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Understanding the temporal dynamics of agri-environmental climate scheme adoption

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The research explores the intricate dynamics of farmers' decision-making in the context of the European Union's agri-environmental-climate schemes (AECS), with a focus on the temporal factors that impact participation and the long-term viability of environmentally friendly practices. The study utilises data from the Hungarian Farm Accountancy Data Network (FADN) from 2014 to 2021. It employs two-step approaches, including duration analysis using the Kaplan-Meier survival function and discrete-time duration logit, probit and complementary log-log models to examine the length of adoption and the determinants of the temporal dynamics of farmers' decision-making in AECS. The results indicate the trade-off-based preference for market income over the AECS subsidy of Hungarian FADN farms, indicating a relatively weak relationship between adoption and maintenance. The research emphasises the importance of taking into account the farm business model (pertaining to farm characteristics) versus policy measures when analysing farmers' choices regarding the (non)renewal of AECS contracts. The study provides valuable insights into farmers' decision-making patterns in relation to changes in their participation in AECS over time.

Keywords: agri-environmental-climate programmes; sustainability adoption assessment; market income; environmental behaviour; farmers decision-making; common agricultural policy

JEL: Q01; Q12; Q20

1. Introduction

The sustainability of farms and modern agriculture, particularly in the context of a circular economy, requires balancing between economic viability, social, and environmental objectives. Farms face increasing trade-offs between competitive market-driven pressures with the need to increase farm income, and the need to adopt environmentally sustainable practices to mitigate the adverse effects of climate change and the degradation of

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agricultural and natural resources (Scandurra *et al.* 2023). Government policies aim to compensate farms for potential losses in market income due to their agri-environmental orientation (Dueri and Mack 2024). Agri-environmental-climate schemes (AECS), introduced under the European Union's (EU) Common Agricultural Policy (CAP), are designed as a key instrument to promote and support sustainable farming practices. These schemes provide financial incentives to encourage farmers to adopt and maintain environmentally friendly production methods, aligning agricultural practices with the circular economy, biodiversity outcomes, the resilience of rural livelihoods and sustainability principles (Baráth *et al.* 2024; Thompson *et al.* 2024). However, AECS remain puzzling and controversial – participation rates vary widely and persistently across farms and regions, defying straightforward economic explanations.

Prior research has explored why farms enter AECS in the first place (Defrancesco *et al.* 2008; Paulus *et al.* 2022; Siebert, Toogood, and Knierim 2006), but much less is known about understanding the factors that keep farmers engaged over time or the *duration* of AECS adoption – how long farmers continue participation and what drives their decision to remain or exit.

Hungary provides an instructive case within Central and Eastern European (CEE) countries, where post-socialist legacies and historical transitions have produced distinctive farm structures, structural challenges and administrative frameworks (Czyżewski, Smędzik-Ambroży, and Mrówczyńska-Kamińska 2020; Fertő and Bojnec 2025; Unay-Gailhard and Bojnec 2015). While earlier CEE studies document age, gender and size effects at the adoption margin (Hynes and Garvey 2009; Cullen *et al.* 2021), the interaction between those factors and governance frictions over the lifecycle of AECS contracts remains under-explored.

Addressing this gap is critical, as long-term AECS participation is essential for delivering and realizing the environmental benefits and resource efficiencies intended by these schemes (Wuepper *et al.* 2024). Moreover, most studies emphasise economic trade-offs while paying scant attention to the policy design and governance constraints – such as administrative complexity and administrative burdens with transaction costs, monitoring requirements and shifting eligibility rules – that can amplify or dampen those trade-offs (El Benni *et al.* 2022; Mack *et al.* 2019; Ritzel *et al.* 2020; Splinter and Dries 2024).

Therefore, this research addresses the question *what drives both the adoption and the duration of AECS participation among Hungarian farms*, given their unique mix of economic pressures and governance constraints. Employing Kaplan–Meier survival functions and discrete-time hazard models augmented with Mundlak corrections, we analyse how farm size, diversification, reliance on unpaid family labour and policy-induced administrative burdens jointly influence AECS longevity. aims to investigate the duration of AECS adoption and its potential drivers by examining how the time dimension influences farmers' decision-making regarding continued participation or exit from AECS. Previous studies have explored the duration of AECS participation in countries such as Ireland (Cullen *et al.* 2021; Hynes and Garvey 2009; Murphy *et al.* 2014) and Italy (Defrancesco, Gatto, and Mozzato 2018; Gatto, Mozzato, and Defrancesco 2019; Pagliacci *et al.* 2020). While some studies have addressed adoption and sustainable participation behaviour in AECS in CEE countries – for example Slovenia (Unay-Gailhard and Bojnec 2015, 2016) – few have applied duration analysis to investigate the determinants of voluntary AECS adoption duration, which has been supported by government measures (Czyżewski, Smędzik-Ambroży, and Mrówczyńska-Kamińska 2020; Fertő and Bojnec 2025).

Previous studies indicate that various farm-specific and socio-economic factors can influence farmers' intentions to participate and sustain involvement in voluntary AECS (Cammarata *et al*. 2024). For example, demographic characteristics such as age and gender can significantly impact farmers' decisions (Gatto, Mozzato, and Defrancesco 2019; Hynes and Garvey 2009). Similarly, farm-level attributes, including economic size, livestock density, and land productivity, have been identified as determinants of AECS participation, although recent evidence suggests these relationships may be *non-linear* (Cullen *et al*. 2021). Moreover, farms face strategic trade-offs between market-oriented income and AECS subsidy-driven income, highlighting the tensions between profitability and environmental responsibility (Bjørnåvold *et al*. 2022).

This study contributes to the literature by addressing these critical knowledge gaps and advancing the understanding of AECS adoption duration in CEE countries. Specifically, we examine the temporal dimension to the determinants of AECS adoption duration, focusing on *farm-specific characteristics* (e.g. farm size, livestock density, and land productivity) and their potentially *non-linear associations* with participation over time. We estimate the non-linear association between economic farm size and AECS adoption duration, calculating and illustrating the turning break-even point where the association shifts from positive to negative. The duration of AECS adoption may be associated with different farm-specific characteristics that can vary over time. Second, we integrate policy-governance variables. Beyond examining the duration of voluntary adoption, it is important to understand its drivers – particularly in relation to AECS subsidy payments over time. In addition, we analyse the influence of *demographic factors* (e.g. age, gender) and policy-governance variables captured through proxies of *labour dynamics* such as unpaid family labour and income diversification to show how administrative capacity shapes sustained AECS adoption. Third, we investigate the trade-offs between *market-driven income approaches* and dependence on the CAP's *AECS subsidies-driven income* to assess their impact on long-term AECS participation (Bjørnåvold *et al*. 2022). Finally, by situating Hungary within the broader EU experience, estimating turning points and identifying thresholds where relationships shift, this study provides novel scientific insights into the complexities of AECS adoption duration and offers comparative insight on how differing governance systems mediate AECS effectiveness. These findings hold significant implications for policymakers, farms and agricultural practice, as they can inform the design of AECS to promote sustained participation, thereby enhancing environmental performance and supporting the transition to circular and sustainable agricultural systems.

The remainder of the article is organized as follows: Section 2 presents the literature review and hypothesis development, focusing on the determinants of farmers' participation and AECS adoption duration. Section 3 outlines the methodology and data used, followed by Sections 4 and 5, which present and discuss the results. The final Section 6 provides conclusions and policy recommendations to support sustainable agricultural practices.

