Agricultural Systems 237 (2026) 104835

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Research Paper

Economic and ecological outcomes of in-house and third-party coffee certifications in Rwanda

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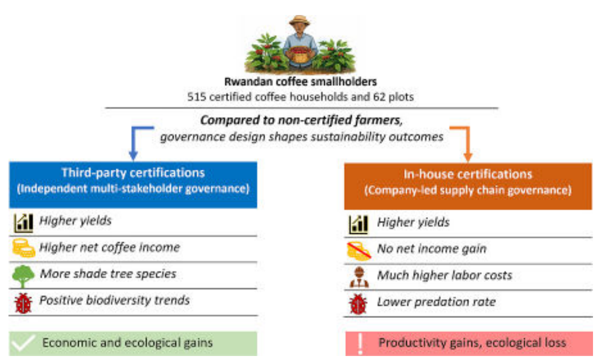
HIGHLIGHTS

- Joint economic and ecological assessment on the same coffee plot.
- Comparison of third-party and in-house certification governance.
- Third-party linked to higher income and greater tree species diversity.
- In-house linked to yield gains but lower arthropod predation rates.
- Governance design shapes sustainability outcomes in coffee systems.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Emma Stephens

ABSTRACT

CONTEXT: Voluntary sustainability standards (VSS) in the coffee sector differ fundamentally in their governance structures, with third-party certifications governed by independent multi-stakeholder organizations and in-house certifications designed and managed by corporations themselves. Whether these governance differences translate into different sustainability outcomes for smallholder farmers remains an open empirical question.
OBJECTIVE: This study examines whether third-party and in-house coffee certifications are associated with different economic and ecological outcomes for smallholder farmers in Rwanda.
METHODS: We draw on survey data from 842 coffee farm households and direct ecological field measurements from a subsample of 99 plots. Endogenous switching regression models are used to estimate associations with economic outcomes, and generalized linear mixed models for ecological outcomes.
RESULTS AND CONCLUSION: Both certification types are associated with higher yields and gross revenues, but only third-party certifications are associated with higher net coffee income and greater shade tree species diversity. In-house certifications are associated with significantly lower arthropod predation rates. These findings suggest that third-party certifications exhibit a synergy pattern, with concurrent economic and ecological gains, while in-house certifications exhibit a trade-off pattern, where productivity gains are accompanied by negative functional biodiversity associations.

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https://doi.org/10.1016/j.agsy.2026.104835
Received 1 February 2026; Received in revised form 29 April 2026; Accepted 26 May 2026
Available online 3 June 2026

SIGNIFICANCE: These results demonstrate that the institutional design of certification schemes, rather than the mere presence of a sustainability label, shapes sustainability outcomes. They underscore the need for corporate programs to integrate binding environmental thresholds and mandatory price mechanisms if voluntary sustainability standards are to deliver on their promise for smallholder farmers and ecosystems alike.

1. Introduction

The global agrifood sector has seen a proliferation of private, market-based regulatory instruments, most notably Voluntary Sustainability Standards (VSS), often referred to as certifications (Hatanaka et al., 2005; Marx et al., 2024). This trend is largely a response to growing consumer and civil society concerns in high-income countries regarding the sustainability of tropical commodities (Tscharntke et al., 2015). However, sustainability itself is a multifaceted and ofted contested concept. In this context, certifications serve as private regulatory tools designed to address social and environmental externalities in production systems by defining and verifying a set of standards (Milder et al., 2015). For companies, they represent a key corporate responsibility strategy (Giuliani et al., 2017; Meemken et al., 2021).

A crucial distinction in the VSS landscape revolves around their governance structures: VSS can be managed by independent third parties or developed "in-house" by companies themselves (Lambin and Thorlakson, 2018). Third-party certifications, such as Rainforest Alliance or Fairtrade, are developed and monitored by independent, often multi-stakeholder organizations with explicit social and environmental mandates (Hatanaka et al., 2005; Depoorter and Marx, 2024). In contrast, in-house certifications, most notably in the coffee sector Starbuck's C.A.F.E. Practices and Nespresso's AAA Sustainable Quality Program, are designed internally. This structure gives companies the flexibility to tailor standards to their specific business objectives, such as securing product quality, ensuring supply chain reliability, and enhancing brand reputation, which may or may not align with broader sustainability goals (Renard, 2010; Giuliani et al., 2017).

