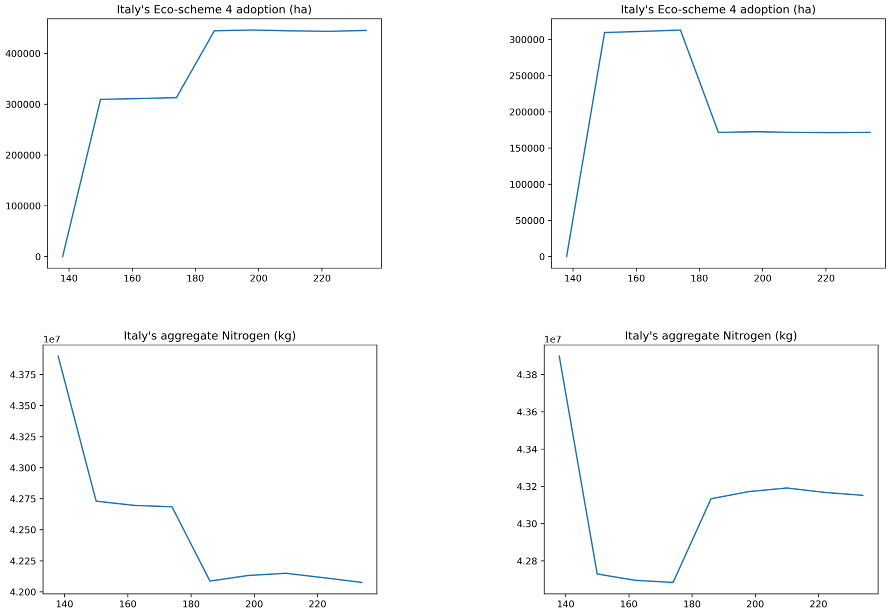


Figure 4: Case A. Effects on Italy's hectares of wheat and input quantity after the adoption of Eco-scheme 4 (introduced at time 140). Left side panel: payment set to 80 euros. Right-hand panel: payment set to 60 euros.

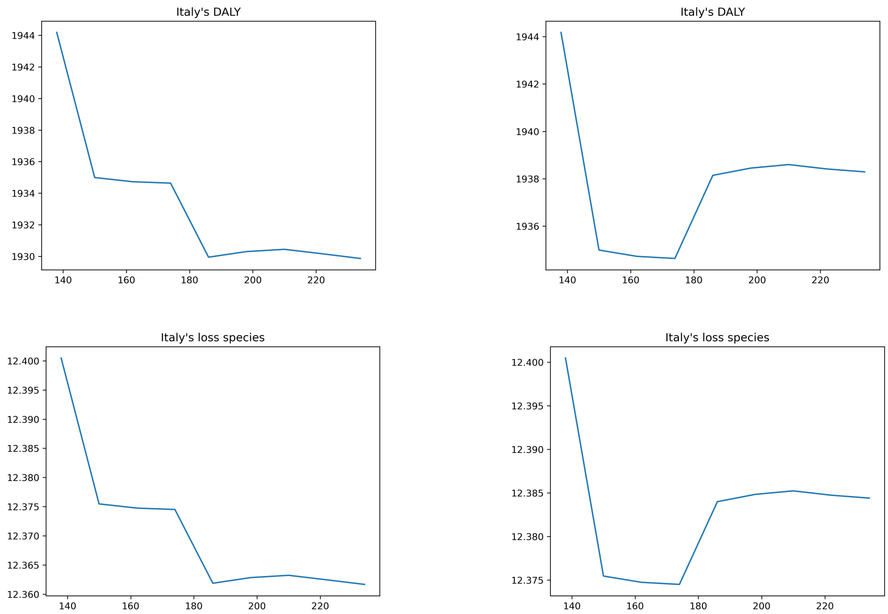


Figure 5: Case A. Effects on Italy's LCA indicators after the adoption of Eco-scheme 4 (introduced at time 140). Left side panel: payment set to 80 euros. Right-hand panel: payment set to 60 euros.

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Simulation of case B. We then present the simulation results for case B, reported in Table 4, where, again, 0.15 indicates a 15% decrease of profit in year 1 and 0.30 a 30% decrease of production in year 2.

It should be noted that the assumed reductions in crop production associated with some measures are intentionally set at relatively high levels. This modelling choice is adopted to make the trade-offs between environmental benefits and economic performance more visible in the simulation results. In practice, the actual impact of these policies on yields may be smaller, particularly when improved agronomic practices or precision farming techniques compensate for reduced input use. The calibration should therefore be interpreted as a stylized representation designed to highlight the mechanisms through which environmental policies affect production decisions.

Name	eco4
Duration	2
Payment/ha	70
Profit reduction	0.15
Product reduction	0.30
Nitrogen	optional|0.2
Herbicide	optional|0.3
Insecticide	optional|0.15
Admin costs	10

Table 4: Calibration of Italian Eco-scheme 4 incentive derived from CAP 2023-2027 environmental policies: case B.

We are particularly interested in highlighting the role that policy changes may play through price adjustments. Because the simulations are conducted under tranquil conditions, international wheat mobility is almost absent due to the persistence of established trading relationships between countries. As a consequence, changes in Italian production and the resulting adjustments in the domestic market do not attract the attention of international buyers. In a more theoretical economic framework, this situation corresponds to treating Italy as a small open economy.

When a policy is introduced that reduces domestic market supply, wheat prices tend to increase. However, higher prices also increase the opportunity cost of participating in the policy. As market prices rise, the foregone revenue from reduced production increases, and some farms may no longer find participation profitable. This mechanism is evident in the charts of Figure 6, 7, and 8.

Therefore, the introduction of a policy, or an increase in its payment level, may generate a crowding-out effect through the price channel: higher wheat prices reduce the policy's attractiveness to some producers. Conversely, a reduction in policy payments may have its negative effects partially mitigated by the decline in domestic prices that follows an increase in supply.