2. Literature review and hypotheses development

More streams developed investigating institutional, governance-focused and cross-cutting interdisciplinary literature on AECS. First, collaborative and co-management governance (Alblas and van Zeben 2023; Emerson, Nabatchi, and Balogh 2012; Olsson *et al*. 2007; Westerink *et al*. 2017), which emphasizes multi-actor participation across scales in scheme design and management. The highlighted challenges are in aligning ecological–social dynamics, area-targeting, farmer contracting, and sustaining institutional intermediaries. Examples include agricultural collectives as bridging organizations (Germany and the Netherlands), where such groups coordinate, mediate, raise awareness, and monitor impacts, serving as boundary actors between farmers and public institutions (Alblas and van Zeben 2023; Prager 2015). In addition, blind spots in Swiss AECS governance: exploring farmer identity, collective practices, and regulatory burden (Forney 2016). Highlights knowledge sharing and informal self-governance as essential, constrained by bureaucracy. Second, multi-level and institutional frameworks focusing on multilevel governance and barrier analysis (e.g. France), which develops a macro–meso–micro lens to map how organizational, power, and finance barriers across governance levels impede AECS outcomes (Amblard 2021). Moreover, institutional change in Finland post-EU accession shows how adopting CAP environmental measures reshaped national institutions, decision procedures, and policy learning (Kröger 2008). In addition, OECD taxonomies of AECS policy and regulation, built frameworks defining AECS types, design criteria (baselines, cost-effective targeting, flexibility, and evaluation), and regulatory tool classifications (Guerrero 2021; Lankoski, Nales, and Valin 2025; Martini 2023; Organisation for Economic Cooperation and Development (OECD) 1998). Third, theoretical and conceptual perspectives that focus on AECS governance as assemblage positions as complex “assemblages” of neoliberal, state, and civil society actors – urging new conceptual approaches (Forney, Rosin, and Campbell 2018; Forney and Epiney 2022). Moreover, collaborative environmental governance principles applied to agriculture – networked governance, social learning, scale matching, yet noting risks in power asymmetry (Bodin 2017; Bodin *et al.* 2020; Folke *et al.* 2005). The institutional analysis and development framework used for analysing collective governance of environmental resources – including farmland commons, and multi-level governance (subsidiarity, and vertical alignment) critical for coordinating CAP-level decisions with regional/local implementation (Guruswamy and McNeely 1998; Ostrom 2010). Fourth, payment mechanisms and market-based instruments focusing on payments of ecosystem services, results-based payments, and polycentric design with critiques of marketization of AECS, balancing incentive schemes with farmer identities (e.g. Massfeller *et al.* 2022); new model-informed result-based AECS payments modelling approach combining action- and result-based payments (Barkowski *et al.* 2021). In addition, incentives and collective action for ecosystem services with theoretical and modelling evidence suggest that polycentric governance (individual and collective incentives) can enhance outcomes when combined with communication. Finally, cross-cutting themes include governance barriers such as institutional fragmentation, power imbalances, limited social learning, and bureaucratic complexity; scale and fit with importance of landscape-scale coordination (multi-level governance) and scale-matching; bridging organizations with collectives, cooperatives, and extension services as intermediaries; incentives and payment design arguing the need to align action- and result-based formats, adopt adaptive, and cost-effective schemes; hybrid theory–practice frameworks such as institutional analysis and development framework, assemblage, multi-level governance, and network approaches. These issues came in front of discussion about agriculture in the next European budget (e.g. Régnier, Noël, and Aubert 2025).

The adoption of AECS has attracted considerable research interest across various countries, including cross-country comparisons and systematic literature reviews (Bazzan, Candel, and Daugbjerg 2023; Canessa *et al.* 2024; Cullen *et al.* 2021). A substantial body of literature examines the determinants of participation in AECS (Defrancesco *et al.* 2008; Greiner 2015; Khalili, Choobchian, and Abbasi 2024; Lastra-Bravo *et al.* 2015; Paulus *et al.* 2022; Schaub *et al.* 2023; Siebert, Toogood, and Knierim 2006). However, cross-sectional survey-based studies dominate this field, focusing primarily on the voluntary adoption of AECS measures and less on the duration of farm contracts associated with AECS subsidy payments.

Various demographic and human capital characteristics, such as age and gender, have been investigated in the empirical literature concerning AECS adoption (Lei and Yang 2024). While results vary across countries and study periods, some findings suggest that younger farmers are more inclined to participate in AECS than older farmers (Hynes and Garvey 2009). Additionally, female farmers have been positively associated with sustained participation in AECS (Gatto, Mozzato, and Defrancesco 2019) and are considered significant drivers of AECS adoption (Fertő and Bojnec 2024; Unay-Gailhard and Bojnec 2021). The impact of agricultural education remains mixed. Based on this literature, we propose the following sub-hypotheses:

H1a: The age of the farm head is negatively associated with the duration of AECS adoption.

H1b: Having a female farm head is positively associated with the duration of AECS adoption.

Considering labour characteristics, in regions characterized by family farming, reliance on unpaid family labour is common. AECS can support additional employment for family members or create new green jobs (Unay-Gailhard and Bojnec 2019). Accordingly, we formulate the following hypothesis:

H2: The share of unpaid labour is positively associated with the duration of AECS adoption.

Among farm-level characteristics, various farm-level attributes have been identified to explain AECS adoption (Cullen *et al*. 2021). It is argued that factors influencing AECS participation vary with farm size (Unay-Gailhard and Bojnec 2015). Several studies indicate that larger farm size is positively associated with continued AECS participation (Defrancesco, Gatto, and Mozzato 2018; Gatto, Mozzato, and Defrancesco 2019; Hynes and Garvey 2009; Murphy *et al*. 2014), while more recent research suggests a non-linear relationship (Cullen *et al*. 2021). Based on these insights, we posit:

H3a: Farm size is positively associated with the duration of AECS adoption, up to a certain threshold.

H3b: A non-linear relationship exists between farm size and the duration of AECS adoption.

Farm-specific resource endowments and their utilization intensity may significantly influence transaction costs and AECS participation (Coggan *et al*. 2017; Unay-Gailhard and Bojnec 2015). Fixed compliance costs and fixed transaction costs can be a significant barrier for AECS participation for the smallest farms (Ducos, Dupraz, and Bonnieux 2009). Regarding livestock density per unit of utilized agricultural area (UAA), extensive farms are more likely to engage in AECS than intensive farms (Cullen *et al*. 2021). However, environmental pollution may escalate if livestock density exceeds certain limits. Therefore, we hypothesize:

H4a: Livestock density per UAA, up to a specific level, is negatively associated with the duration of AECS adoption.

H4b: A non-linear relationship exists between livestock density per UAA and the duration of AECS adoption.

The relationship between land productivity and AECS participation has been discussed extensively in the literature, although findings are often context dependent. While some have identified a negative association for large farms and a positive one for small farms (Unay-Gailhard and Bojnec 2015), other highlighted that higher land productivity can enable farms to better meet the requirements and compliance standards associated with AECS adoption (Cullen *et al*. 2021). Furthermore, land productivity may provide greater economic flexibility, allowing farmers to balance environmental objectives with profitability. Based on these considerations, and in light of empirical results, we propose the following hypothesis:

H5: Higher land productivity is positively associated with the duration of AECS adoption.

Regarding market orientation and income sources, farms may face trade-offs between a stronger market orientation, greater reliance on market income, and dependence on Common Agricultural Policy (CAP) subsidies concerning AECS adoption (Bjørnåvold *et al*. 2022; Was *et al*. 2021). Higher dependence on subsidies relative to market income can increase the likelihood of AECS participation (Cullen *et al*. 2021). Thus, we hypothesize:

H6: The share of market income is negatively associated with the duration of AECS adoption.

Soil quality is an agri-environmental indicator introduced into the Farm Accountancy Data Network (FADN). It assesses the soil's capacity to provide environmental services and respond to external influences (Eurostat 2018). Literature suggests that grassland plays a central role in AECS and circular food systems (Ait Sidhoum, Canessa, and Sauer 2023; Wuepper *et al*. 2024). Adoption of AECS measures appears less prevalent on high-quality soils, such as arable land. Therefore, we propose:

H7: Soil quality is negatively associated with the duration of AECS adoption.

Farm diversification with diversified farming systems producing multiple products offer an agroecological alternative to modern industrial agriculture (Kremen, Iles, and Bacon 2012). While ecological-economic trade-offs exist in diversified systems (Rosa-Schleich *et al*. 2019), diversification may serve as a survival strategy to mitigate risks associated with specialization (Bojnec and Knific 2021). AECS adoption can help farmers to cope with uncertainty (Lapierre *et al*. 2023), and diversification positively affects biodiversity and ecosystem services (Beillouin *et al*. 2021; Tamburini *et al*. 2020). Based on these considerations, we hypothesize:

H8: The number of products per farm is positively associated with the duration of AECS adoption.

Land fragmentation can be another driver of the duration of AECS adoption. Agricultural reforms in CEE countries have led to land fragmentation (Ciaian *et al*. 2018). Fragmentation can increase cultivation and operational costs (Deininger *et al*. 2017; Wang *et al*. 2020), complicate management decisions (Ntihinyurwa and De Vries 2020), and impact farm profitability (Di Falco *et al*. 2010). AECS adoption requires administrative efforts that may intensify with more land parcels (Zindler *et al.* 2024). Therefore, we hypothesize:

H9: The number of parcels a farm cultivates is negatively associated with the duration of AECS adoption.

Off-farm income is an additional source of farm household income. A positive association was observed between off-farm income and AECS participation for medium and large farms, but not for small farms (Unay-Gailhard and Bojnec 2015). Accordingly, we formulate:

H10: Off-farm income is positively associated with the duration of AECS adoption.

