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Article

Transition to Organic Farming in Italy Through a Dynamic Mathematical Programming Model: Impacts on Agricultural Area and Budget Allocations

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Abstract

The European Union aims to achieve the target of 25% of land under organic farming by 2030. Italy reached the share of 18.7% in 2022, although significant regional differences persist. This study analyzes farms' conversion response in the Lazio region (Italy) to evaluate the effectiveness of higher economic incentives in promoting organic conversion. The agro-economic supply model AGRITALIM is applied to a sample of 587 FADN farms. The model simulates individual farm conversion choice, distinguishing between conversion and maintenance phases, and accounting for conversion costs, yield, and price variations associated with each period. Results show limited effects of increased economic support: the 2023–2027 Common Agricultural Policy reform, characterized by higher support, leads to a 5.1% increase in the area under organic farming, while a 40% increase in financial support generates an expansion of 12%. Farm responses are highly heterogeneous: rural provinces, larger and arable farms are more responsive, while smaller farms and livestock are less likely to convert. These findings highlight the need for integrated policy strategies combining financial support, reduced costs, technical assistance, and improved market access. The methodological approach adopted in this study provides a useful tool for supporting the design of targeted and effective policy interventions.

Keywords: organic farming; mathematical programming; CAP

1. Introduction

In December 2019, the European Commission introduced the European Green Deal, aiming for climate neutrality by 2050. Within this framework, the Farm to Fork Strategy (F2F), specifically focused on the agricultural sector, highlights the benefits of organic farming and sets a target for 25% of EU agricultural land to be organic. The 2014–2022 Common Agricultural Policy (CAP) had already supported organic farming expansion, allocating substantial financial resources to the sector. In Italy, a significant boost in this direction came from the Rural Development Programs (RDPs), which introduced Measure 11, specifically aimed at supporting organic farming. As a result, by 2022, the organic area reached 18.7%, a 7.5% increase compared to 2021, bringing Italy closer to the F2F target set for 2027. However, each region had the flexibility to define the role of organic farming within its RDP strategy. This led to disparities at the national level, partly due to regional agricultural characteristics that need to be considered.

Organic farming differs significantly from conventional farming, especially in management practices and productivity [1,2]. It faces sector-specific risks, i.e., the challenges of transition, soil conservation, and price volatility, with premium prices not always guaranteed [3–5]. While higher prices should compensate for lower yields [6], this is not always the case, especially for livestock products and vegetables [7]. The fragility of the production system can be exacerbated by specific territorial and climatic conditions, making economic returns uncertain [8]. Moreover, the difficulty of

transitioning from conventional to organic farming remains a barrier, especially for small and medium-sized farms [9,10].

Several studies have investigated and modelled the conversion to organic farming. Among them, most usually use individual farms [5] or representative farms, usually hypothesizing a 100% conversion [11,12]. Others use partial equilibrium models not considering all crops and countries across the EU [13] or considering the organic target of 25% jointly with other F2F measures (Barreiro-Hurle et al., 2021; Henning et al., 2021). Recently, Kremmydas et al. (2024), Kremmydas et al. (2023), and [18] have used static farm-level models to analyze organic conversion patterns, the effects of alternative budget allocations, and different policy strategies aimed at achieving the F2F organic target. This study builds on that literature by adopting a dynamic agro-economic modelling framework that explicitly represents farms’ conversion decisions over time. This approach allows farmers to optimize resource allocation and investment choices within an intertemporal frame and to account for the distinct cost-benefit conditions characterizing the conversion and maintenance phases of organic farming.

In this setting, the study has two main objectives: (i) to develop a dynamic farm-level model that explicitly distinguishes between the conversion and maintenance phases, enabling farm-specific adjustment decisions without imposing full conversion; and (ii) to assess how increases in CAP support affect the expansion of land under organic farming, taking into account farm-level and territorial heterogeneity.

To reach these goals, the Lazio region is considered a case study. The analysis simulates a set of scenarios characterized by progressively higher payment levels for organic farming, with the aim of assessing the effectiveness of increased budget allocations in promoting conversion and contributing to the F2F 25% target. The underlying hypothesis is that higher levels of CAP support can promote the expansion of organic farming in the region. Simulations are carried out through an agro-economic supply model applied to an Italian Farm Accountancy Data Network (FADN) sample of 391 farms for the year 2020.