This difference in governance raises critical questions about credibility and effectiveness. In-house certifications are often viewed with skepticism, facing allegations that they may function as sophisticated "greenwashing" mechanisms rather than as genuine drivers of sustainable development (Giovannucci et al., 2008). The core of this skepticism lies in the potential for corporate conflicts of interest and governance capture, where the lack of independent oversight could lead to a "decoupling" of standards from practice, namely, a gap between formal compliance and actual on-the-ground conduct (Giuliani et al., 2017). Yet third-party certifications are not without criticism either, with recurring concerns raised about auditor conflicts of interest, the exclusion of the poorest farmers, and the limited enforcement capacity of infrequent audits (Hatanaka et al., 2005; Meemken et al., 2021). More broadly, empirical evidence on the socioeconomic and ecological implications of voluntary sustainability standards remains mixed and context-dependent (Oya et al., 2018; Meemken et al., 2021), and studies explicitly comparing third-party and in-house certifications are virtually absent from the literature, leaving a significant gap in our understanding of how governance structure shapes sustainability outcomes (Dietz et al., 2020; Panhuysen and Pierrot, 2020).

This paper addresses this research gap by asking: Are different governance structures in sustainability certifications, specifically third-party versus in-house standards, associated with different economic and ecological outcomes for coffee farmers? To answer this, we draw on a socioeconomic cross-sectional farm survey complemented by direct ecological field measurements from Rwanda's coffee sector, analyzing the data using endogenous switching regression models and generalized linear mixed models, and pursue two objectives. First, we analyze whether adopting in-house and/or third-party certifications is associated with better economic performance at the plot level, specifically examining coffee gross revenue, net revenue, production costs, and yield. Second, we assess whether adopting in-house and/or third-party certifications is associated with positive ecological outcomes, focusing on both vegetation (shade tree diversity) and animal (bioacoustics and arthropod predation) diversity, using direct field measurements.

This study makes two contributions to the literature. First, while third-party certifications have received growing empirical attention (Oya et al., 2018; Meemken et al., 2021), in-house certifications remain underrepresented. By directly comparing both types within a single national context and explicitly analyzing how governance structures shape sustainability outcomes, we extend the foundational work of Haggar et al. (2017), who compare certification types but do not examine the underlying institutional mechanisms driving the observed differences. Second, studies jointly analyzing the socioeconomic and ecological effects of voluntary sustainability standards remain scarce (Haggar et al., 2017; Vanderhaegen et al., 2018; Wätzold et al., 2025); we contribute direct empirical evidence to this underexplored intersection by incorporating vegetation and animal diversity measures rarely captured in the VSS literature. We focus on Rwanda's coffee sector, where multiple in-house and third-party certification schemes operate simultaneously, providing a unique opportunity for direct comparative analysis within a single national context.

The results of this study suggest that third-party certifications are associated with higher yields, greater net income, and improved shade tree diversity, representing synergies between economic and ecological sustainability outcomes. In contrast, in-house certifications are associated with productivity gains but no income improvements and are associated with negative ecological outcomes, indicating a trade-off. These results highlight the need for sustainability certifications to combine independent governance, integrated economic and ecological objectives, and market conditions that enable price mechanisms to function effectively.

The paper is organized as follows. Section 2 provides background on in-house and third-party certifications, along with a conceptual discussion. Section 3 describes the methods and empirical approach, while Section 4 presents the results and discussion. Section 5 concludes the paper.

2. Background and conceptual framework

The emergence of VSS as a dominant form of private governance has profoundly influenced the socioeconomic and ecological outcomes for farm households (Meemken et al., 2021; Wollni et al., 2025). However, significant distinctions in the institutional design and objectives of third-party versus in-house certifications suggest that their associations with economic and ecological outcomes are not uniform. This section presents a conceptual framework to explain the potential pathways through which these different certification models may be associated with different coffee-related economic and ecological indicators.