Lagged participation captures farmers' experience, which is expected to increase over time. Farmers may enhance their knowledge and understanding of AECS through improved information and accumulated experience, increasing the likelihood of continued participation (Defrancesco, Gatto, and Mozzato 2018; Hynes and Garvey 2009). Policymakers can enhance adoption rates by improving trust and involving farmers in decision-making regarding the design and implementation of the AECS measures (Van Schoubroeck *et al.* 2025). These endogenous and behavioural factors of on-farm biodiversity management (Klebl, Feindt, and Piorr 2024) can be captured by considering lagged AECS participation, reflecting path dependence. Thus, we propose:

H11: Previous participation in AECS is positively associated with the duration of AECS adoption.

To account for heterogeneity among different farming types, we include farm-type fixed effects in our analysis. Additionally, some studies incorporate time and time-squared variables to capture various endogenous and exogenous determinants (Defrancesco, Gatto, and Mozzato 2018; Gatto, Mozzato, and Defrancesco 2019). Therefore, we also include year-time fixed effects to control for temporal factors influencing AECS adoption.

3. Methodology and data

3.1. Methodology

We employed a two-stage analysis. First, the duration analysis of AECS was estimated using the survival function, $S(t)$, using the non-parametric Kaplan-Meier product limit estimator (Cleves, Gould, and Gutierrez 2004). We assumed that a sample contains n independent observations denoted (t_i, c_i), where $i = 1, 2, \ldots, n$, t_i is the survival time, and c_i is the censoring indicator variable C, taking a value of 1 if a failure occurred, and 0 otherwise of observation i. It was assumed that there are $m < n$ recorded times of failure. The rank-ordered survival times were denoted as $t_{(1)} < t_{(2)} < \ldots < t_{(m)}$, while n_j denotes the number of subjects at risk of failing at $t_{(j)}$, and d_j denotes the number of observed failures. The Kaplan–Meier estimator of the survival function is then:

$$\hat{S}(t) = \prod_{t(i)<t} \frac{n_j - d_j}{n_j} \tag{1}$$

with the convention that $\hat{S}(t) = 1$ if $t < t_{(1)}$. Given that many observations are censored, it is noted that the Kaplan–Meier estimator is robust to censoring and uses information from both censored and non-censored observations.

Second, following the recent literature (Cullen *et al*. 2021; Defrancesco, Gatto, and Mozzato 2018; Gatto, Mozzato, and Defrancesco 2019), we adopted a discrete-time approach to assess the drivers of the duration of the AECS measures. In the context of discrete-time analysis, the discrete-time hazard is considered: Pit refers to the conditional probability that the individual experiences the target event at time t, given that no event has occurred prior to that. In other words, it represents the likelihood that the individual is at risk of facing the event at that specific time:

$$P_{it} = P(T_i = t | T_i \geq t) \tag{2}$$

where T_i is a discrete time variable that describes the occurrence of an event for ith individual. The logit model is mainly employed for discrete-time hazards, denoting an explanation for the logarithm of the odds of an event happening at a specific time t:

$$\ln \frac{P_{it}}{1 - P_{it}} = \propto (t) + \boldsymbol{x}^{i^{\prime}} \boldsymbol{\beta} \tag{3}$$

where $\alpha(t)$ characterises the time-dependent nature of the event's log odds, whereas x^i represents the predictors, which include both time-varying and time-constant covariates.

Addressing time-constant endogeneity posed a methodological challenge. A fixed-effects model was initially considered because it effectively controls for unobserved heterogeneity that remains constant over time. However, applying a fixed-effects panel logit model resulted in a substantial loss of observations (72% of groups) due to the exclusion of groups with all-positive or all-negative outcomes, rendering them uninformative for within-group variation. Additionally, the dataset includes important time-invariant variables, such as gender and soil quality, which are omitted in fixed-effects models due to their lack of variation over time.

Given these limitations, we adopted random-effects panel models, which account for both within- and between-group variation. While random-effects models do not inherently resolve endogeneity concerns, they allow us to include time-invariant variables and reduce the loss of observations. To mitigate potential bias from time-constant endogeneity, we tested the robustness of our random-effects models using the Mundlak corrections, which incorporates group-level means of time-varying covariates to detect correlation between unobserved heterogeneity and regressors.

Furthermore, to ensure the robustness of our results, we complemented the random-effects logit model with discrete-time random-effects probit and complementary log-log (clog-log) models (Tables A1 and A2 in Appendix A). Using multiple links serves two purposes. First, it provides a built-in robustness check, because all three specifications rely on the same underlying likelihood framework yet make different distributional assumptions about the latent error term. The logit model assumes a logistic distribution and is widely used in AECS-duration studies because its odds-ratio interpretation is intuitive (Defrancesco, Gatto and Mozzato 2018; Cullen *et al.* 2021). The probit link, based on a normal distribution, offers a direct comparison when marginal effects are of interest and helps guard against potential overestimation of tail probabilities that can occur with logit. Finally, the clog-log specification is more appropriate when the hazard is skewed toward early exits—a pattern often documented for voluntary AECS (Murphy *et al.* 2014). By triangulating results across these links, we ensure that our substantive conclusions are not an artefact of a single functional form.

We also empirically tested four different models, with and without fixed effects, to compare the consistency of results. Non-linear effects of key variables, such as farm size and livestock density, were examined by including squared terms.

3.2. Data

The panel datasets from the Hungarian Farm Accountancy Data Network (FADN) range from 2014 to 2021. The FADN is an informative resource that helps assess the effects of CAP measures and monitor farms' financial performance and operational activities within EU Member States (Coppola *et al*. 2022; Kelly *et al*. 2018; Uehleke, Leonhardt, and Hüttel 2024). Based on national surveys, FADN provides farm-level data for agricultural holdings whose size qualifies them as commercial. The farm-level data are presented using the following criteria: regional farm location, economic scale, and farming type. We used balanced panel data of 1,265 farms per year with a total number of observations of 8,855.

Although FADN is the most detailed longitudinal source of farm-level data available for the EU member states, it purposely excludes very small and non-commercial holdings. In Hungary, these smaller farms account for a non-trivial share of utilised agricultural area (UAA) and are often family-run operations with limited administrative capacity – exactly the type of holdings that may face the highest barriers to AECS participation. Both data collectors and farmers face challenges in collecting and reporting environmental data, and farmers are not a homogeneous group depending on a set of socio-economic and attitudinal factors (Gaál and Becsákné Tornay 2024). Consequently, our hazard estimates are representative of the commercial farm population but may understate early exit rates and overstate the role of capital-intensive characteristics when extrapolated to the full universe of farms. We partially mitigate this limitation by (i) controlling for farm size and labour structure, and (ii) interpreting our results as upper-bound effects for the broader sector.

3.3. Descriptive statistics

Unlike in some other CEECs, like Slovenia, participation in AECS among Hungarian FADN farms is less widespread: only 27.8% have adopted these measures.

The picture is mixed according to the demographic characteristics of farm heads. It is well known that farms in CEECs are mostly headed by men, which is also confirmed for our sample, with 10.4% of farms headed by females (Table 1). The heads of farms are, on average, 61.2 years old, but their age varies between 26 for the youngest and 81 for the oldest.

According to the socioeconomic characteristics of farm labour, farms rely on their own unpaid family labour in proportions of 61.1%, with variation between 0% and 100.0%.

There is a large difference between the smallest (4 thousand euro) and the largest (39.52 million euro) economically sized farms. Large differences among farms also exist in terms of land productivity in euros per ha of UAA and livestock density in livestock units per ha of UAA.

Table 1. Descriptive statistics for variables.

Variable	Obs	Mean	Std. Dev.	Minimum	Maximum
Participation in AECS	8855	0.278	0.448	0.000	1.000
Gender (male = 1, female = 0)	8851	0.896	0.305	0.000	1.000
Age (year)	8845	61.2	10.9	26	81
Economic size (1,000 euro)	8855	237.1	976.1	4	39520.5
Share of unpaid labour (%)	8855	61.1	38.6	0.000	100
Land productivity (1,000 euro/ha)	8855	6,358.4	54562.2	5.558	2.24e + 06
Livestock density (livestock unit/ha)	8855	0.987	5.028	0.000	157.345
Soil quality (golden crown)	8855	13.328	11.149	0.000	45.260
Number of products	8855	4.166	2.725	1.000	17.000
Number of parcels	8855	20.888	35.146	1.000	990.000
Share of market income (%)	8855	79.0	14.0	2.0	100
Share of off-farm income (%)	8855	4.8	13.1	0.0	100

Source: Authors' calculations.