2. Materials and Methods

2.1. Data

Utilizing an agro-supply model rooted in microeconomic data and designed to consider farm-specific choices, i.e., AGRITALIM, the analysis provides detailed responses for each farm, leveraging data at the farm level from the Italian FADN. Specifically, for this analysis, AGRITALIM was applied to a FADN sample of 578 conventional farms in the Lazio region for the year 2020.

Table 1 shows the main descriptive statistics for the sample, specifically for the group of conventional and organic farms. In terms of spatial distribution, organic farms are mainly located in Viterbo (52.9%), in Rieti (24.6%), followed by Rome (13.4%), Frosinone (7.0%), and Latina (2.1%). The distribution over farm size, instead, is homogeneous: farms between 5 and 15 hectares represent the 31.0%, farms between 15 and 40 hectares represent the 25.7%, and farms above 40 hectares represent the 35.8%. Instead, small farms under 5 hectares only represent the 7.5%. Table 2 shows the distribution over Type of Farming (TF), showing that some sectors are more prone to conversion, such as Olive groves (62.5% of organic farms) and Vineyards (52%). Others, such as Cereals are all classified as Conventional.

Table 1. Descriptive Statistics of the selected FADN sample, and for the Conventional and Organic groups of farms.

Variable	UM	Conventional		Organic		Total	
		Mean	SD	Mean	SD	Mean	SD
Land	Ha	32.6	49.0	48.1	63.5	37.6	54.6
Operating Income	€/ha	3466.2	7043.9	1908.3	2764.5	2962.2	6044.2

Livestock Units (LSU)	Number of heads/ha	22.7	141.6	2.7	6.7	15.2	112.5
Hired Work	Working Units/ha	0.2	0.5	0.1	0.1	0.2	0.4
Family Work	Working Units/ha	0.1	0.4	0.1	0.1	0.1	0.3
Gross Margin	€/ha	4367.2	7930.3	2604.4	3176.8	3796.9	6814.9
Total Gross Output	€/ha	7196.8	9264.4	4143.3	5398.5	6208.9	8333.8
Crop Gross Output	€/ha	4434.4	7892.9	2944.7	4813.1	3952.4	7075.5
Livestock Gross Output	€/ha	2359.4	5670.6	867.9	2755.1	1876.8	4966.8

Table 2. Distribution of Conventional and Organic farms over Type of Farming.

Type of Farming	Conventional	Organic	Total	% Organic Farming on Total
Dairy Cattle	49	9	58	15.5
Cereals	12	0	12	0.0
Livestock	81	48	129	37.2
Tree Crops	51	44	95	46.3
Granivores	12	12	24	50.0
Mixed Crops and Livestock	30	22	52	42.3
Olive Groves	6	10	16	62.5
Horticulture	60	20	80	25.0
Arable farms	78	9	87	10.3
Vineyards	12	13	25	52.0
Total	391	187	578	32.4

2.2. The AGRITALIM Model

Operating within the category of agro-economic supply models, AGRITALIM is based on non-linear Mathematical Programming, combining Leontief technology for variable costs with a quadratic cost function. It is calibrated through the Positive Mathematical Programming (PMP) approach [19,20]. The main components of the objective function and constraints concern land, labor (both manual and mechanic), water and feed availability (Eq. 1). AGRITALIM maximizes the farm operative income, considering market elements (prices of outputs and inputs), production functions (linking crop yields and inputs), agricultural policy support, and depreciation costs. Specifically, in this study, the model maximizes farm income over two phases, i.e. conversion and maintenance, incorporating the allocation of resources and investment decision. Future revenues are discounted using an interest rate (r). Equations 1 and 2 describe the objective function:

$$\max Z = \sum_t \frac{1}{(1+r)^t} Income_t \tag{1}$$

$$Income_t = [(pc + \Delta pc_t BIN_t) \cdot (y + \Delta y_t BIN_t) + Pbio_t BIN_t - (c + \Delta c_t BIN_t)] X_t \quad \forall t \tag{2}$$

The model maximizes the discounted operating income Z for each farm (Eq. 1), where t denotes the two phases of organic adoption: conversion and maintenance. The discount factor $1/(1 + r)^t$ accounts for the intertemporal valuation of income streams. Period-specific income, $Income_t$, is defined in Equation (2). The variables pc and y denote output prices and yields, respectively, while X represents the levels of each activity, expressed in hectares for crops and number of heads for livestock. The parameter c represents production costs associated with each activity.