2.1. Institutional design: independent versus corporate governance

The primary distinction between third-party and in-house certifications lies in their governance. Third-party certifications are typically developed, owned, and governed by independent, often multi-stakeholder organizations such as Fairtrade International or the Rainforest Alliance (Marx et al., 2024). Their governance processes often involve a balance of interest among NGOs, producer representatives, companies, and sometimes public bodies (Lambin and Thorlakson, 2018). A key feature of this model is the requirement for independent third-party auditors to assess compliance, creating a clear separation between the entity that sets the standard and the one that enforces it. Because the certifying body has no direct commercial interest in the supply chain, this arms-length structure is considered more impartial and credible (Hatanaka et al., 2005). Depoorter and Marx (2024) identifiy three complementary mechanisms through which well-designed standards foster compliance: enforcement (monitoring and sanctions), market incentives (premiums and market access), and capacity building (training and technical support). Third-party certifications generally deploy all three mechanisms, and notably, Depoorter and Marx (2024) explicitly exclude in-house corporate programs from their comparative VSS framework on the grounds that their voluntary and compliance-oriented nature is questionable.

In-house certifications are designed and governed directly by private companies (Renard, 2010; Giuliani et al., 2017). These certifications are tailored to corporate supply chain objectives, with an emphasis on product quality, traceability, and supplier reliability. Producer involvement in standard-settings is often minimal, and auditing is frequently conducted by company-appointed entities, reinforcing corporate control over both design and enforcement (Renard, 2010). Dietz et al. (2018) provide quantitative support for the governance distinction through the Voluntary Coffee Standard Index (VOCSI), which scores mainstream coffee standards across economic, social, environmental, and enforcement dimensions. C.A.F.E. Practices scores 9.7 and Nespresso AAA scores 13.5 out of 100, compared to 39.7 for Rainforest Alliance and 32.8 for Fairtrade International. Dietz et al. (2018) further note that for standards with heavy corporate participation, audit results remain private information, limiting external scrutiny of compliance and effectiveness.

These governance differences in independence, accountability, and enforcement intensity, provide the structural basis for expecting divergent economic and ecological associations across certification types.

2.2. Economic outcomes

The differences in governance are expected to shape economic outcomes through distinct pathways. Third-party certifications often place a stronger emphasis on direct price interventions. For instance, Fairtrade establishes a price floor and a mandatory premium (Fairtrade, 2019), while the Rainforest Alliance requires buyers to pay a sustainability differential in cash (Rainforest Alliance, 2023). This focus on price support is a core part of their mission to improve farmer livelihoods. In contrast, in-house certifications rarely guarantee premiums or floor prices. Instead, price incentives, when present, tend to be quality dependent (Renard, 2010; Dietz et al., 2020) and are not publicly disclosed in program evaluation frameworks (Dietz et al., 2018).

The effects on coffee yields and costs are also expected to vary. Social and environmental-focused certifications like Fairtrade or Organic may not prioritize productivity, sometimes leading to stagnant or even lower yields if not paired with sufficient agronomic support (Beuchelt and Zeller, 2011). Conversely, in-house certifications, designed to secure a reliable supply of quality coffee, consistently emphasize productivity-enhancing practices. This often translates into a high-investment, high-return strategy. For example, Haggar et al. (2017) report 40% higher production costs for C.A.F.E. Practices farms, reflecting an intensive model aimed at boosting productivity and quality. While both certification types can raises costs, the cost structure reflects their underlying objectives: broader sustainability for third-party certifications, and productivity and quality for in-house certifications.