The share of market income is, on average, 79% (with some farms 100% dependent), although some farms (as much as 98%) largely rely on non-market income, such as state subsidies and sometimes off-farm income. On average, the share of off-farm income is 4.8%, although the share ranges from no off-farm income to 100%.

Soil quality is rather heterogeneous across farms. On average, farms create 4.2 products, but this varies between 1 and 17 products per farm. Interestingly, UAA per farm is substantially fragmented. On average, farms cultivate land on almost 21 parcels, which varies from 1 to 990 parcels per farm.

4. Results

4.1. Comparison of AECS with non-AECS farms

We compare AECS and non-AECS farms using the Kruskal-Wallis non-parametric test to determine whether there is a statistically significant difference between the two groups of farms for the variable tested. Table 2 shows that AECS farms are significantly less women-oriented but have younger heads. They are also significantly larger in economic size but use less family and more paid labour and, surprisingly, have higher land productivity. In addition, they have significantly higher livestock density (livestock unit per ha), number of products, and number of parcels, but significantly lower soil quality and share of market income and earn a smaller share of off-farm income.

4.2. Duration of AECS participation at the farm level

Figure 1 presents the number of spells during the period of analysis. More than half of the farms experienced a single spell, meaning they did not re-enter an AECS. Over 20% of farms re-entered an AECS once, and almost a quarter re-entered an AECS twice within three separate spells. This re-entry dynamic is relatively vigorous compared to other CEECs, such as Slovenia.

Figure 2 clearly confirms that only slightly more than 10% of farms were engaged in AECS during the period analysed, and more than 40% were engaged in an AECS

Table 2. Means of variables according to participation in an AECS.

	AECS = 0	AECS = 1	Kruskal–Wallis test (*p*-value)
Gender (male = 1, female = 0)	0.889	0.915	0.001
Age (year)	61.6	60.2	0.001
Economic size (1,000 euro)	140.5	487.6	0.001
Share of unpaid labour (%)	65.5	49.5	0.001
Land productivity (1,000 euro/ha)	5431.2	8764.8	0.010
Livestock density (livestock unit/ha)	0.751	1.599	0.001
Soil quality (golden crown)	14.2	11.0	0.001
Number of products	3.883	4.901	0.001
Number of parcels	17.8	28.6	0.001
Share of market income (%)	82.1	71.1	0.001
Share of off-farm income (%)	4.9	4.5	0.208
N	6392	2463	

Source: Authors' calculations.

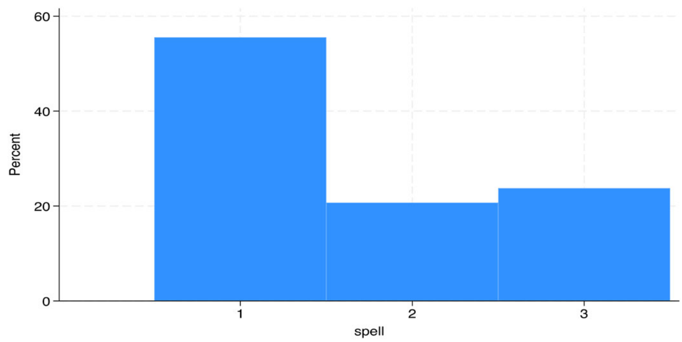

Figure 1. Number of spells.
Source: Authors' calculations.

for only one year. More than 35% of farms exited the AECS after two years. Exit after a different number of years occurred less often, at between 1 and 3 per cent.

Results about the previous duration of AECS participation are reinforced by the Kaplan-Meier survival estimates for the AECS. As expected, the survival rates declined from year to year over the period of analysis, and in the last year, 26% of the AECS farms used the scheme for the whole period (Figure 3). The mean of AECS duration is 2.35 years, while the median value is two years. In comparison to Slovenia, for example, this indicates a shorter duration.

A closer examination may reveal that while overall participation was robust, there were noticeable regional disparities in the uptake of AECS across Hungary. Some regions exhibited higher participation rates, often attributed to specific environmental vulnerabilities, such as critical biodiversity hotspots or areas prone to severe soil erosion, or to targeted local initiatives that effectively promoted the AECS (see also European Commission 2025). This uneven distribution suggests that the environmental impact of AECS might also be spatially varied, with more concentrated benefits in areas of higher uptake.

The participation rates, coupled with the substantial financial allocation, present an interesting dynamic. While these numbers may suggest a strong initial engagement and commitment from the farming community, there were also reported challenges related to

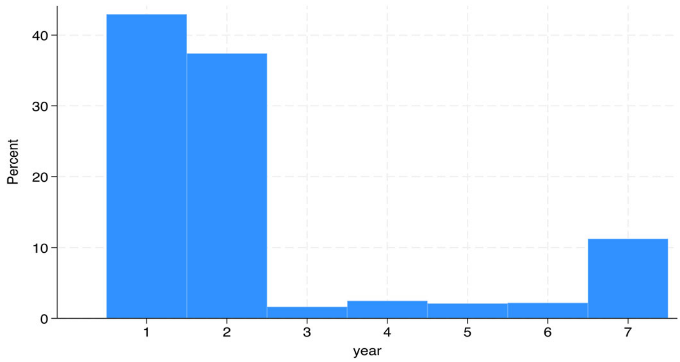

Figure 2. Duration of AECS.
Source: Authors' calculations.

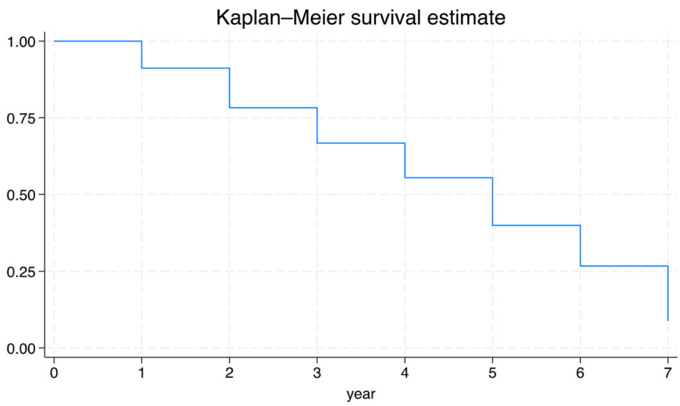

Figure 3. Kaplan–Meier survival estimates for AECS.
Source: Authors' calculations.

administration, payments, and farmer satisfaction (Poláková *et al.* 2022). This indicates that the participation might be primarily driven by the financial incentive offered by the schemes, rather than an intrinsic environmental motivation or ease of participation. This implies that even with a strong financial pull, underlying administrative and design flaws, such as complexity and payment delays, can create friction and dissatisfaction among farmers. Such operational issues could potentially hinder deeper, sustained environmental commitment or the adoption of more ambitious environmental measures, despite the initial willingness to engage for financial support (European Commission 2025). This highlights a need to refine program delivery and support mechanisms, rather than solely relying on increasing incentives, to foster long-term environmental stewardship.

4.3. Determinants of AECS participation

The regression results from the random-effects logit models (Table 3) and the Mundlak-corrected random-effects logit models (Table 4) provide valuable insights into the drivers of participation in AECS. The inclusion of Mundlak corrections enables the analysis to account for time-constant endogeneity, offering a clearer understanding of within- and between-group effects.

Table 3. Results of random-effects logit models of participation in agri-environment schemes.

	(1)	(2)	(3)	(4)
Gender	0.124	0.184	0.532	0.625
Age	−0.037***	−0.032***	−0.026**	−0.022**
Economic size	0.002***	0.001***	0.002***	0.001***
Economic size^2	−0.000***	−0.000***	−0.000***	−0.000***
Share of family labour	−1.617***	−1.425***	−2.087***	−1.920***
Lagged participation	0.199	0.282**	1.418***	1.458***
Land productivity	0.000**	0.000***	0.000**	0.000***
Stocking density	0.029	0.018	0.033	0.003
Stocking density^2	0.000	0.000	0.001	0.001
Soil quality	−0.051***	−0.045***	−0.009	0.009
Number of products	0.164***	0.269***	0.113**	0.245***
Number of parcels	−0.001	0.006	−0.004	0.006
Share of market income	−12.733***	−12.684***	−14.107***	−14.773***
Share of off-farm income	−0.179	−0.137	−1.709**	−1.644**
Constant	9.192***	12.825***	5.945***	10.239***
Farm types fixed-effect	No	Yes	No	Yes
Year fixed-effect	No	No	Yes	Yes
N	7582	7416	7582	7416
Log pseudolikelihood	−1.3e + 03	−1.3e + 03	−990.778	−978.586
Wald *p*-value	0.000	0.000	0.000	0.000
Rho	0.000	0.000	0.000	0.000

Note. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. All models include farm-type and year-fixed effects.
Source: Authors' calculations.