The transition to organic farming is modeled through a binary variable, BIN_t , which activates the organic farming payment $Pbio_t$ when a farm chooses to convert ($BIN_t = 1$). The same variable also activates the differential terms Δpc_t , Δy_t , and the cost differential component Δc_t , capturing deviations in prices, yields, and marginal costs under organic management relative to conventional farming. The differential parameters were calibrated using FADN data from the previous three years for organic crops and livestock within the same geographical area, province, and altitude class. For non-converting farms ($BIN_t = 0$), all differential terms are null, and conventional production conditions apply.

Considering that Italy is already at 18.7% of organic land [21], and aiming to reach 25%, assuming the target is set at the Member State level, a contribution from each region will be necessary. This is especially relevant since, under the CAP 2014-2020, rural development measures (including support for organic farming) were implemented through regional Rural Development Programmes (RDPs). Under the CAP 2023-2027 Strategic Plans (CSPs), support for organic farming and other rural development measures continues to be implemented at national and regional levels as part of each Member State’s plan, with allocations often tailored to regional needs. The Italian CSP allocates record financial resources to organic farming. In particular, the intervention dedicated to the adoption and maintenance of organic farming practices receives the largest budget among all rural development interventions, with a total allocation exceeding 2.2 billion euros. This corresponds to approximately 48% of all agri-environment interventions and about 14% of total public expenditure planned under the second pillar over the programming period (ISMEA, 2024).

Based on this, an analysis was conducted on the share of organic land across all Italian regions. Some, particularly in the North, show organic areas around 5-6%, such as Lombardy and Piedmont. This is largely due to the characteristics of farming in those regions, where intensive and profitable livestock farming likely limits the expansion of organic practices. This suggests that other regions, where the trend in organic farming has been more positive in recent years, can help achieve the overall target of 25%. Thus, the simulations are based on a set of assumptions involving a progressively higher commitment from regions with greater shares of organic land, such as Lazio, where 22.6% of the regional area was organic in 2020. Simulations are designed to assess farms’ sensitivity to changes in policy support for organic farming. Specifically, the analysis evaluates whether alternative payment levels can foster further conversion and to what extent they contribute to increasing the regional organic area.

As a first scenario, the model considers the CAP 2023–2027 payment levels for organic farming as defined in the CAP Strategic Plan. Compared to the previous programming period, payments in Lazio decreased from 483 to 376 €/ha during the conversion phase and from 406 to 318 €/ha during the maintenance phase. This scenario represents the baseline policy framework.

Importantly, while unit payments are lower, the overall budget allocated to organic farming is substantially higher. This reflects a policy choice aimed at broadening participation by spreading available resources over a larger number of farms and hectares. The simulations, therefore, assess whether this strategy is sufficient to sustain further conversion, or whether higher per-hectare payments would be more effective in achieving more ambitious regional organic targets.

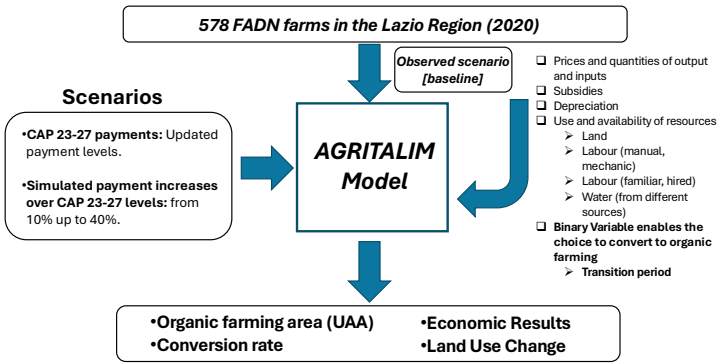


Figure 1. The AGRITALIM model, inputs, outputs, and simulated scenarios.