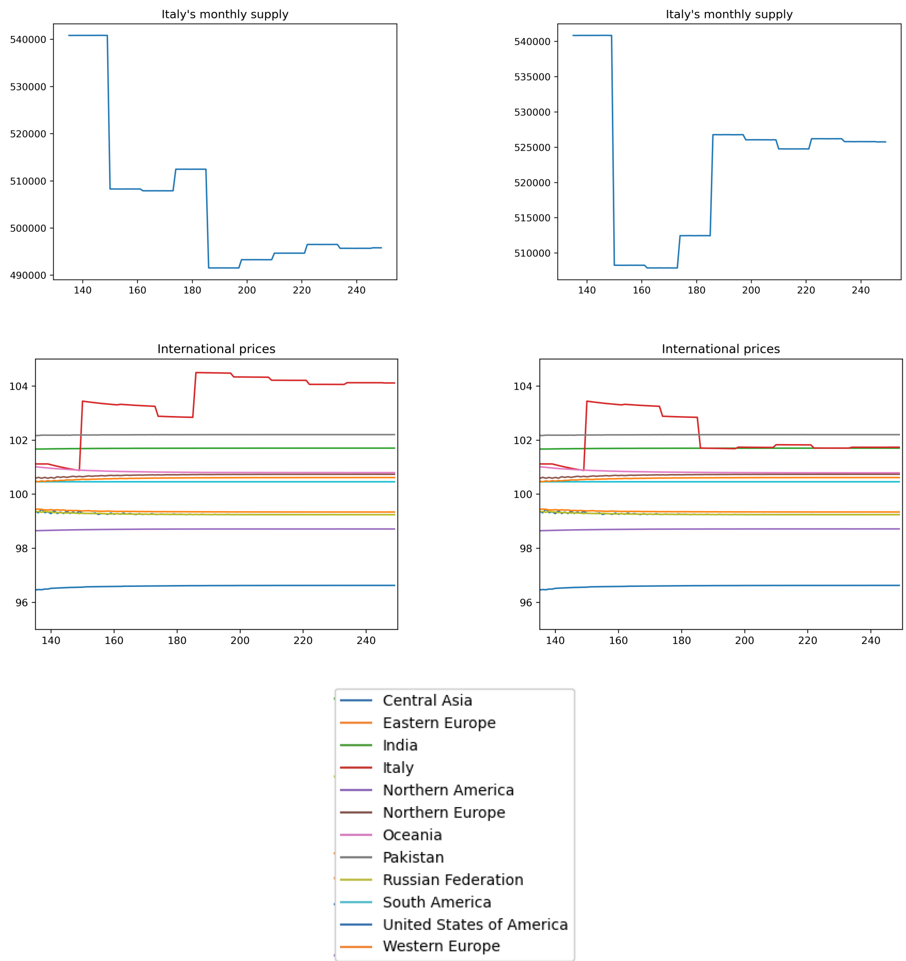

Figure 6: Case B. Effects on Italy's supply and international prices of wheat after the adoption of Eco-scheme 4 (introduced at time 140). Left side panel: payment set to 80 euros. Right-hand panel: payment set to 60 euros.

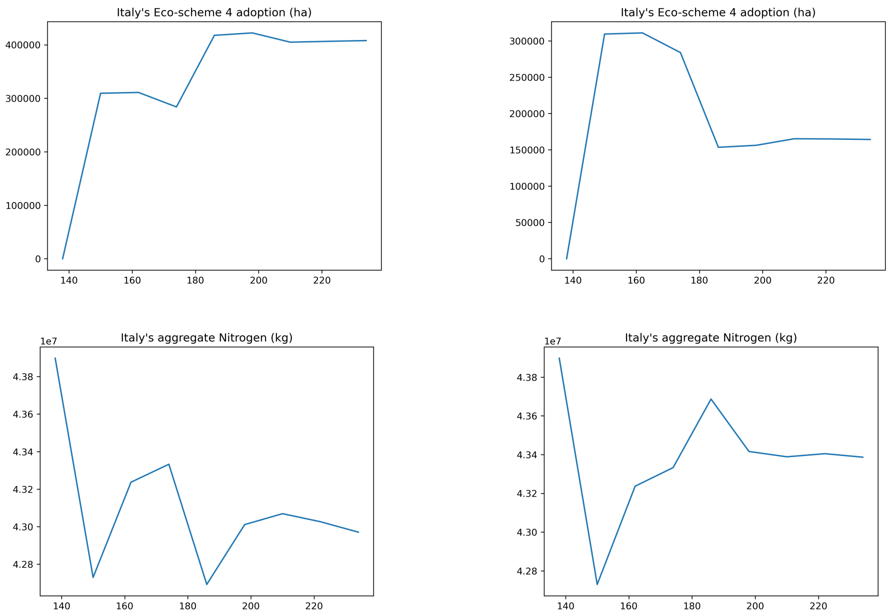

Figure 7: Case B. Effects on Italy's hectares of wheat and input quantity after the adoption of Eco-scheme 4 (introduced at time 140). Left side panel: payment set to 80 euros. Right-hand panel: payment set to 60 euros.

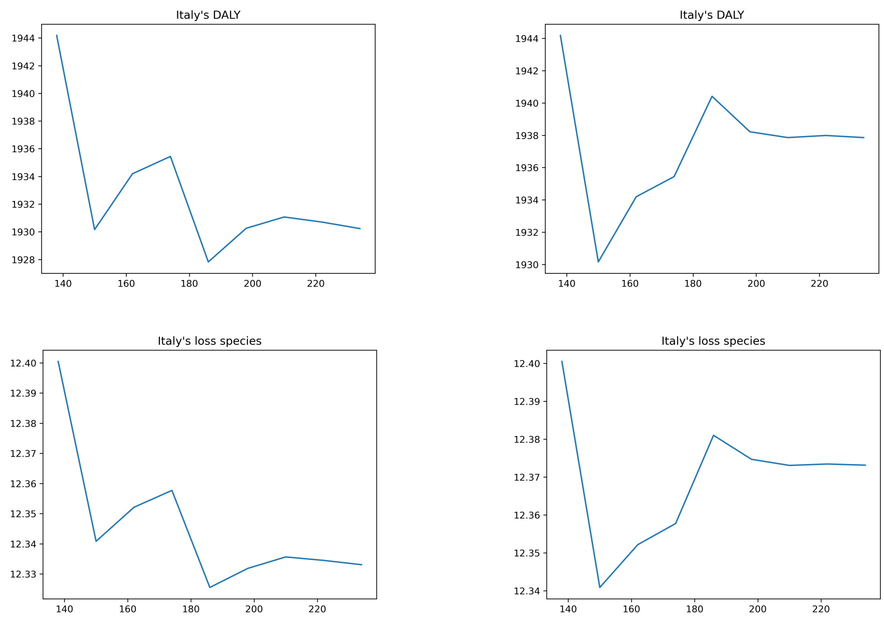

Figure 8: Case B. Effects on Italy's LCA indicators after the adoption of Eco-scheme 4 (introduced at time 140). Left side panel: payment set to 80 euros. Right-hand panel: payment set to 60 euros.