Table 3 presents four specifications of the random-effects logit model. The baseline model (1) does not include fixed effects, while model (2) controls for farm-type fixed effects, model (3) includes year fixed effects, and model (4) incorporates both farm-type and year fixed effects to improve robustness. Across all specifications, the economic size of the farm emerges as a significant and positive predictor of AECS participation, confirming findings from earlier studies (Hynes and Garvey 2009; Murphy *et al*. 2014). However, the significantly negative squared term for economic size indicates diminishing returns, suggesting that very large farms are less likely to participate beyond a threshold economic size of 17,375.4 euro (Figure 4). This non-linear relationship is consistent across all specifications and highlights the need to consider economic farm size thresholds when designing AECS policies.

The share of family labour is consistently and significantly negatively associated with AECS participation, suggesting that farms reliant on family labour may face resource or administrative constraints that hinder their ability to engage with AECS requirements. Land productivity is positively associated with participation in all models, indicating that farms with higher productivity are better equipped to participate and comply with program demands.

Lagged participation is significant only in models (2, 3 and 4), with stronger associations observed when year fixed effects are included. This suggests a path dependence where prior engagement increases the likelihood of continued participation, aligning with the previous findings (Cullen *et al*. 2021).

Interestingly, the share of market income is negatively associated with AECS participation in all models, indicating that farms reliant on market-driven income streams

Table 4. Results of random-effects logit models with Mundlak corrections.

	(5)	(6)	(7)	(8)
Gender	−0.297**	−0.345**	−0.195	−0.223
Age	−0.026	−0.025	0.020	0.021
Economic size	0.003***	0.003***	0.002**	0.002**
Economic size^2	−0.000***	−0.000***	−0.000***	−0.000***
Share of family labour	−0.560	−0.562	−0.768	−0.773
Lagged participation	−0.867***	−0.856***	−0.132	−0.128
Land productivity	0.000**	0.000	0.000***	0.000**
Stocking density	0.045	0.054	0.050	0.063
Stocking density^2	0.000	0.000	0.000	0.000
Soil quality	−0.036***	−0.036***	−0.002	−0.001
Number of products	0.229***	0.228***	0.142**	0.141*
Number of parcels	0.022**	0.023**	0.010	0.008
Share of market income	−10.145***	−10.297***	−9.766***	−10.252***
Share of off-farm income	0.332	0.313	−1.094	−1.119
mean_age	0.023	0.021	−0.024	−0.026
mean_share of family labour	0.573	0.454	0.656	0.467
mean_size	−0.003***	−0.003***	−0.003***	−0.003***
mean_size^2	0.000***	0.000***	0.000***	0.000***
mean_productivity	−0.000**	−0.000*	−0.000***	−0.000***
mean_stockingdensity	−0.093	−0.090	−0.106	−0.108
mean_stockingdensity^2	0.001	0.001	0.001	0.000
mean_number of products	−0.146**	−0.164**	−0.085	−0.114
mean_number of parcels	−0.025**	−0.025**	−0.011	−0.009
mean_share of market income	10.616***	10.186***	9.761***	9.221***
mean_share of off-farm income	0.041	0.044	1.268	1.263
mean_lagged participation	10.355***	10.307***	11.946***	11.880***
Constant	−4.535***	−3.517***	−8.390***	−6.744***
Farm types fixed-effect	No	Yes	No	Yes
Year fixed-effect	No	No	Yes	Yes
N	7582	7416	7582	7416
Log pseudolikelihood	−2.3e + 03	−2.2e + 03	−2.0e + 03	−1.8e + 03
Wald *p*-value	0.000	0.000	0.000	0.000
Rho	0.844	0.777	0.859	0.801

Note. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. All models include farm-type and year-fixed effects.
Source: Authors' calculations.

are less likely to engage in AECS. These results contrast with the previous studies (Cullen *et al.* 2021; Murphy *et al.* 2014).

The share of off-farm income shows mixed effects, being insignificant in models (1) and (2) but negatively associated with AECS participation in models (3) and (4), suggesting that temporal and structural dynamics influence the relationship.

While soil quality is negatively associated with participation in models (1) and (2), it becomes insignificant in models (3) and (4). This finding highlights potential trade-offs in land use, with higher-quality land more likely allocated for commercial farming rather than AECS.

Conversely, the number of products per farm is positively associated with AECS participation in all models, reflecting the importance of diversification in supporting adoption.

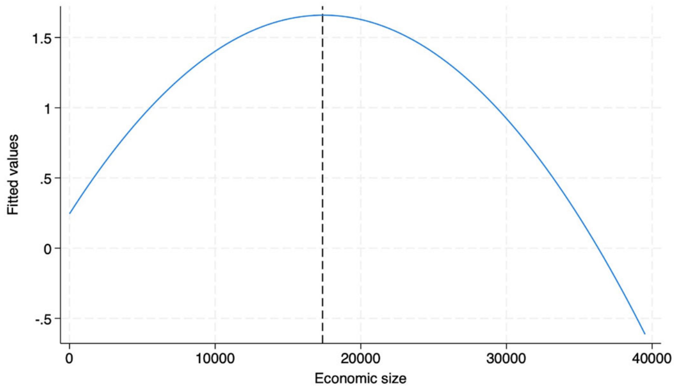

Figure 4. The turning point: the economic size of farms and participation in an AECS.
Source: Authors' calculations.

The number of parcels per farm, however, is not significant in any model, indicating no clear relationship between land fragmentation and AECS participation.

Table 4 incorporates Mundlak corrections, addressing time-constant endogeneity by including group means of time-varying variables. This approach disentangles within-group (time-varying) effects from between-group (time-constant) effects, providing more nuanced insights into AECS participation drivers. Notably, the Mundlak corrections significantly improve model fit, with higher log pseudolikelihoods compared to the baseline models in Table 3. Furthermore, the intraclass correlation (rho) decreases substantially in the Mundlak models in Table 4, indicating that much of the unobserved group-level variation is captured by the included group means.

The economic farm size remains positively associated with AECS participation, and the squared term remains negative, confirming the non-linear relationship observed in Table 3. However, the Mundlak corrections reveal additional insights: the mean economic farm size has a significant negative association, suggesting that farms with larger average economic sizes across time are less likely to participate. This contrasts with the positive within-group association, highlighting the nuanced influence of economic farm size on participation decisions.

Lagged participation, which was significant and positive in Table 3, shows contrasting results in the Mundlak models. Within-group associations are significantly negative, indicating that previous participation reduces the likelihood of continued engagement. However, the mean lagged participation is strongly positive, reflecting structural differences where farms with a history of participation are more likely to engage overall. These findings suggest that while repeat participation may face diminishing returns at the individual level, historical participation remains a strong predictor of broader engagement tendencies.

The Mundlak corrections also refine the interpretation of family labour. Unlike in Table 3, where family labour had a significant negative association, it becomes insignificant in the Mundlak models, indicating that earlier findings overstated its association due to unobserved heterogeneity. Similarly, land productivity remains positively associated within farms, but has a small negative between-group effect, suggesting that productivity gains primarily drive short-term engagement.

The number of products per farm retains its positive within-group association, highlighting the role of diversification in fostering participation. However, the mean number of products has a negative between-group association, indicating that highly diversified farms may face structural barriers to sustained engagement.

The Mundlak corrections highlight the importance of addressing time-constant endogeneity in AECS participation analysis. By capturing group-level effects, it reduces potential biases and enhances model robustness. The significant between-group associations for variables such as economic farm size, lagged participation, and the share of market income underscore the importance of distinguishing structural factors from time-varying dynamics.

While the Hungarian case reflects some broader trends in AECS adoption across the EU, it is shaped by country-specific institutional factors. During the 2014–2020 CAP period, Hungary's Rural Development Programme incorporated several key AECS measures that were designed to address the country's specific environmental priorities (European Commission 2025). First, AECS payments constituted the largest component of AECS in Hungary. They aimed to support biodiversity, improve water quality, and enhance soil health through a variety of commitments. Examples of practices supported under AECS payments included extensive grassland management, the establishment of buffer strips along watercourses, and specific crop rotations designed to reduce nutrient leaching and improve soil structure. Second, Natura 2000 payments provided support to farmers managing agricultural land within the Natura 2000 network, which comprises sites designated for the protection of Europe's most valuable and threatened species and habitats. Payments compensated farmers for income foregone and costs incurred due to restrictions on agricultural activities necessary to maintain or restore the ecological integrity of these high nature value areas. Finally, organic farming supports recognizing the broader environmental benefits of organic agriculture. Hungary also provided dedicated support for farmers converting to, and maintaining, organic farming practices. This included support for both the conversion period and for ongoing organic management, promoting reduced reliance on synthetic inputs, enhanced soil fertility, and increased biodiversity. These specific measures collectively formed Hungary's approach to leveraging AECS for environmental protection and sustainable agricultural development.