3. Results

The model provides results in terms of the variation of land under organic farming at the farm level. Specifically, it allows us to determine the rate of conversion and, consequently, the variation in unitary payments necessary to stimulate conversion and to assess the cost-effectiveness of this mechanism.

Table 3 shows the main results in terms of variation in the number of organic farms and UAA under organic farming. The CAP 2023–2027 reform represents a step forward in the conversion of farms, leading to an increase of 5.1% in UAA under organic farming. However, this result is achieved at the cost of a 15.4% increase in the budget. This pattern becomes even more evident in the other scenarios, i.e., farms respond in a relatively rigid way to increases in unitary payments. In fact, with a 15% increase in the unitary payment, the number of converted farms rises to 17, increasing to 20 farms in the intermediate scenario (+25%) and reaching 24 farms in the scenario with a 40% increase in payments. These changes correspond to increases of 7.8%, 8.5%, and 11.9% in UAA under organic farming, respectively, supported by overall budget increases of 25.8%, 29.9% and 47.5%. In other words, a substantial increase in regional expenditure, amounting to approximately €554,864, leads to the conversion of only 24 farms (around 12%), making this strategy relatively not cost-effective for policymakers, as shown by Figure 3.

The reasons behind this conversion can be different, and this is also explicitly shown by the spatial distribution of conversion. Looking at Figure 2, for example, the provinces that show an increase in the share of UAA under organic farming are mainly Rome and Viterbo, while Rieti, Frosinone, and Latina show very limited increases (between 0 and +2.9% in all scenarios considered). Rome, instead, shows a high sensitivity, with already large increases under the CAP 2023–2027 baseline (+20.2%) and further increases of +40.4%, +43.2%, and +49.2% in the +15%, +25% and +35% scenarios, respectively. A similar pattern is observed for Viterbo, which shows increases ranging from 18.9% up to 29.8% in the scenario with a +35% increase in unitary payments.

These results partially confirm the baseline situation, in which Viterbo and Rieti already showed a higher incidence of organic farming, while Rome, Frosinone, and Latina displayed a lower incidence. However, according to the results, Viterbo and Rome show a strong potential for expansion, while Rieti remains substantially stable, and Frosinone and Latina confirm a rigid response. This can be explained by the characteristics of these provinces, with Viterbo and Rieti being much more rural, while Latina and Frosinone are characterized by more intensive agricultural systems.

Further information emerges from the distribution of converting farms, in particular with respect to the incidence of UAA by type of farming. Conversion mainly occurs among Arable Crops farms, which already show high sensitivity under the CAP 2023–2027 baseline (+71%) and increase organic area up to 122.6% under this type of farming. Mixed Crops and Livestock farms follow, with more limited increases ranging from 4.4% in the CAP 2023–2027 scenario to 15.8% in the +35% scenario. Finally, Mixed Crops farms respond only starting from a +25% increase in payments, and their variation remains stable even in higher scenarios (+40.2%). Herbivores and Granivores farms, instead, do not respond to increases in unitary payments. Also in this case, the results show that the types of farming more prone to increasing organic area are mixed and arable systems, while for the other types, and especially for livestock farms, conversion is more difficult and less economically convenient in the short run. Moreover, sectors with an already high incidence in the baseline, such as olive groves and tree crops, do not show any relevant variation.

At the farm size level, the farms that convert the most are large farms, which already represented the largest share of UAA under organic farming in the baseline (Table 5). These farms increase both in terms of representativeness and in terms of converted area, from 16.1% in the CAP 2023–2027 scenario up to 28.5% in the +35% scenario. The increase for medium-sized farms (15–40 ha) is more limited, with converted UAA rising from 2.1% to 8.4% over the same scenarios. Small and medium

farms (5–15 ha) show a stable increase of 4.9% in UAA under organic farming, i.e., they are not sensitive to increases in unitary payments. Finally, very small farms (<5 ha) do not show any sensitivity to higher payments. Overall, these results show that different farm size classes react differently: although the baseline distribution of organic land was relatively homogeneous, conversion dynamics under increasing payments favor larger farms, while smaller farms remain unresponsive even in the presence of significant increases in policy support.

Table 3. Simulated Scenarios and their effects on conversion to organic farming and overall budget for organic payments.