2.2 A note of the model parametrization for comparability of Eco-scheme 4, SRA19, and SRA20

The ECOWHEATALY model simulates three policy instruments included in the Italian CAP Strategic Plan: Eco-scheme 4 under Pillar I and the agri-environmental measures SRA19 and SRA20 under Pillar II. Although these policies share the common objective of reducing the environmental impact of agricultural production, their institutional design and the nature of the associated constraints differ substantially. For this reason, a specific calibration strategy is required to ensure internal consistency and comparability across policy scenarios.

In the model, each policy is parameterized through a set of elements that characterize both the economic incentives and the production constraints faced by farmers. These parameters include: (i) the duration of the commitment, (ii) the public contribution, (iii) the percentage loss of profit, (iv) the percentage loss of production, (v) the percentage reduction in nitrogen use and whether the reduction is binding or optional, (vi) the percentage reduction in herbicides and whether the reduction is binding or optional, (vii) the percentage reduction in insecticides and whether the reduction is binding or optional, and (viii) the total administrative cost required for participation.

For SRA19 and SRA20, the calibration follows a benchmark-based approach that allows the economic impact of the policy to be determined endogenously within the model. First, the profit-maximizing combination of inputs (nitrogen, herbicides, and insecticides) is determined in the absence of policy constraints. This benchmark represents the unconstrained technological and economic optimum for each farm. The policy targets in terms of input reductions are then defined relative to this baseline level. Once the policy constraints are imposed, farms re-optimize their production decisions subject to the required reductions in input use. The resulting adjustments in input use, production levels, and profits allow the model to determine endogenously the implied losses in output and profitability associated with the policy.

The calibration of Eco-scheme 4 follows a different logic. In this case, the reduction in input use is not imposed as a binding technological constraint but remains largely voluntary. As a consequence, the model cannot derive the associated losses in output and profit through the same endogenous mechanism used for SRA19 and SRA20. Instead, the calibration of Eco-scheme 4 relies on jointly specifying the policy contribution and the assumed percentage losses in profit and production. This approach provides greater flexibility and allows the simulated contribution levels to remain broadly consistent with the payments observed in the actual CAP implementation.

However, this flexibility creates a potential comparability issue when Eco-scheme 4 is simulated jointly with SRA19 and SRA20. In order to ensure consistency across policy scenarios, the contribution associated with Eco-scheme 4 must be calibrated in relation to the profit losses generated endogenously by SRA19 and SRA20. For this reason, the simulated payment level of Eco-scheme 4 may deviate from the observed policy values when the three measures are analyzed simultaneously. This adjustment ensures that differences in adoption and economic outcomes across policies reflect structural differences in the policy design rather than inconsistencies in the calibration of incentives.

A further institutional distinction concerns the governance structure of these policies. Eco-scheme 4 belongs to Pillar I of the CAP and is implemented through a nationally uniform framework. By contrast, SRA19 and SRA20 are part of Pillar II and are implemented at the regional level. In practice, many Italian regions do not activate these measures because their implementation requires detailed monitoring of farm-level input reductions and involves significant administrative complexity.

In the ECOWHEATALY simulations, a simplifying assumption is therefore adopted: SRA19 and SRA20 are assumed to be implemented uniformly across all regions. Within the modelling framework, it is possible to construct a farm-specific benchmark for input use and to calculate the required reductions relative to this baseline. In reality, however, policy authorities generally lack the detailed micro-level information necessary to define such benchmarks for each farm, which partly explains the limited regional uptake of these measures.

2.3 SRA19: Reduction of Pesticide Use

The intervention SRA19 ("Reduction of pesticide use") is part of the agri-environment–climate commitments implemented under Pillar II of the Italian CAP Strategic Plan (2023–2027). The measure aims to reduce the environmental and health risks associated with plant protection products by encouraging farmers to decrease pesticide intensity and adopt reinforced integrated pest management (IPM) practices. Participation is voluntary and typically involves a multiannual commitment, generally lasting five years.

Under the scheme, farmers receive a per-hectare payment conditional on achieving a measurable reduction in pesticide use relative to baseline levels and on implementing reinforced IPM practices. These include monitoring pest populations, applying treatment thresholds, prioritizing low-impact active substances, and maintaining detailed treatment records. Payments are designed to compensate farmers for additional management costs, potential yield reductions, and increased production risks associated with lower chemical input use.

From an economic perspective, SRA19 can be interpreted as a conditional agri-environmental contract that modifies farmers' input decisions. Let H denote herbicide use and I insecticide use. The policy can be represented either as a constraint on pesticide intensity (e.g., $H \leq \bar{H}$ and $I \leq \bar{I}$), or as a conditional payment received only if pesticide use remains below specified thresholds. In both interpretations, the intervention increases the relative cost of chemical pest control, thereby encouraging farmers to reduce pesticide inputs and adopt alternative crop management practices.

Quantitative comparison of baseline and reduced pesticide use To assess the potential impact of SRA19 on cereal production systems, it is useful to compare baseline pesticide use with the reduced input levels required under the intervention. In conventional wheat production systems, herbicides and fungicides are important components of crop protection strategies, particularly for weed and disease control.

Under SRA19, farmers are required to reduce pesticide intensity relative to baseline practices. In many regional implementations, the reduction target typically ranges between 20% and 30% of baseline pesticide use. The measure, therefore, implies a shift toward lower chemical intensity combined with reinforced integrated pest management practices.

Although these reductions may increase pest pressure or production risk in some circumstances, improved monitoring and targeted treatments can partially offset the potential negative effects on yields.

2.3.1 Average input and revenue effects of SRA19

To represent the effects of SRA19 in the model, we consider a stylized reduction in pesticide use consistent with the policy objectives of the Italian CAP Strategic Plan. In particular, we assume that herbicide and insecticide applications are reduced relative to baseline levels.

Let H_0 and I_0 denote baseline herbicide and insecticide use. Under SRA19, pesticide inputs are reduced to:

$$H^p = (1 - \delta_H)H_0, \qquad I^p = (1 - \delta_I)I_0$$

where δ_H and δ_I represent the reduction rates. Based on typical program requirements, we assume reductions in the range of 20–30%.

The policy provides a per-hectare payment intended to compensate farmers for additional management costs, potential yield reductions, and increased production risk associated with lower pesticide intensity.