5. Discussion

The findings of this study offer significant insights into the temporal dynamics of AECS adoption among Hungarian farms, contributing to the broader discourse on sustainable agriculture and the circular economy (Le Gloux *et al*. 2025). By analysing adoption duration and its key determinants using a robust two-step approach—Kaplan–Meier survival estimates and discrete-time hazard models with Mundlak corrections—this research provides a nuanced understanding of farmers' decision-making processes over time. The findings underscore the significance of considering time-varying factors in understanding farmers' choices between continuing with AECS and leaving the scheme.

The literature contributes valuable insights to the ongoing discourse about the adoption and duration of AECS in promoting eco-friendly practices among European farmers. It provides a comprehensive overview of how these schemes encourage environmentally friendly practices among farmers in Europe (Unay-Gailhard and Bojnec 2016; Canessa *et al*. 2024). This could encourage farmers' to adopt corporate social responsibility to achieve more sustainable economic, environmental, and social sustainability development and farmland biodiversity in the rural circular economy (Bux, Zhang, and Ali 2024; Gutiérrez-Briceño *et al*. 2024; Zul Azlan *et al*. 2024).

The research reveals that 28% of the Hungarian FADN farms joined an AECS, with only around a quarter displaying sustained involvement. The adoption patterns indicate fluctuation between AECS adoption and maintenance. However, fewer than 60% of the Hungarian FADN farms that adopted AECS remained for one continuous spell during the period analysed, while the rest stayed for two or three. This suggests that more than 40% of farms switch between AECS adoption and maintenance. The duration of the adoption of AECS is explained by farm-specific demographic and factor endowments, AECS adoption path dependence, type of farming- and time-fixed effects.

Based on the empirical regression results, we cannot reject sub-hypothesis H1a concerning the age of the head of the farms. However, we can reject H1b about women head of farms because the regression coefficients are statistically insignificant. It would be important to support gender equality in the dynamics of technology adoption (Mishra *et al*. 2020), eco-efficient farming (Fertő, Baráth, and Bojnec 2025) and the quality of youth employment, particularly women (Tsambou *et al*. 2024).

H2 concerning the share of unpaid labour can be rejected because the regression coefficients are significant but negative. Unexpectedly, a greater share of unpaid family labour is associated with a shorter adoption duration of AECS, a finding that diverges from our original expectation. However, these results and findings are less obvious when the Mundlak corrections are applied. While family labour is often considered a resource for flexibility and resilience in farm management (Unay-Gailhard and Bojnec 2019), several studies suggest that reliance on unpaid labour may, in fact, limit a farm's administrative and operational capacity to comply with complex AECS requirements (Barnes *et al*. 2024). These findings echo the argument that AECS participation often necessitates a certain level of professionalization and administrative ability, which may be lacking in farms predominantly reliant on unpaid family workers (Dessart, Barreiro-Hurlé, and van Bavel 2019). This pattern may be particularly pronounced in CEE contexts, where generational renewal and farm succession challenges further exacerbate administrative capacity constraints (Unay-Gailhard and Bojnec 2015). Thus, while family labour is traditionally a source of strength, it may, under specific institutional conditions, hinder sustained engagement with policy schemes that require administrative rigor.

We cannot reject H3a concerning the positive association between economic farm size or H3b (the robustness test) on the non-linear relationship between economic farm size and the adoption duration of AECS. Economically, larger farms up to a certain size adopted AECS for longer than smaller ones. These findings are consistent with previous literature regarding the positive (Defrancesco, Gatto, and Mozzato 2018; Gatto, Mozzato, and Defrancesco 2019; Hynes and Garvey 2009; Murphy *et al*. 2014) and non-linear association between farm size and the adoption duration of AECS (Cullen *et al*. 2021).

Contrary to our sub-hypotheses H4a on livestock density per UAA and the H4b robustness test can be rejected concerning the non-linear relationship between livestock density per UAA and the adoption duration of AECS because the regression coefficients are statistically insignificant, suggesting no clear relationship with AECS adoption duration. Previous research has highlighted that intensive livestock production can have a negative environmental impact and may deter AECS participation due to increased pollution and regulatory scrutiny (Cullen *et al*. 2021; Schaub *et al*. 2023). For instance, farms with high livestock densities may face stricter compliance requirements or higher opportunity costs associated with reducing stocking rates, which can discourage long-term participation in agri-environmental schemes (Gatto, Mozzato, and Defrancesco 2019). However, other studies suggest that moderate levels of livestock density can contribute to agrobiodiversity and landscape management, potentially supporting AECS objectives under certain conditions (Ait Sidhoum, Canessa, and Sauer 2023). The lack of a significant association in our data may reflect the heterogeneity of farming systems and policy implementation across different contexts (Paulus *et al*. 2022). Further research is warranted to disentangle the nuanced effects of livestock intensity on environmental scheme participation, particularly in the CEE countries.

H5 on land productivity cannot be rejected as the regression coefficients are significantly positive. Higher land productivity increases the adoption duration of AECS. The results and finding are less obvious when the Mundlak corrections are applied. It was argued that increasing crop rotational diversity can increase agricultural resilience and enhance cereal yields mitigating and reducing the environmental impacts on food production (Bowles *et al*. 2020).

H6 on the share of market income cannot be rejected. The association is highly significantly negative, strongly suggesting trade-offs between market-driven and CAP subsidy-driven income related to the voluntary adoption of AECS. However, the former with an increase in food production in Europe could dramatically affect farmland biodiversity (Jeanneret *et al*. 2021). Therefore, it could be important to link and integrate ACES sustainability objectives with consumption values and green behaviour related to market income and consumers' willingness-to-pay, such as for eco-labelling and branding as alternatives (Chwialkowska *et al*. 2024). Agricultural diversity and AECS subsidies can be also important for stability of farm income (Harkness *et al*. 2021). Farm economic sustainability can be also important for farm survival (Fertő *et al*. 2024).

On the basis of models (1, 2 and 5), H7, which posits that soil quality is negatively associated with the adoption duration of AECS, cannot be rejected. However, in other models, this association is statistically insignificant. These mixed results suggest that outliers possibly affect the association when controlled either with the year-fixed effects or simultaneously by both the year and farm-type fixed effects. This can be linked to climate change and cropland management compromising soil integrity, multifunctionality, and biodiversity loss (Jeanneret *et al*. 2021; Pe'er *et al*. 2022).

H8 concerning the number of products per farm cannot be rejected. In each of the eight models, the association is significantly positive at least at a 10% level. The more products a farm produces, the greater its potential viability in relation to the adoption duration of AECS in the longer term.

Except for models (5) and (6), H9 can be rejected because the regression coefficients concerning the number of parcels per farm are statistically insignificant. With these mixed results, we cannot confirm that the number of parcels per farm is negatively associated with the adoption duration of AECS. This could suggest possible trade-offs in the relationship between the number of parcels and cultivation costs (Valtiala *et al*. 2023).

H10 on off-farm income can be rejected because the regression coefficient is not significant except for models (3) and (4). This finding is inconsistent with the research for Slovenia (Unay-Gailhard and Bojnec 2015) and for Switzerland (El Benni and

Schmid 2022) where off-farm income and direct payments are an indispensable farm diversification strategy.

The results regarding the set H11 on lagged participation in the AECS are mixed. As expected, in the models (2, 3 and 4), it indicates significant path dependence on lagged voluntary participation expressed by the lagged adoption duration of AECS. These results related to path dependence with lagged participation in the AECS confirm previous empirical evidence about sustainable adoption participation behaviour based on different methodological approaches and for different years (Unay-Gailhard and Bojnec 2016). This could provide evidence in favour of improving incentive mechanisms for AECS farming contracts (Raina, Zavalloni, and Viaggi 2024). However, when the Mundlak corrections approach is applied, the results turned out negatively significant in models (5) and (6), and insignificant in models (7) and (8). This can indicate a possible impact for farmer self-identity and attitudes on participation in AECS (Cullen *et al.* 2020).