Δ Payment	CAP 23–27	+ 10%	+ 15%	+ 20%	+ 25%	+ 30%	+ 35%	+ 40%
Δ Organic farms (n)	12	14	17	19	20	21	22	24
Δ UAA under organic farming (ha)	1,074	1,189	1,637	1,710	1,780	1,860	1,933	2,495
Δ of UAA under organic farming on total (%)	5.1	5.7	7.8	8.2	8.5	8.9	9.2	11.9
Δ Organic budget payments (€)	180,127	226,248	302,002	335,087	349,883	388,832	420,827	554,864
Δ of Organic budget payments (%)	15.4	19.4	25.8	28.7	29.9	33.3	36.0	47.5

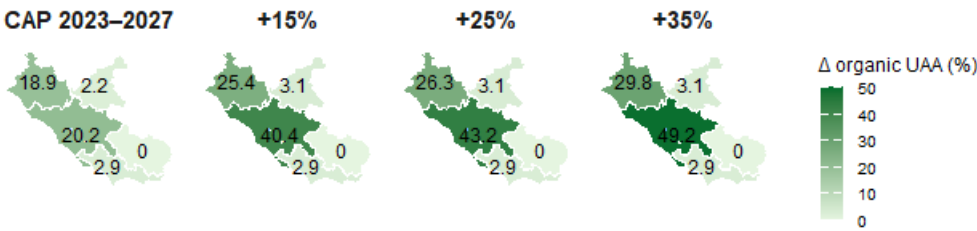


Figure 2. Increase in Organic Farming over the baseline by Province in selected scenarios. .

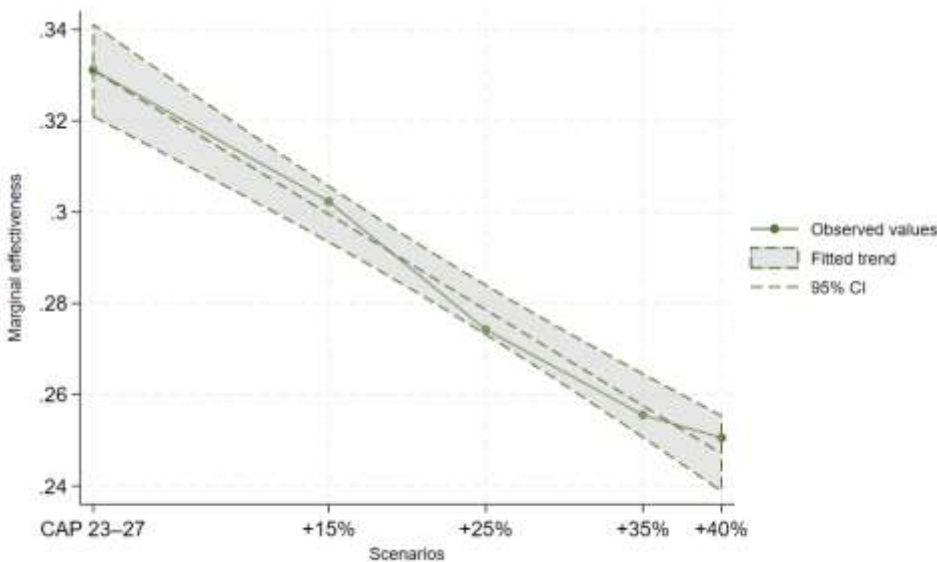


Figure 3. Marginal economic effectiveness of each scenario on organic conversion.

Table 4. Variation in Organic Farming (%) over the baseline in selected scenarios by Type of Farming.

Type of Farming (TF)	Baseline (ha)	CAP 2023-2027	15%	25%	35%
Mixed Crops	103	-	-	40.2	40.2

Mixed Crops and Livestock	692	4.4	6.8	6.8	15.8
Arable Crops	1434	71.0	109.1	111.3	122.6
Tree Crops	1308	1.9	1.9	1.9	1.9
Herbivores	4310	-	-	-	-
Granivores	216	-	-	-	-
Total	8063	13.3	20.3	21.2	24.0

Table 5. Variation in Organic Farming (%) over the baseline in selected scenarios by Farm Size.