2.3.2 Implementation of SRA19 in ECOWHEATALY

To implement the measure in ECOWHEATALY, we first compute the production inputs the farmer would choose in the absence of a policy. Full details of this computation are given in Task Report 2.2. However, briefly report the solution strategy. Given the specific farm parameters:

- $\bar{y}$ the maximum attainable yield
- s_i the share of yield loss if no input i is used
- λ_i the contribution of input i to the yield

The target yield $\hat{y}^*$, i.e., the yield that maximizes profit, is computed. Using this figure, the farm computes the production inputs $\hat{x}_i^*$.

These values are the **baseline levels** against which the policy's measurable reduction in pesticide use is evaluated.

To link the policy to the theoretical model, we make the following notation pairing:

- x_1 is N, therefore $\hat{N}^*$ denotes the nitrogen baseline level.
- x_2 is H, therefore, $\hat{H}^*$ denotes the herbicide's baseline level.
- x_3 is I, therefore, $\hat{I}^*$ denotes the insecticides baseline level.

We have to evaluate what happens if the farm uses

$$H^p = (1 - \delta_H)\hat{H}^*, \qquad I^p = (1 - \delta_I)\hat{I}^*$$

instead of $\hat{H}^*$ and $\hat{I}^*$.

We recall at this point that the farm chooses according to

$$\hat{y} = \min(y_{x_i})$$

then, given H^p and I^p, we compute

$$y_H = \bar{y}(1 - s_H) + \bar{y}s_H(1 - e^{-\lambda_i H^p})$$

and

$$y_I = \bar{y}(1 - s_I) + \bar{y}s_I(1 - e^{-\lambda_i I^p})$$

Recall also that in the unconstrained case we have $\hat{y}^* = y_N = y_H = y_I$, whereas in the constrained case we have $y_{H^p} < y_N = \hat{y}^*$ and $y_{I^p} < y_N = \hat{y}^*$. However, we do not know whether $y_{I^p} < y_{H^p}$ or not.

Therefore, the production inputs must be set in such a way that their conditional yield equals

$$\hat{y} = \min(y_H, y_I)$$

Thus, once we have identified $\hat{y}$, we recompute the inputs using

$$\hat{x}_i = -\frac{1}{\lambda_i} \ln\left(\frac{(1 + \bar{s}_i - s_i)\bar{y} - \hat{y}}{\bar{s}_i\bar{y}}\right)$$

For clarity, suppose we have $\hat{y} = y_H$. In this case, $\hat{H} = H^p$, $\hat{I} < I^p$ and $\hat{N} < \hat{N}^*$. Similarly, if $\hat{y} = y_I$, $\hat{N}$ is the one that constrains y_N to equal y_I, $\hat{H} < H^p$ and $\hat{I} = I^p$. In any case, the farm satisfies the policy requisites.

Adopting and switching The above considerations allow computation of the farm profit under the two alternative assumptions: policy adoption and non-adoption.

The change in profit can be computed precisely using the microeconomic model. Denoting the change in profit as $\delta\hat{\pi}_{SRA19}$, the policy adoption and switch are performed as described in the case of Eco-scheme 4. The probability of joining SRA19 is proportional to $S - \delta\hat{\pi}_{SRA19} - K/A$:

$$p(SRA_{19}) \propto S - \delta\hat{\pi}_{SRA19} - \frac{K}{A}.$$

where S is the policy reward per hectare, K is the additional bureaucratic and switching costs required to obtain this benefit, and A is the farm acreage. Considerations regarding the nature of these variables are the same as those we highlighted in the Eco-scheme 4 section.

The simulation timeline also traces the Eco-scheme 4 case. Refer to the text in that section and to Algorithm 1 for a visual representation.

Farms that joined the scheme compute inputs annually as described by the microeconomic model reported above in this section.

2.3.3 Results of SRA 19 adoption

The input parameter for the SRA19 analysis in the ECOWHEATALY model is reported in Table 5. Recall from Section 2.2 that, unlike for Eco-scheme 4, we do not need to use external parameters to estimate profit and production losses; in this case, they are computed endogenously by the model. The results of this calibration are visualized in Figure 10.

Name	sra19
Duration	5
Payment/ha	5
Profit reduction	–
Product reduction	–
Nitrogen	optional|0.25
Herbicide	mandatory|0.25
Insecticide	mandatory|0.25
Admin costs	30

Table 5: Calibration of Italian SRA19 incentive derived from CAP 2023-2027 environmental policies.

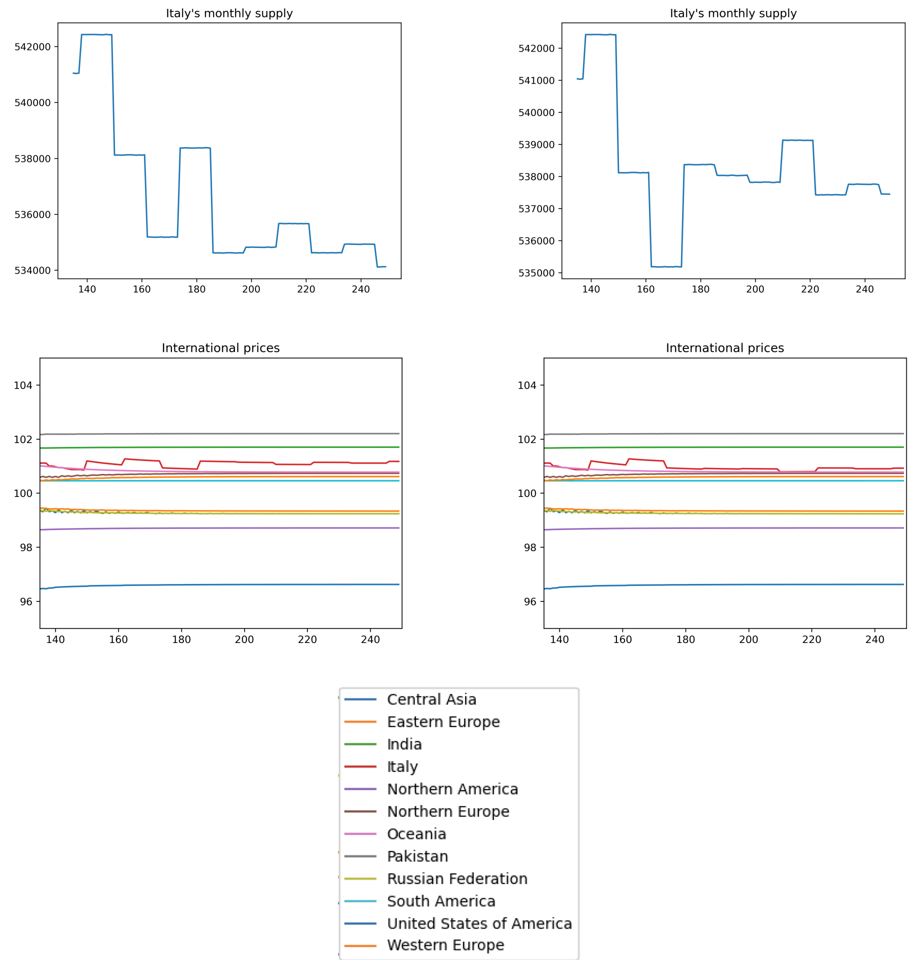

Figure 9: Effects on Italy's supply and international prices of wheat after the adoption of SRA19 (introduced at time 140). Left side panel: payment set to 7. Right-hand panel: payment set to 3.