2.3. Ecological outcomes

Based on the differing institutional designs, we also hypothesize different ecological associations. The environmental dimension is central to third-party certifications like the Rainforest Alliance, which explicitly targets biodiversity conservation and ecosystem health through requirements for shade cover and prohibitions on deforestation (Rainforest Alliance, 2023). In contrast, environmental criteria in in-house certifications appear to be structured primarily to support coffee quality and supply chain reliability rather than broader conservation goals (Renard, 2010; Giuliani et al., 2017). In C.A.F.E. Practices, for instance, product quality traceability criteria are classified as required component for certification, while many environmental criteria are scored but not strictly required (Café Practices, 2016). A farm can therefore achieve certification while failing to meet specific environmental thresholds, provided quality and traceability requirements are satisfied. This design logic is reflected in the comparative evidence: Dietz et al. (2018) show that in-house programs score relatively low across all three dimensions of sustainable development in the VOCSI, with a large share of their environmental standards classified as non-obligatory for certification. At the farm level, Haggar et al. (2017) find that this translates into measurably lower vegetation diversity on in-house certified farms relative to those under third-party schemes. Taken together, these structural and empirical patterns lead us to hypothesize that third-party certifications will be associated with stronger and broader ecological outcomes, particularly in vegetation complexity and animal diversity, compared to in-house certifications.

3. Methods

3.1. Data and background

Coffee plays a crucial role in Rwanda's national economy and rural development. The sector is dominated by approximately 400,000 smallholder farmers who manage roughly 42,000 ha, with average farm sizes ranging from 0.1 to 0.26 ha (NAEB, 2023). Despite its economic importance, coffee productivity has stagnated since the mid-2000s, driven by aging trees and limited access to extension services.

Sustainability standards have been present in Rwanda since the early 2000s, with certified production expanding significantly since 2014. The predominant standards include third-party certifications (Fairtrade, Organic, Rainforest Alliance) and in-house corporate programs (Starbucks C.A.F.E. Practices) (AgriLogic, 2018). In Rwanda, certification takes place at the level of the Coffee Washing Stations (CWSs), which serve as certificate holders and are responsible for implementing certification requirements. Consequently, farmers do not bear the direct costs of certification such as fees or audits.

During the data collection period, a government zoning policy was in effect, establishing geographic zones around each CWS and requiring farmers to sell exclusively to their designated CWS to improve traceability. Because the CWS holds the certificate, all farmers geographically assigned to a certified CWS must comply with its certification requirements. From the individual farmer's perspective, participation in a certification scheme is therefore largely decoupled from their socioeconomic characteristics, creating a unique institutional setup that we leverage in our estimation strategy.

To collect data on coffee production, certifications, and ecological outcomes, we conducted a stratified random selection of certified and non-certified CWSs across five major coffee-producing districts in Rwanda (Rusizi, Nyamasheke, Karongi, Rutsiro, and Huye). These districts are highly representative of Rwanda's broader smallholder coffee production landscape in terms of farm size, production systems, and certification presence. The selected CWSs were identified from a list provided by local authorities, and farmers were then randomly chosen from a complete list provided by each selected CWS.

Data collection took place between November 2022 and January 2023. Socioeconomic data were collected through structured interviews conducted directly on the coffee plots, with the primary coffee farm manager, typically the household head, as the respondent. The interviews covered farmer and household characteristics including gender, age, literacy, farming experience, household size, cooperative membership, and asset ownership, as well as farm-level data on coffee production, input use, costs, revenues, and adoption of agricultural practices, specifically focusing on shade tree planting, organic fertilization, mulching, pruning, and pest monitoring strategies. Coffee prices and premiums were recorded separately based on payments received from the CWS. Interviews were conducted in Kinyarwanda and lasted between 1.5 and 2 h on average. The final sample for the economic analysis comprises 842 farm households: 327 non-certified, 268 certified only by third-party schemes, 119 certified only by the in-house scheme, and 128 holding dual certifications. Ecological data were collected from a randomly selected subsample of 99 of these farms. Full details of the sampling framework and field protocols are provided in Appendix A1.