A central result of this study highlights the *trade-offs between market-driven incomes and AECS subsidies*. Farms with a higher share of market income demonstrate shorter AECS adoption durations, suggesting that competitive market pressures often outweigh policy-driven incentives for environmental sustainability. This aligns with findings from prior studies (Bjørnåvold *et al.* 2022) and underscores the challenge of aligning economic incentives with ecological objectives for the improved provision for biodiversity and soil quality (Eichhorn, Kantelhardt, and Schaller 2024; Neyret *et al.* 2023). Policymakers need to address this gap improving agricultural policy by strengthening the value proposition of AECS participation, for example, through improved eco-labelling schemes, premium pricing for sustainable products, or enhancing the administrative efficiency of subsidy access (Huber *et al.* 2024). The European Green Deal, government support programmes and green agricultural policies, and investment funds can have substantial economic, environmental and social impacts on the sustainability of food systems, consumers and farmers (Guyomard *et al.* 2023; Lassalas *et al.* 2024).

The *non-linear relationship between economic farm size and AECS adoption duration* reveals a critical turning point: mid-sized farms are most likely to sustain participation, while very large farms tend to exit. This finding aligns with the previous findings (Cullen *et al.* 2021) and highlights the need for tailored support strategies that account for farm size heterogeneity. For instance, smaller farms may require greater technical and financial support to sustain their participation, while large farms may need incentives aligned with production efficiency goals.

The study also identifies that *farm-level diversification* – measured by the number of products—positively influences AECS adoption duration. Diversified farms appear more resilient to administrative burdens and economic trade-offs, supporting the literature on diversified farming systems' ecological and economic benefits (Rosa-Schleich *et al.* 2019; Tamburini *et al.* 2020). Promoting diversification can serve as a dual strategy to mitigate risks associated with specialization while advancing sustainable production practices.

In contrast, the *negative association between unpaid family labour and AECS duration* is particularly notable. This finding suggests that AECS participation may demand professionalized labour and administrative capacity that unpaid family labour struggles to meet. Supporting the adoption of digital technologies and targeted farmer training programs could address these barriers, enabling farms reliant on unpaid labour to sustain participation (Granado-Díaz *et al.* 2024).

AECS increased awareness of environmental issues on farms with a positive learning effect, where participation in the schemes contributed to a greater understanding of ecological principles and sustainable practices. However, this positive perception was often tempered by significant concerns regarding the operational aspects of the schemes (see also European Commission 2025). Farmers frequently highlighted the substantial administrative burden, complex application processes, and rigid rules as major barriers to uptake and effective implementation. Furthermore, concerns were consistently raised about payment delays and, in some cases, insufficient payment rates, which impacted their willingness to participate or commit to long-term measures. The overly complex policy design of AECS also contributed to difficulties in understanding the requirements and implementing them correctly. Literature has identified possible limits of farmers' cooperation and working together for conservation (Riley *et al*. 2018) as a possible reason for individual participation vis-à-vis in new collective AECS (Hardy *et al*. 2020; Limbach 2024; Sander *et al*. 2024; Splinter and Dries 2024).

The study partly confirms the importance of *path dependence*, when lagged participation positively influences AECS adoption duration. This result highlights the cumulative benefits of experience and familiarity with scheme requirements. Improving outreach, training, and technical assistance could accelerate this learning process for first-time adopters, reducing early attrition rates.

Farm advisory services can play an important role in knowledge transfer, improving farm economies and administration capacity, promoting greater environmental sustainability impacting multiple ecosystem services, and building trust in long-term relationships between advisors and landowners/farmers (Geranmayeh *et al*. 2025; Krafft *et al*. 2022; Vrain and Lovett 2020). A critical support gap identified was insufficient access to training and advisory services. This hindered farmers' capacity to effectively implement and maintain the often-complex environmental practices required by AECS measures. The lack of adequate knowledge transfer between research institutions, advisory services, and farmers was a recurring issue, indicating a systemic challenge in disseminating best practices and technical guidance. These *soft* infrastructure elements, such as advisory services, knowledge transfer, and administrative capacity, represent the enabling environment for successful AECS implementation. Complex environmental practices require specific knowledge, skills, and ongoing support. Without adequate advisory services, farmers may struggle to understand, correctly implement, or adapt to the requirements of AECS, leading to *reduced* environmental effectiveness, or even non-compliance. Limited administrative capacity translates to delays and errors, further deterring farmers. This suggests that simply increasing budgets or designing "perfect" schemes is insufficient; significant investment in human capital, extension services, and administrative efficiency is paramount for translating policy intent into on-the-ground environmental benefits.

To sum up the main findings, at the farm manager level, it is important to address the issue of the age of the head or farm manager. It could be important to strengthen the role of high-quality farmer training in the green circular economy (Lei and Yang 2024).

At the farm-specific level, bigger farms (according to economic size) of up to a certain size, farms with greater land productivity and a greater number of products are positively linked with the adoption duration of AECS. Vice versa, farms with a larger share of family labour, higher land soil quality, a bigger share of market income and a higher share of off-farm income are less so.

There may be a complementary relationship between the adoption duration of AECS and economic farm size up to a certain farm size and a substitution relationship between the adoption duration of AECS and the share of off-farm income. In addition, there seems to be a substitutional relationship between the adoption duration of AECS and farm market income (defined as total farm income minus off-farm income and CAP subsidies that a farm receives). Therefore, it is important to target result-based, multiple and alternative sustainability objectives in an era of digitalisation, such as economic, environmental and social efficiency and effectiveness development in the sustainable agriculture and rural communities (Bartkowski *et al*. 2021; Taoumi and Lahrech 2023). They may differ by type of farming, for example for viticulture (Kuhfuss and Subervie 2018), diversification economies in dairy farming (Wimmer and Sauer 2020) or crop protection (Finger *et al*. 2024).

While the CAP's AECS subsidies are important, the preference seems to be for the market-driven income in trade-offs of the CAP's AECS subsidies. This business model could appear to be different than in some other CEE countries, which may be explained by the different farm structures and geographic-environmental characteristics. Obtaining CAP AECS subsidies requires administration and monitoring capacity on the farm, which can be costly, and for which capacity may be lacking when the farm head is elderly, and there is no successor (Finn *et al*. 2009; Peterson *et al*. 2015; Unay-Gailhard and Bojnec 2015). Financial incentives can also fail in trade-offs between agricultural productivity and pro-conservation behaviour. The networking and cooperation through a bottom-up approach (Barnes *et al*. 2024), fostering social capital on collective action for effective governance of AECS (Barghusen *et al*. 2022; Reichenspurner, Barghusen, and Matzdorf 2024), empowering citizen-led adaptation and use of digital technologies by farmers can be also essential to improve transparency and efficiency of the government support system and systemic climate change risks management (Granado-Díaz *et al*. 2024).

Policy stability can also strengthen farmers' attitude, trust and transparency in government decision-making for participating in AECS (Chang, Benjamin, and Sauer 2024; Jakku *et al*. 2019). The administrative framework for managing AECS in Hungary faced considerable challenges. Farmers frequently expressed concerns regarding the significant administrative burden, complex application processes, and rigid rules associated with the schemes. These procedural complexities often led to payment delays, further impacting farmers' willingness to participate or commit to long-term environmental measures. Furthermore, limited administrative capacity at regional and local levels was observed to affect the efficient delivery of AECS. This suggests that the success of AECS is not solely dependent on financial incentives or environmental objectives, but also heavily reliant on the efficiency and user-friendliness of the administrative systems in place.

The implementation of AECS in Hungary during the 2014–2020 CAP period faced several significant challenges that collectively constrained their overall effectiveness: administrative burden placed on farmers with complex application processes, rigid rules, and frequent payment delays; monitoring and evaluation gaps and the lack of policy coherence between AECS and other agricultural policies, particularly direct payments under Pillar 1, creating contradictory and conflicting incentives for farmers; insufficient support services with inadequate access to training, advisory services, and effective knowledge transfer mechanisms; limited administrative capacity at regional and local levels further impacted the efficient delivery of AECS, contributing to delays and operational inefficiencies; the targeting effectiveness of AECS could be improved to maximize environmental benefits in critical areas; and low public awareness of the benefits of AECS and their contribution to environmental protection, potentially limiting broader societal support for these initiatives.