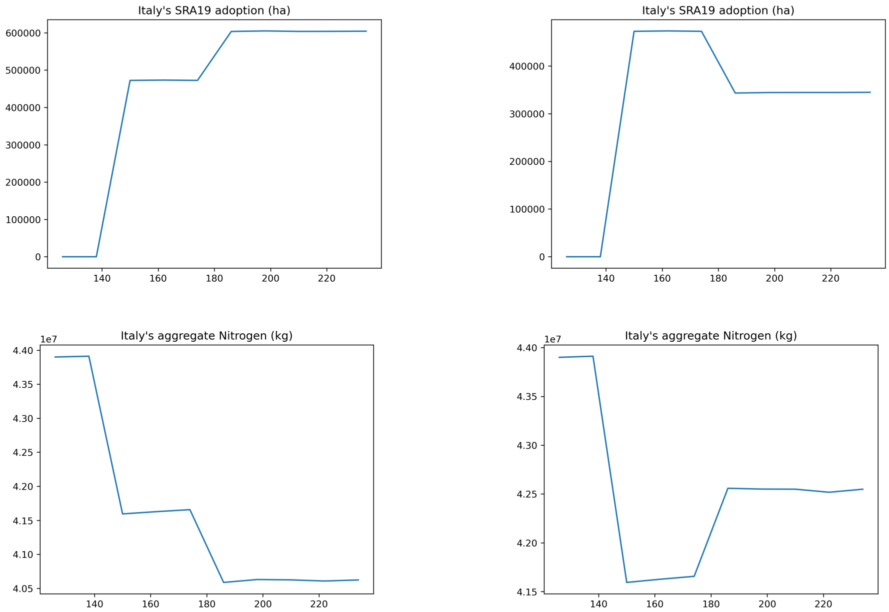

Figure 10: Effects on Italy's hectares of wheat and input quantity after the adoption of SRA19 (introduced at time 140). Left side panel: payment set to 7. Right-hand panel: payment set to 3.

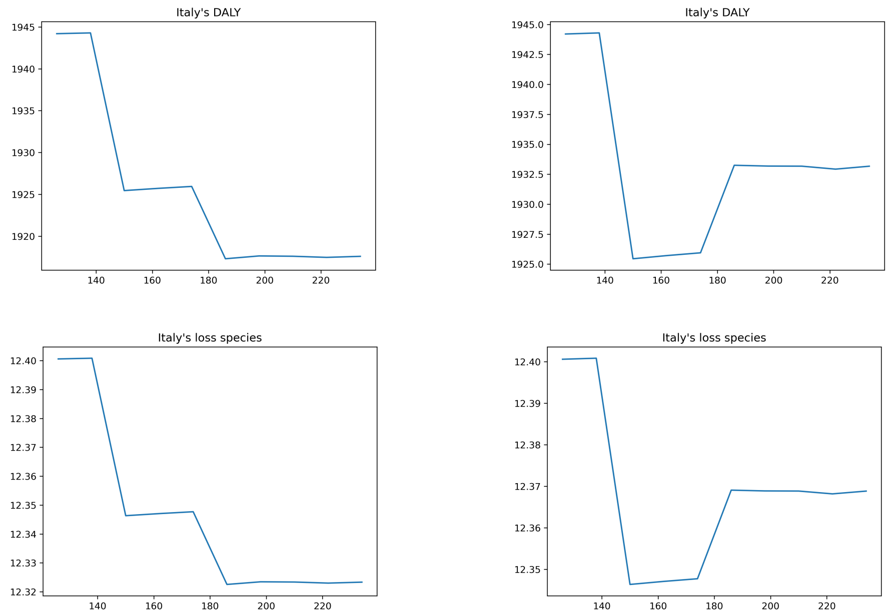

Figure 11: Effects on Italy's LCA indicators after the adoption of SRA19 (introduced at time 140). Left side panel: payment set to 7. Right-hand panel: payment set to 3.

2.4 SRA20: Sustainable Nutrient Management

The intervention SRA20 ("Sustainable nutrient management") is part of the agri-environment-climate commitments implemented under Pillar II of the Italian CAP Strategic Plan (2023–2027). The measure aims to reduce the environmental impacts associated with excessive fertilizer use, particularly nitrogen, by encouraging farmers to adopt improved nutrient management practices. Participation in the scheme is voluntary and typically involves a multiannual commitment, generally lasting five years.

Under the program, farmers receive a per-hectare payment conditional on implementing nutrient management plans and reducing fertilizer intensity relative to baseline practices or regional technical standards. These requirements may include soil testing, improved fertilization timing, and the adoption of precision fertilization techniques to increase nutrient-use efficiency. Payments are intended to compensate farmers for additional management costs, potential yield reductions, and increased production risk associated with lower fertilizer use.

From an economic perspective, SRA20 can be interpreted as a policy affecting the optimal level of nitrogen input. Let N denote nitrogen use. The intervention may be represented either as a constraint on fertilizer application (e.g., $N \leq \bar{N}$) or as a conditional payment contingent on fertilization remaining below a specified threshold. In both cases, the policy encourages farmers to reduce nitrogen use and adopt more efficient fertilization practices.

Quantitative comparison of baseline and sustainable fertilization The SRA20 intervention targets the environmental impacts associated with excessive nutrient use, particularly nitrogen fertilizers. In conventional cereal production systems, nitrogen fertilization is a major determinant of crop yields but also a major source of negative environmental impacts, including nitrate leaching and greenhouse gas emissions.

Under SRA20, farmers are encouraged to adopt improved nutrient management practices and to reduce fertilizer intensity relative to conventional fertilization levels. In many implementations, nitrogen application is reduced by approximately 15–20% compared to baseline agronomic practices.