3.2. Economic and ecological indicators

Economic indicators are selected to capture the full production-to-welfare pathway through which certifications are expected to shape farmer livelihoods: from changes in yields and revenues, through to costs, and ultimately to net income as the measure of whether productivity gains translate into genuine household welfare improvements. From the survey data, we derived four economic performance indicators at the coffee plot level: *coffee yield, gross coffee income, coffee production costs,* and *net coffee income*. *Coffee yield* is expressed in kilograms of fresh coffee cherries per hectare and represents the coffee harvested in the previous 12 months on the most productive coffee plot. *Gross coffee income* is *coffee yield* multiplied by *coffee price* and is expressed in USD per hectare. The variable *coffee production costs* refers to expenses on the most productive plot, in USD per hectare, covering hired labor and fertilizers. It excludes opportunity costs of family labor and owned land, so net coffee income reflects monetary, not full economic, profitability. *Net coffee income* is calculated by subtracting *coffee production costs* from *gross coffee income* and is expressed in USD per hectare.

Ecological indicators are selected to capture a structure-to-function pathway: certifications that promote agroforestry and biodiversity-friendly management are expected first to alter the structural complexity of the coffee plot environment, reflected in shade tree density and diversity, and these structural changes are in turn expected to support improved ecosystem functioning, captured through the bioacoustics index and arthropod predation rate. Thus, our ecological performance indicators relate to vegetation and animal diversity. Indicators for vegetation diversity include the *number of shade trees*, *shade tree species*, and *shade tree diversity*. Indicators capturing animal diversity consist of a *bioacoustics index* and *predation rate*. Similar to Wätzold et al. (2025), we selected these two groups of indicators for two primary reasons. First, improved vegetation diversity is expected to enhance animal diversity and ecosystem functioning (Tscharntke et al., 2011). Second, the chosen animal diversity variables effectively indicate ecosystem functioning and biodiversity, as bird communities and predator insects respond quickly to environmental changes, signaling early biodiversity loss and shifts in ecosystem health (Duffy, 2002).

Number of shade trees is the total number of shade trees on the most productive coffee plot, and it is expressed as the number of shade trees per hectare. *Number of shade tree species* is the total number of tree species on the most productive coffee plot. Number of trees and tree species were counted and identified on-site by field ecologists; doubtful cases were verified using the PlantNet plant identification application and local botanical expertise. We use the *Shannon* and *Simpson diversity indices* to measure shade tree diversity. The *Shannon diversity index* quantifies species diversity by considering species richness and evenness within a community. In contrast, the *Simpson diversity index* measures the probability that two individuals randomly selected from a sample belong to different species, emphasizing species dominance (Magurran, 2003). In other words, higher Shannon values indicate greater overall biodiversity in terms of both richness and evenness, while a higher Simpson index (1 - D) suggests a more even species distribution, with no single species dominating the ecosystem.

Arthropod *predation rate* is the proportion of fake plasticine caterpillars deployed in each coffee plot that predators attack (Howe et al., 2009; Schwab et al., 2021), serving as an indicator of the ecosystem service provided by biological control. Green plasticine caterpillars (Pelikan Nakiplast) were placed by field ecologists at two positions on each plot: fixed to coffee tree trunks, branches, or leaves at approximately 1.5 m height, and on the ground attached to sticks or leaves. Caterpillars were left in place for 24 h before retrieval, and bite marks left by arthropod predators were identified using reference images and magnifying glasses. Ambiguous marks were photographed and classified as morphobites for subsequent analysis.

The *bioacoustics index* is calculated based on the total sound level and the number of frequency bands utilized by animals, reflecting the relative abundance of the avian and arthropod communities (Boelman et al., 2007). Sounds were recorded using AudioMoth autonomous recorders (Hill et al., 2019), deployed on each sampled farm for a continuous 24-h period at a sample rate of 48 kHz with medium gain. The Bioacoustic Index was calculated within the 2000 to 8000 Hz frequency range to focus on biologically relevant sounds and exclude low-frequency anthropogenic noise.

3.3. Estimation strategy

3.3.1. Endogenous Switching Regression (ESR) for estimating economic outcomes

Certification may be endogenous to economic outcomes if unobserved factors such as farmer ability or the sustainability awareness of CWS managers affect both certification and performance. Although Rwanda's zoning policy reduces farmer-level selection bias, its imperfect implementation and potential selection at the CWS level mean some bias may remain. To address this, we use an endogenous switching regression (ESR) approach (Maddala, 1983), a two-stage method widely applied in impact evaluation (Abdulai, 2016; Wätzold et al., 2025). The first stage estimates the probability of certification using a probit model, while the second stage models the outcomes separately for certified and non-certified farmers, correcting for selection bias via inverse Mills ratios.