Farm Size (ha)	Baseline (ha)	CAP 2023-2027	15%	25%	35%
<5	49.8	-	-	-	-
5-15	511	4.9	4.9	4.9	4.9
15-40	1160	2.1	5.7	8.4	8.4
>40	6343	16.1	24.4	25.0	28.5
Total	8063	13.3	20.3	21.2	24.0

4. Discussion

This study introduces a methodological advancement for analyzing the conversion to organic farming by combining detailed farm-level data from the Italian FADN with the AGRITALIM agro-economic model. The strength of this approach lies in its dynamic structure, which allows the modeling of farms’ decision-making over time, explicitly taking into account the costs and potential productivity losses experienced during the conversion phase. These costs and losses are differentiated by crop and livestock product and are based on observed historical data. Unlike many studies that focus solely on full conversion or employ static models, our approach enables the explicit modeling of the conversion decision for each individual farm, capturing the real trade-offs that farmers face during the transition process. By relying on observed farm-level data, the model provides a more accurate representation of farmers’ responses to policy incentives and market conditions, making it a valuable tool for simulating the impacts of agricultural policies and for supporting the design of targeted and sustainable interventions.

The results indicate that increasing unitary payments for organic farming leads to relatively limited gains in terms of converted area and the number of farms involved. [16] estimate that achieving the 25% organic target at the EU level would require an increase in the Pillar 1 budget ranging between 4% and 21%, depending on the allocation strategy, while [22], in addition, show that such increases may come at the expense of other CAP measures. In line with these findings, our results suggest that, at the regional level, the response to higher payments is relatively rigid, pointing to the presence of structural and technical barriers that go beyond financial incentives.

Several studies state that organic farmers, in addition to the typical risks of agriculture, also face sector-specific risks such as those of transition, soil conservation, crop protection, as well as increased price volatility and lower yields [3]. [23] further show that profit maximization alone is often insufficient to induce conversion, as regulatory, informational, and institutional factors also play a relevant role. These elements help explain the limited responsiveness to payment increases observed in our simulations.

The CAP 2023–2027 reform already generates a moderate increase in organic UAA (+5.1%), but this outcome is accompanied by a substantial increase in public expenditure (+15.4%). This pattern becomes even more pronounced under higher payment scenarios, suggesting a relatively rigid response from farms in the Lazio region to financial incentives. Under the most ambitious scenario (+40%), the additional conversion results in an increase in organic UAA of approximately 12%, supported by nearly a 50% rise in the organic budget. These findings point to a declining cost-effectiveness of payment-based strategies, where increases in public spending generate relatively modest additional environmental benefits. Similar patterns of heterogeneous responses to policy incentives across regions and farm types have been highlighted at the EU level [18], suggesting that structural and sector-specific constraints influence the effectiveness of organic conversion policies

The analysis also reveals marked heterogeneity in conversion responses across provinces, farm types, and farm sizes. Spatially, conversion is mainly concentrated in the provinces of Rome and Viterbo, while other provinces, such as Rieti, Frosinone, and Latina, show very limited responsiveness across all scenarios. These differences partly reflect pre-existing structural characteristics and baseline levels of organic farming, with more rural and extensive provinces exhibiting greater potential for expansion compared to areas characterized by intensive agriculture. In addition, physical and climatic conditions may further amplify production fragility, reducing the effectiveness of economic incentives in certain contexts [7,24].

At the sectoral level, arable crop farms are the most responsive to increased payments, mixed farms display moderate responses, and livestock farms show little to no reaction. This is consistent with the results of [25], who highlight higher production and market risks in organic livestock systems, where sales often take place in niche markets characterized by price volatility and lower yields. Similarly, [2,26] state that farms in intensive sectors tend not to convert because of technical and organizational rigidities. These results confirm that structural and technical constraints, particularly in livestock, may limit the feasibility of organic conversion even in the presence of higher financial support.

Farm size further reinforces this trend, with medium-to-large farms accounting for most of the converted area, while smaller farms appear largely insensitive to changes in unitary payments. This finding is consistent with previous studies showing that farms requiring a more intensive production process tend to convert only when sufficient land endowments and scale economies are available [26,27]. Moreover, access to profitable markets for organic products is often limited to larger farms, also because the benefits of selling organic products go largely to intermediaries and traders, while exporting to richer markets is only accessible to larger farms [28–30]. As a result, conversion barriers remain strong for small and medium-sized farms, which represent the majority of Italian agriculture [9,10,31].