These reductions are typically accompanied by improved nutrient management strategies, such as soil testing and optimized fertilization timing, to maintain nutrient-use efficiency while reducing environmental impacts.

2.4.1 Average input and revenue effects of SRA20

To incorporate SRA20 into the model, we represent the policy as a reduction in nitrogen input relative to baseline fertilization levels. Let N_0 denote baseline nitrogen application. Under the sustainable nutrient management scheme, nitrogen use becomes:

$$N = (1 - \delta_N)N_0$$

where δ_N represents the reduction rate induced by the policy. Consistent with the objectives of the intervention, we assume reductions in nitrogen use in the range of 15–20%.

As with other agri-environment–climate measures, farmers receive a per-hectare payment designed to compensate for additional management costs and potential yield effects associated with reduced fertilization.

2.4.2 Implementation of SRA20 in ECOWHEATALY

The computation here traces that of SRA19. We start from the **baseline** levels of inputs computed under the assumption that their level maximizes profit. As above they are denoted with $\hat{N}^*$, $\hat{H}^*$, $\hat{I}^*$. We have to evaluate what happens if

$$N^p = (1 - \delta_n)\hat{N}^*$$

The conditional yield of nitrogen now is

$$y_N = \bar{y}(1 - s_N) + \bar{y}s_N(1 - e^{-\lambda_i N^p})$$

because $y_N < \hat{y}^*$, also $\hat{y}_H$ and $\hat{y}_I$ must be equal to y_N

We now recompute the inputs using

$$\hat{x}_i = -\frac{1}{\lambda_i} \ln\left(\frac{(1 + \bar{s}_i - s_i)\bar{y} - \hat{y}}{\bar{s}_i\bar{y}}\right)$$

where $\hat{y} = y_N$.

In this situation we have $\hat{N} = N^p$, $\hat{H} < \hat{H}^*$, and $\hat{I} < \hat{I}^*$.

Adopting and switching As happens in SRA19, the change in profit can be computed precisely using the microeconomic model.

Denoting the change in profit as $\delta\hat{\pi}_{SRA20}$, the adoption and switch of the policy is performed as described in the previous cases. The probability of joining SRA20 is proportional to $S - \delta\hat{\pi}_{SRA20} - K/A$:

$$p(SRA_{20}) \propto S - \delta\hat{\pi}_{SRA20} - \frac{K}{A}.$$

where S is the policy reward per hectare, K is the additional bureaucratic and switching costs required to obtain this benefit, and A is the farm acreage. Considerations regarding the nature of these variables are the same as those we highlighted in the Eco-scheme 4 section.

The simulation timeline also traces the Eco-scheme 4 case. Refer to the text in that section and to Algorithm 1 for a visual representation.

Finally, note that farms that joined the scheme compute inputs annually as described by the microeconomic model reported above in this section.

2.4.3 Results of SRA20 adoption

The input parameters for the SRA20 analysis in the ECOWHEATALY model are reported in Table 6. As with SRA19, we do not need external parameters to estimate profit and production losses, as these are computed endogenously by the model. The results of this calibration are visualized in Figure 12.

Name	sra20
Duration	5
Payment/ha	5
Profit reduction	–
Product reduction	–
Nitrogen	mandatory|0.25
Herbicide	optional|0.25
Insecticide	optional|0.25
Admin costs	30

Table 6: Calibration of Italian SRA20 incentive derived from CAP 2023-2027 environmental policies.

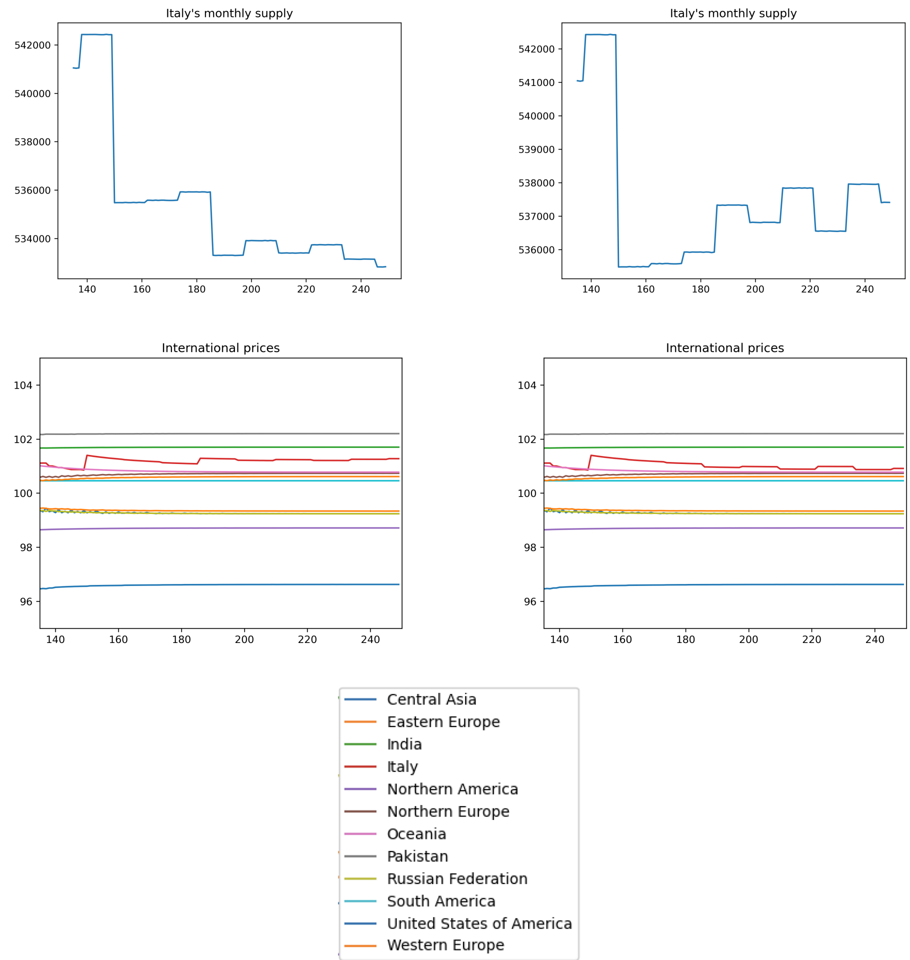

Figure 12: Effects on Italy's supply and international prices of wheat after the adoption of SRA20 (introduced at time 140). Left side panel: payment set to 7. Right-hand panel: payment set to 3.