We estimate three separate ESR model specifications three times to separately assess the effects of all certified farmers (VSS), third-party certified farmers (TP-VSS), and in-house certified farmers (IH-VSS) relative to non-certified farmers. To estimate a farmer's probability of being certified, we use a utility maximization framework and employ a probit model in the first stage:

$$CERT_i = Z_i\gamma + n_i \tag{1}$$

where $CERT_i$ can be represented as VSS_i, TP_i, and IH_i, corresponding respectively to certification under any, third-party (TP), or in-house (IH) certification. Eq. 1 is run separately for each treatment. Z_i is a vector of control variables, including one instrument, γ is a parameter to be estimated and n_i is an error term with mean zero and variance σ^2.

In the second stage, we estimate a switching-regression model that specifies separate outcome equations for certified and non-certified farmers:

- The outcome equation for certified farmers ($CERT_i = 1$):

$$Y_{i,CERT} = X_{i,CERT}\beta_{CERT} + \sigma_{CERT,n}\lambda_{i,CERT} + \vartheta_{i,CERT} \tag{2.1}$$

- The corresponding equation for non-certified farmers ($CERT_i = 0$)

$$Y_{i,N} = X_{i,N}\beta_N + \sigma_{N,n}\lambda_{i,N} + \vartheta_{i,N} \tag{2.2}$$

As in Eq. 1, $CERT_i$ denotes certification status, defined as VSS_i, TP_i, and IH_i, corresponding to any (VSS), third-party (TP), or in-house (IH) certification. In each case, Y_i represents the outcome variable of interest, while X_i includes control variables. The coefficient β is the parameter to be estimated, capturing the effect of certification on outcomes.

Following Heckman (1979), we include the inverse Mills ratios from the selection eq. (1), denoted as λ_i. The covariance terms σ_n represent the error terms, which have conditional means of zero.

Control variables include household demographics, economic factors, and land characteristics, as described in the previous sub-section. District fixed effects account for regional heterogeneity. To address overlap between third-party and in-house certifications, we include the alternative certification as a control variable in Eq. 2.1 when estimating effects for TP or IH.

For identification, the ESR model requires at least one variable that influences certification status (included in Z_i) but does not directly affect the outcome variable (excluded from X_i) (Abdulai, 2016). We use coffee washing station (CWS) ownership as an instrument, based on the assumption that cooperative- and exporter-owned CWSs are more likely to obtain certification than individually[1] owned ones. This is because cooperatives often pursue high-value markets that benefit their members, and exporters have greater access to international buyers (Wollni and Zeller, 2007). Farmers are assigned to CWSs through Rwanda's zoning policy and are not necessarily cooperative members, which supports the exogeneity of CWS ownership.

To further support the exclusion restriction, we emphasize that CWS ownership is distinct from management. A single owner may operate multiple CWSs under different managers, and not all CWSs under the same ownership are certified. This weakens any direct link between ownership and farm-level outcomes. In addition, coffee prices in Rwanda are regulated by the government, limiting owners' ability to influence farmer income. A falsification test following Di Falco and Veronesi (2013) confirms that CWS ownership is correlated with certification status but not with economic outcomes among non-certified farmers (Appendix A2). Together, these factors suggest that the observed economic effects can be attributed to certification rather than ownership.