However, [4] state that organic farms are generally less financially constrained, but they are also more dependent on public payments [32]. [6,33,34] conclude that, on equal terms, the financial situation of organic farms could get much worse without the liquidity contribution of public payments, underlining the relevance of policy support for the expansion of organic land. Therefore, the combination of market, productive, and policy conditions is key in the decision to convert. Many authors stress the relevance of the combination of these three factors, where the higher prices obtained by organic products in the market should compensate for the lower yields [6,33–35], even though this is not always the case, especially for livestock products and some vegetables, as well as under specific soil conditions [7,25,36].

These results should be interpreted in light of the behavioral assumptions embedded in the model, which assume rational, profit-maximizing farmers who respond to policy incentives based on expected revenues and costs. While this framework allows a clear assessment of economic trade-offs, it does not fully capture non-economic drivers of conversion decisions, such as risk preferences, personal values, information constraints, or generational factors. Moreover, the model considers only fully organic farms and does not account for possible reversion from organic to conventional farming. The limited responsiveness observed even under favorable payment scenarios may therefore reflect not only economic rigidities but also the presence of structural and informational barriers that are not explicitly modelled.

5. Conclusions

This study highlights the complexity of promoting organic farming in the Lazio region, in Italy. The results show that increases in payment-based incentives generate relatively limited effects in terms of converted area and the number of farms willing to adopt organic practices. This suggests a rigid response to policy payments alone. This rigidity reflects the presence of structural, technical, and informational constraints that play a significant role in shaping farm-level decisions and cannot be overcome exclusively through higher public support. The analysis demonstrates that increasing

unitary payments for organic farming leads to limited additional conversion, highlighting a declining cost-effectiveness of purely payment-based strategies. Conversion responses are highly heterogeneous across provinces, farm types, and farm sizes: arable farms and medium-to-large farms are the most responsive, while livestock and small farms remain largely unresponsive even under ambitious payment scenarios.

From a methodological perspective, this study contributes to the literature by combining detailed farm-level data from the Italian FADN with a dynamic agro-economic model that explicitly accounts for the conversion phase, including temporary productivity losses and higher costs. This framework allows for a realistic representation of farmers’ decisions over time.

Instead, from a policy perspective, these findings suggest that strategies relying solely on higher organic payments are unlikely to achieve widespread adoption. More comprehensive policy strategies are needed, combining financial incentives with measures aimed at reducing fixed conversion costs, providing targeted technical assistance, and facilitating market access, particularly for structurally disadvantaged farm types. Market access, price premiums, structural conditions, and technical constraints therefore emerge as key determinants of farmers’ willingness to convert to organic farming. Furthermore, the dynamic nature of the model emphasizes the importance of continuous monitoring and evaluation of policy outcomes over time. Farm-level simulation tools, such as the one proposed in this study, can support evidence-based policy design and help identify more targeted and cost-effective pathways to achieve the objectives of the F2F Strategy. Future research could further integrate non-economic factors influencing farmers’ decisions, such as risk preferences, sociodemographic factors, and information access in the modelling framework, in order to improve the accuracy of predictions and policy relevance.

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Data Availability Statement: The data used in this study are not publicly available due to licensing restrictions. The dataset was provided by a third party under an institutional license for research purposes. In particular, the data were supplied by CREA-PB (Council for Agricultural Research and Economics – Policy and Bioeconomy), and are subject to usage restrictions that prevent public dissemination. For this reason, the authors are not authorized to share or redistribute the dataset.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A: Mathematical Representation and Calibration of the AGRITALIM Model

Appendix A.1. Objective Function

$$\max Z = \text{GPS} + \text{CAP} + \text{RCA} - \text{VC} - \text{QC} - \text{EXL} - \text{FP} - \text{PW} - \text{DRO} - \text{DRNI}$$

Operating income = Z

Gross Saleable Production = $\text{GSP} = pc * yc * XC + pm * ym * XA + revnm * XA$