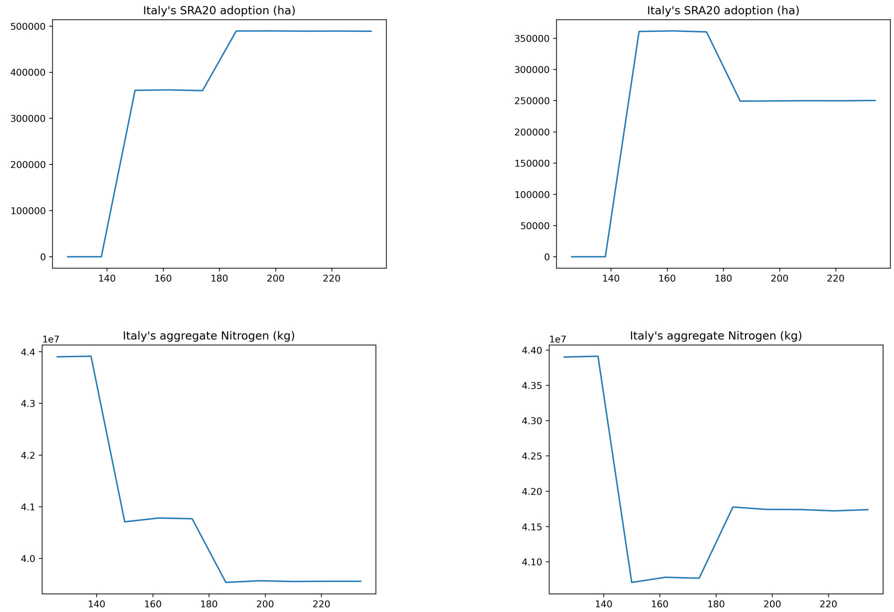

Figure 13: Effects on Italy's hectares of wheat and input quantity after the adoption of SRA20 (introduced at time 140). Left side panel: payment set to 7. Right-hand panel: payment set to 3.

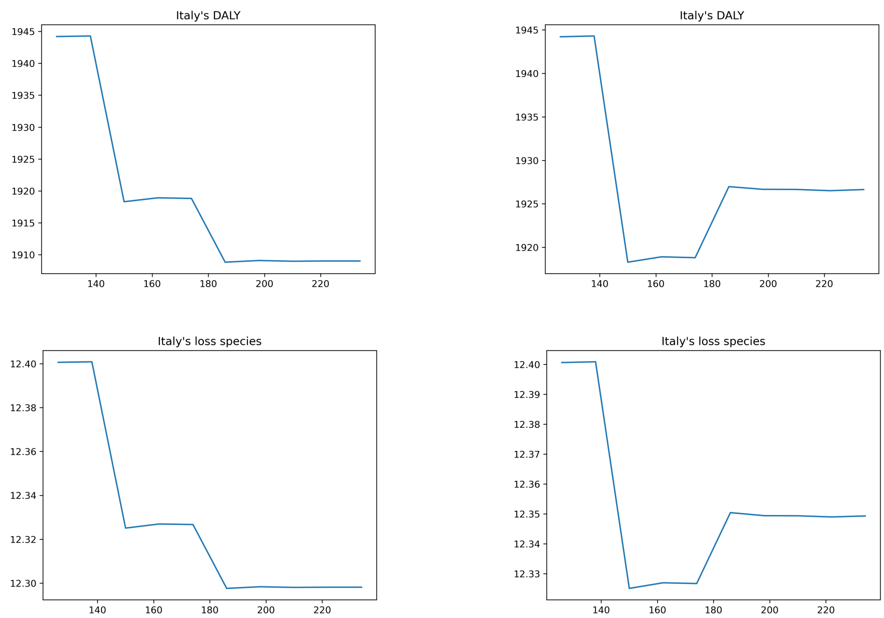

Figure 14: Effects on Italy's LCA indicators after the adoption of SRA20 (introduced at time 140). Left side panel: payment set to 7. Right-hand panel: payment set to 3.

2.5 Simulating the CAP green Policies

We now simulate a setting in which the previously analyzed policies are simultaneously available to farmers. Since Italian legislation allows it, in this setting, it is also possible to combine the SRA19 and SRA20 policies. Table 7 summarizes the parameters used to represent the environmental policies considered in the model. The table reports the approximate payment levels and the stylized effects of each policy on input use. These values are consistent with the objectives of the Italian CAP 2023-2027 Strategic Plan. They are intended to capture the order of magnitude of the policy incentives rather than their exact administrative implementation. See section 2.2 for a discussion of parameter settings. The results of this calibration are visualized in Figure 15, 16, and 17.

Name	Eco4	SRA19	SRA20	SRA19+20
Duration	2	5	5	5
Payment/ha	5	5	5	5.5
Profit reduction	0.01	–	–	–
Product reduction	0.0	–	–	–
Nitrogen	optional|0.25	optional|0.25	mandatory|0.25	mandatory|0.25
Herbicide	optional|0.25	mandatory|0.25	optional|0.25	mandatory|0.25
Insecticide	optional|0.25	mandatory|0.25	optional|0.25	mandatory|0.25
Admin costs	10	30	30	45

Table 7: Parametrization of CAP 2023-2027 environmental policies.

Name	None	ECO4	SRA19	SRA20	SRA19+20	sum
n. farms	72756	37278	19827	3574	2052	135487
hectares	471159	283638	230905	34730	44690	1065122

Table 8: Number of farms that adopt CAP 2023-2027 green policies in ECOWHEATALY model simulation and dedicated hectares.