We estimate the ESR model using the full-information maximum likelihood method (Lokshin and Sajaia, 2004) to jointly estimate the selection and outcome equations, clustering standard errors at the CWS level to account for potential correlation among farmers delivering to the same CWS. We then compute the average treatment effect on the treated (ATT) separately for each certification type, defined as the difference between the observed outcomes of certified farmers and their hypothetical counterfactual outcomes had they not been certified. It is estimated as follows:

$$E(Y_{i,CERT}|\ CERT_i = 1) = X_{i,CERT}\beta_{CERT} + \sigma_{CERT,n}\lambda_{i,CERT} \quad (3.1)$$

$$E(Y_{i,CERT}|\ CERT_i = 0) = X_{i,CERT}\beta_{CERT} + \sigma_{CERT,n}\lambda_{i,CERT} \quad (3.2)$$

$$ATT = E(Y_{i,CERT}|\ CERT_i = 1) - E(Y_{i,CERT}|\ CERT_i = 0) \quad (3.3)$$

3.3.2. *Generalized linear mixed models for estimating ecological outcomes*

We use ecological and survey data from 99 coffee plots to assess the relationship between different certifications and ecological outcomes. Generalized Linear Mixed Models (GLMM) are used rather than standard OLS because the ecological outcome variables differ in their distributional properties: species richness is a count variable modelled using a Poisson distribution, while continuous outcomes such as diversity indices, bioacoustics index, and arthropod predation rate follow a Gaussian distribution. The mixed-model structure additionally allows us to account for the nested nature of the data, whereby farmers linked to the same CWS share similar environments, practices, and resource access, introducing intra-cluster correlation that would bias standard errors in a simple OLS framework. Following Vanderhaegen et al. (2018), we apply generalized linear models, specified as follows for consistency with the economic analysis:

$$Y_i = \beta_0 + \beta_1 VSS + \beta_2 X_i + \beta_3 E_i + \varepsilon_{ij} \quad (4.1)$$

$$Y_i = \beta_0 + \beta_1 TP + \beta_2 IH + \beta_3 X_i + \beta_4 E_i + \varepsilon_i \quad (4.2)$$

The outcome variable Y_i includes *shade tree count, species richness, Shannon and Simpson diversity indices, bioacoustics index,* and *arthropod predation rate*. The main difference between eqs. 4.1 and 4.2 lies in the treatment variable: in eq. 4.1, *VSS* is a binary indicator for any certification, while in eq. 4.2, *TP* and *IH* represent third-party and in-house certifications, respectively. The control vector *X* includes coffee production and households' characteristics, such as the number and age of coffee trees, plot size, household head's gender, age, literacy, occupation, household size, off-farm income, share of agricultural land, and cooperative membership. Vector *E* includes environmental factors: tree cover within a 1 km radius, distance to the nearest primary forest, and plot altitude. CWS-level random effects are included to account for within-cluster dependencies, following Krumbiegel et al. (2018).

Ecological outcomes are likely less affected by selection bias than economic ones, as unobserved farmer characteristics are more closely tied to welfare than to vegetation or animal diversity (Wätzold et al., 2025). However, since certification may still relate to environmental conditions, we examined pre-certification vegetation using the enhanced vegetation index within a 500-m radius and found no significant differences between certified and non-certified plots (Appendix A3).

4. Results and discussion

This section presents and discusses the empirical findings in relation to the study's two objectives: first, whether certification type is associated with different economic outcomes for smallholder coffee farmers; and second, whether certification type is associated with different ecological outcomes. We begin with descriptive statistics of the sample, followed by adoption of good agricultural practices and coffee prices, before turning to the ESR and GLMM results for economic and ecological outcomes respectively.

4.1. *Descriptive statistics*

4.1.1. *Sample characteristics*

Table 1 presents summary statistics of the explanatory variables for non-certified farmers, all certified farmers (VSS), third-party certified farmers (TP-VSS), and in-house certified farmers (IH-VSS). We compare each of the three certified groups to non-certified farmers. The group of certified farmers exhibits several differences compared to non-certified farmers. They have a higher literacy rate and more farming experience. In terms of household characteristics, a greater proportion of certified farmers have access to financial accounts, own a slightly larger proportion of land, and dedicate more land to agriculture. Cooperative membership is significantly higher among certified farmers, and they are located farther from markets. Regarding farm characteristics, certified farmers have a lower coffee tree density.

Third-party certified farmers differ significantly from non-certified farmers in several key characteristics, including age, farming experience, financial access, cooperative membership, market distance, and are more likely to be associated with cooperatively or exporter-owned CWSs. In-house certified farmers also exhibit significant differences from non-certified farmers, particularly in literacy and proximity to forests, whereas there are no differences in cooperative membership, land ownership, and market access.