CAP payments = $\text{CAP} = dp + cpc * XC + cpa * XA$

Revenues from Complementary Activities = RCA

Variable Costs = $\text{VC} = pfp * qfp * XC + acc * XC + aca * XA$

$$\text{Quadratic Costs} = \mathbf{QC} = \frac{1}{2} \mathbf{XC}' \mathbf{Q} \mathbf{XC} + \frac{1}{2} \mathbf{XA}' \mathbf{Q} \mathbf{XA}$$

$$\text{External Labour} = \mathbf{EXL} = \mathbf{ph} * \mathbf{XH}$$

$$\text{Feed Purchased} = \mathbf{FP} = \mathbf{pf} * \mathbf{XF}$$

$$\text{Pumped Water} = \mathbf{PW} = \mathbf{pw} * \mathbf{XW}$$

$$\text{Depreciation Rates Observed} = \mathbf{DRO}$$

$$\text{Depreciation Rates New Investments} = \mathbf{DRNI} = \mathbf{drtc} * \mathbf{ADTC} + \mathbf{drsf} * \mathbf{ADSF}$$

Variables

XC = hectares of crops

XA = number of animals

XH = hours of labour

XF = quantity of feed

XW = quantity of water pumped

ADTC = additional area of tree crops

ADSF = additional area of stables and facilities

Market

pc = prices of crops

pm = prices of milk

pfp = prices of factors of production (fertilizers, pesticides)

ph = prices of external labour

pf = prices of feed purchased

pw = prices of water pumped

drtc = depreciation rates of new investments (tree crops)

drsf = depreciation rates of new investments (animals)

Production function

yc = yields of crops

ym = yields of milk

qfp = quantities of factors of production (fertilizers, pesticides)

Common Agricultural Policy payments

dp = decoupled payments

cpc = coupled payments for crops

cpa = coupled payments for animals

Revenues and average costs

revnm = revenues from other animal products, no milk (meat, eggs, honey,...)

acc = average costs for crops (per hectare)

aca = average costs for animals (per number)

Appendix A.2. Constraints

$$\begin{aligned} \sum_j \mathbf{XC}_{j,n} &\leq \mathbf{ald}_n \quad \forall n \\ \sum_j \mathbf{ml}_{j,n} * \mathbf{XC}_{j,n} + \sum_{ja} \mathbf{ml}_{ja,n} * \mathbf{XA}_{ja,n} &\leq \mathbf{alb}_n \quad \forall n \\ \sum_j \mathbf{mw}_{j,n} * \mathbf{XC}_{j,n} &\leq \mathbf{awt}_n \quad \forall n \\ \sum_{jt} \mathbf{XC}_{jt,n} &\leq \mathbf{atc}_n + \mathbf{ADTC}_n \quad \forall n \\ \sum_{ja} \mathbf{msf}_n * \mathbf{XA}_{ja,n} &\leq \mathbf{asf}_n + \mathbf{ADSF}_n \quad \forall n \end{aligned}$$

$$\begin{aligned} \sum_{ja} nr_{n,ja,nutr} * XA_{n,ja} &\leq \sum_j XC_{j,n} * yc_j * nc_{j,nutr} \\ &+ \sum_f XF_n * nc_{f,nutr} \quad \forall n,nutr \\ \sum_{jan} rc_n * XA_{jan,n} &\geq \sum_{jap} XC_{jap,n} \quad \forall n \end{aligned}$$

Sets shown in the mathematical representation

- j = types of crops
- n = farms
- ja = types of animals
- jt = tree crops
- jan = types of animals non-productive
- jap = types of animals productive
- nutr = nutrients in animal feeding

Other sets (not shown in the mathematical representation): geographical area [NUTS 2 and NUTS 3], altimetric level, types of cultivation (field, vegetable garden, greenhouse), following crops, main vegetable product, animal production, time

Matrix coefficients

- ml = labour (manual and mechanical) needs for each crop and animal
- mw = water needs for each irrigated crop
- msf = square meter of stables and facilities per animal
- nr = nutrient requirements for each animal
- nc = nutrient content in each produced or purchased feed
- rc = ratio between productive and non-productive animals

Availabilities

- ald = land availability per farm
- alb = labour availability per farm
- awt = water availability per each source (e.g., water users' association, well,...) and farm
- atc = tree crops area per farm
- asf = total square meters of stables and facilities

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