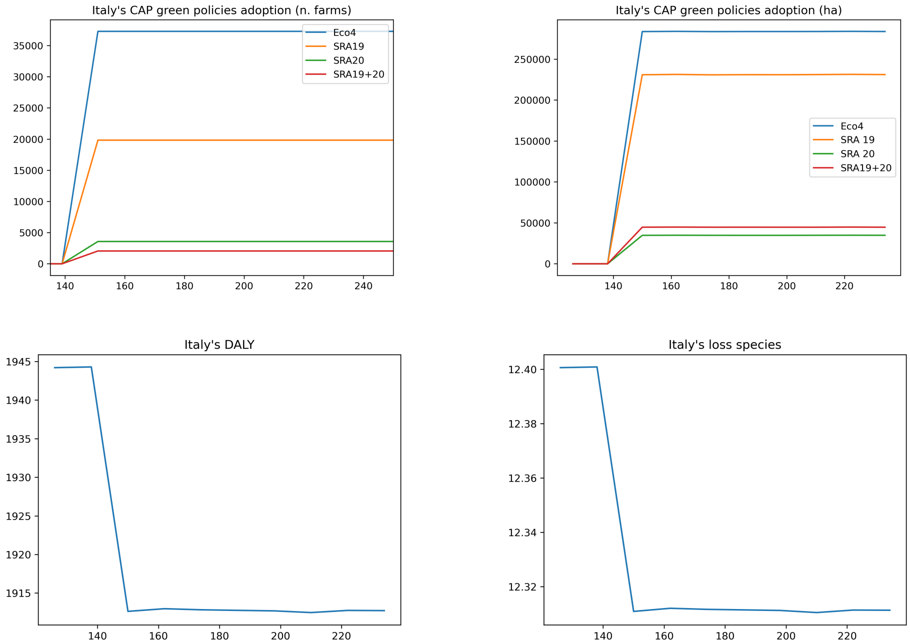

Figure 15: Italy's adoption of green policies and effects on Italy's LCA indicators after introduction of CAP (at time 140).

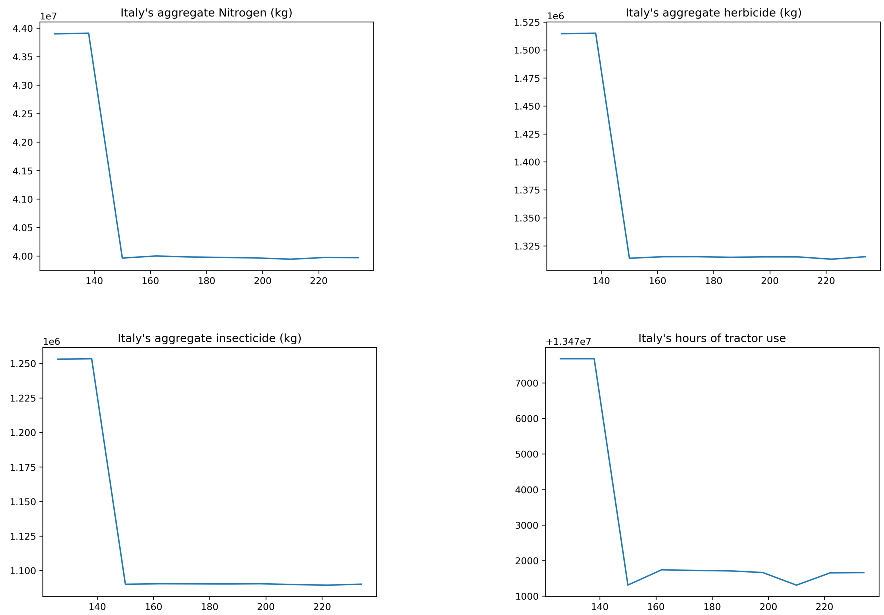

Figure 16: Effects on Italy's wheat production inputs after the introduction of CAP policies (at time 140).

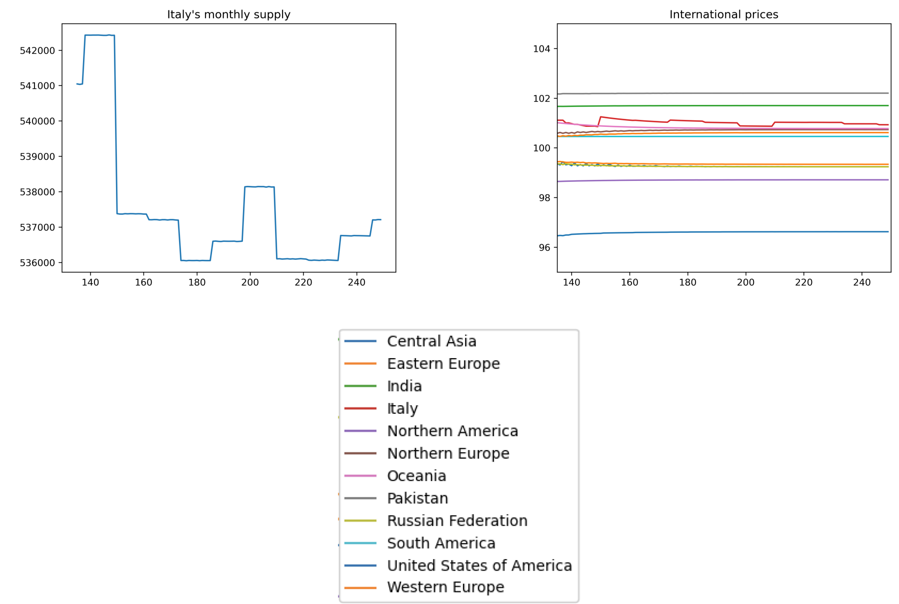

Figure 17: Effects on Italy's monthly supply and international prices of CAP policies introduction (at time 140).

3 Conclusions

This report presents the simulation results obtained within Task 3 of the ECOWHEATALY project, which aimed to evaluate the effects of environmental agricultural policies and external market shocks on the wheat production system. Using the integrated modelling framework developed in the earlier stages of the project, the analysis combined global market dynamics, heterogeneous farm behaviour, and environmental impact assessment within a single computational environment.

The simulation experiments explored how policy measures implemented within the Common Agricultural Policy, including Eco-scheme 4 and agri-environmental measures such as SRA19 and SRA20, may influence production decisions and environmental outcomes in the Italian wheat sector. These policies aim to reduce the environmental impact of agricultural production by encouraging crop diversification and lowering the use of chemical inputs such as fertilizers and pesticides.

The results highlight the importance of considering both economic and environmental dimensions when evaluating agricultural policy interventions. Environmental policies may generate positive sustainability outcomes by reducing input intensity and associated emissions, but their economic implications depend on farmers behavioural responses and on prevailing market conditions.

The simulations also illustrate how external shocks affecting the global wheat market may propagate through international trade networks and influence domestic production decisions. Changes in prices, trade restrictions, or supply disruptions can significantly alter the incentives faced by farmers, thereby affecting both production levels and environmental impacts.

By integrating farm-level decision-making, global market dynamics, and environmental assessment, the ECOWHEATALY modelling framework provides a comprehensive tool for analysing the complex interactions between agricultural policies and market forces. The results obtained in this task demonstrate the usefulness of this approach for exploring policy scenarios and assessing potential trade-offs between economic performance and environmental sustainability.

Future research within the project will extend these simulations to a broader range of scenarios and policy configurations, aiming to support evidence-based policy design for sustainable wheat production systems.

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