Among exploration of opportunities for enhancing AECS effectiveness and uptake are streamlining administrative procedures and simplifying policy design to reduce the burden on farmers and increasing accessibility; better spatial targeting of AECS to areas with the highest environmental need and potential for impact would maximize the ecological benefits of financial investments; investing in human capital and in robust, accessible, and tailored training and advisory services with a strong network of expert advisors and effective knowledge transfer mechanisms to empower farmers to adopt and maintain complex environmental practices more effectively; exploring a shift towards more outcome-based payments and robust monitoring systems to incentivize actual environmental results, rather than merely adherence to prescribed practices; encouraging and facilitating longer-term commitments in AECS contracts for achieving sustained environmental benefits, as ecological processes often require extended periods to show significant improvement.

There is an ongoing and critical need for adaptive policy design that prioritizes simplification, strengthens administrative and advisory capacities, and ensures a holistic approach to agricultural and environmental policy (European Commission 2025). For Hungary and the broader EU, fostering truly sustainable farming systems requires not only continued financial investment but also a concerted effort to enhance the enabling environment for farmers, improve data collection for accountability, and resolve inherent policy contradictions.

Some other behavioural factors can also affect the adoption of sustainable farming practices in the context of circular agri-food supply chain governance (Dessart, Barreiro-Hurlé, and van Bavel 2019; Huber, Späti, and Finger 2023; Kamau, Roman, and Biber-Freudenberger 2023). These are issues for further research.

6. Conclusion

This study analysed the determinants influencing both the adoption and duration of participation in AECS among Hungarian farms, employing robust methodological approaches, including Kaplan-Meier survival analysis and discrete-time hazard models with Mundlak corrections. Our findings indicated the non-linear relationship between farm economic size and AECS participation; smaller farms initially benefit significantly, while very large farms experienced diminishing returns. Farm diversification emerged as a positive determinant of AECS duration, suggesting resilience benefits from diversified agricultural systems. Conversely, reliance on unpaid family labour negatively impacted AECS duration, likely due to limited administrative capacity and resource constraints. Furthermore, the study identified mixed effects regarding repeat participation, suggesting both benefits and challenges in sustaining long-term involvement.

To enhance AECS effectiveness, policymakers should implement targeted, size-sensitive incentives, offering greater financial and technical support and assistance to smaller and mid-sized farms to overcome resource constraints, while aligning incentives for larger farms with efficiency goals. Additionally, differentiated engagement strategies – such as onboarding support for new participants and ongoing engagement activities for repeat participants – are recommended to sustain motivation and long-term compliance. Finally, aligning market incentives with environmental outcomes, through initiatives such as eco-labelling and premium pricing for sustainably produced goods, could effectively balance ecological objectives with market-driven incomes.

Supporting diversification through integrated subsidies and advisory services could further strengthen AECS participation. Farms with a greater variety of products are better equipped to navigate administrative and economic challenges.

Simplifying administrative requirements and labour-related constraints, introducing user-friendly digital tools, professional training programs, and advisory services can specifically assist family-operated farms, especially for ones with limited administrative capacity, to AECS participation. The negative association between family labour and AECS duration reflects the challenges family-run farms face in meeting administrative and compliance requirements.

The mixed effects of lagged participation demonstrate the importance of considering both within- and between-farm dynamics. While historical participation strongly predicts continued engagement at the group level, individual-level analysis reveals diminishing returns, suggesting potential program fatigue. These findings highlight differentiated targeted engagement strategies – such as onboarding support for new AECS adopters and ongoing engagement activities for repeat participants – to sustain motivation and long-term compliance.

The study also reveals trade-offs between soil quality and AECS participation, with higher-quality soils often allocated for market-driven production. This finding underscores the complexity of balancing economic and environmental goals and suggests that nuanced policies are required to address these competing priorities. Integrating incentives for high-quality soils into AECS programs could enhance participation while preserving productive farmland.

The findings contribute to broader sustainability efforts by emphasizing the need for integrated strategies that align economic viability with environmental outcomes, through initiatives such as eco-labelling and premium pricing for sustainably produced goods. Promoting diversified farming systems, aligning market-driven incentives with ecological and sustainability goals, and reducing administrative burdens are essential steps toward enhancing AECS adoption and retention. Finally, it would be important to increase public awareness launching initiatives to educate the broader public about the benefits of AECS and their contribution to environmental protection. This can foster greater societal support and appreciation for the efforts of farmers engaged in environmental stewardship.

While this research provides a robust foundation for future studies on AECS and sustainable agricultural practices, the results and their potential implications for generalizability may be limited due to the use of the Hungarian FADN dataset with the minimum size threshold excluding small and non-commercial farms, and use of a single AECS variable. Some of these can be covered by new data collected through remote sensing, but farmers also need to provide data. This depends on farmers' perceptions of environmental issues and their attitudes towards willingness to collect relevant data (Gaál and Becsákné Tornay 2024). Future work combining FADN with the (micro-aggregated) Farm Structure Survey or qualitative interviews with smallholders could help to gauge how these excluded groups might alter the magnitude – or even the direction – of some determinants. Expanding the analysis to other regions and incorporating additional environmental variables could further enhance understanding of AECS dynamics. By addressing the interplay between economic and environmental factors, this study supports the transition toward a greener, more sustainable agricultural sector and contributes to the broader discourse on achieving the goals of the circular economy and climate resilience. Finally, future research would benefit from integrating qualitative methods, such as interviews and focus groups with stakeholders, to gain deeper insights into farmers' motivations, perceived barriers, and administrative experiences. A mixed-methods approach combining quantitative survival models with qualitative data would offer a more comprehensive understanding of AECS participation dynamics and support more targeted policy development.

Author contributions

Imre Fertő: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Funding acquisition, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review and editing.
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Data availability statement

The data that support the findings of this study are available from the Hungarian Ministry of Agriculture but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Appendix A

Table A1. Results of random effects probit models of participation in agri-environment schemes.

	1	2	3	4
Gender	0.073	0.105	0.315	0.340
Age	−0.021***	−0.018***	−0.014**	−0.013**
Economic size	0.001***	0.001***	0.001***	0.001***
Economic size^2	−0.000***	−0.000***	−0.000***	−0.000***
Share of family labour	−1.617***	−1.425***	−2.087***	−1.920***
Lagged participation	0.119	0.174**	0.740***	0.747***
Land productivity	0.000*	0.000***	0.000**	0.000***
Stocking density	0.018	0.009	0.022	0.006
Stocking density^2	0.000	0.000	0.000	0.000
Soil quality	−0.029***	−0.025***	−0.005	0.005
Number of products	0.094***	0.149***	0.066**	0.134***
Number of parcels	−0.001	0.003	−0.002	0.003
Share of market income	−6.775***	−6.745***	−7.716***	−8.080***
Share of off-farm income	−0.184	−0.127	−0.912**	−0.844**
Constant	4.858***	6.836***	3.254***	5.592***
Farm types fixed-effect	No	Yes	No	Yes
Year fixed-effect	No	No	Yes	Yes
N	7582	7416	7582	7416
Log pseudolikelihood	−2.3e + 03	−2.2e + 03	−2.0e + 03	−1.8e + 03
Wald *p*-value	0.000	0.000	0.000	0.000
Rho	0.847	0.778	0.860	0.802

Note. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. All models include farm-type and year-fixed effects.
Source: Authors' calculations.

Table A2. Results of random effects complementary log-log models of participation in agri-environment schemes.

	1	2	3	4
Gender	−0.001	0.095	0.386**	0.484***
Age	−0.027***	−0.025***	−0.020	−0.018***
Economic size	0.002***	0.001***	0.002***	0.001***
Economic size^2	−0.000	−0.000	−0.000	−0.000
Share of family labour	−0.933***	−0.943***	−1.500***	−1.396***
Lagged participation	0.020	0.084	0.861***	0.859***
Land productivity	0.000***	0.000***	0.000***	0.000***
Stocking density	0.023	0.016	0.020	−0.001
Stocking density^2	0.000	0.000	0.001**	0.001
Soil quality	−0.040***	−0.037***	−0.008***	0.003
Number of products	0.117***	0.194***	0.100***	0.190***
Number of parcels	0.004*	0.004*	−0.003	0.003
Share of market income	−8.050***	−8.103***	−9.320	−9.993***
Share of off-farm income	−0.343	−0.184	−1.402***	−1.318***
Constant	5.106***	8.093***	3.066***	6.340***
Farm types fixed-effect	No	Yes	No	Yes
Year fixed-effect	No	No	Yes	Yes
N	7582	7416	7582	7416
Log pseudolikelihood	−2.3e + 03	−2.3e + 03	−2.0e + 03	−1.9e + 03
Wald *p* value	0.000	.	.	0.000
Rho	0.853	0.796	0.872	0.827

Note. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. All models include farm-type and year-fixed effects.
Source: Authors' calculations.