The divergence in cooperative membership reflects the distinct institutional designs of the two types of standards. Third-party certifications structurally require or incentivize smallholder organization: Fairtrade mandates democratic cooperatives with an elected board and general assembly (Fairtrade, 2019), and the Rainforest Alliance requires

[1] Individually owned CWSs are privately owned and do not have ownership links to exporters or roasters further along the supply chain.

Table 1
Descriptive statistics of socioeconomic variables.

	Non-certified	VSS	TP-VSS	IH-VSS
	mean (sd)	mean (sd)	mean (sd)	mean (sd)
Socioeconomic variables				
Household head characteristics				
Gender (1 = male)	0.76 (0.02)	0.75 (0.02)	0.73 (0.02)	0.78 (0.03)
Age (years)	54 (0.76)	55 (0.55)	56** (0.61)	53 (0.77)
Literacy (1 = yes)	0.77 (0.02)	0.82* (0.2)	0.81 (0.02)	0.85** (0.02)
Farming experience (years)	32 (0.92)	34* (0.66)	35*** (0.76)	31 (0.95)
Main occupation (1 = farmer)	0.91 (0.01)	0.93* (0.01)	0.93 (0.01)	0.94 (0.01)
Household characteristics				
Household size (number)	4.97 (0.12)	4.98 (0.10)	4.87 (0.10)	5.21 (0.14)
Non-coffee income (USD/year)	822 (61)	925 (52)	961 (62)	912 (68)
Financial account (1 = yes)	0.76 (0.02)	0.87*** (0.01)	0.88*** (0.02)	0.87*** (0.02)
Proportion of owned land[§]	4.57 (0.05)	4.67* (0.03)	4.69* (0.03)	4.63 (0.05)
Proportion of land under agriculture[§]	2.64 (0.04)	2.72* (0.03)	2.73* (0.03)	2.70 (0.04)
Cooperative membership (1 = yes)	0.37 (0.03)	0.64*** (0.02)	0.68*** (0.02)	0.41 (0.03)
Distance to market (km)	3.96 (0.21)	4.63*** (0.16)	4.70*** (0.19)	4.39 (0.25)
Coffee plot characteristics				
Land (ha)	0.14 (0.01)	0.14 (0.01)	0.15 (0.01)	0.14 (0.01)
Coffee trees (number)	392 (33)	370 (23)	389 (28)	365 (33)
Density (coffee trees/ha)	3117 (92)	2913* (54)	2972 (82)	2988** (81)
Districts				
Rusizi	0.17 (0.02)	0.29*** (0.02)	0.38*** (0.02)	0.21 (0.03)
Nyamasheke	0.22 (0.02)	0.18 (0.02)	0.14*** (0.02)	0.39*** (0.03)
Karongi	0.23 (0.02)	0.12*** (0.01)	0.15*** (0.02)	0.08*** (0.02)
Rutsiro	0.18 (0.02)	0.16 (0.02)	0.12** (0.02)	0.15 (0.02)
Huye	0.19 (0.02)	0.25* (0.02)	0.21 (0.02)	0.17 (0.02)
Instrument				
CWS ownership (1 = cooperative or exporter)	0.16 (0.02)	0.69*** (0.02)	0.85*** (0.02)	0.52*** (0.02)
Observations	**327**	**515**	**396**	**247**
Environmental variables				
Tree cover in 1-km radius (%)	11.26 (1.14)	11.33 (0.91)	11.14 (0.95)	11.34 (1.43)
Distance to the closest natural forest (km)	12.80 (1.37)	11.27 (0.92)	11.51 (1.12)	8.07*** (1.01)
Altitude	1689 (24)	1660 (22)	1667 (27)	1633 (33)
Observations	**37**	**62**	**47**	**35**

Note: Third-party (TP) and In-house (IH) certifications are not mutually exclusive; therefore, farmers with both types of certifications are included in both groups. Significant differences in means for each certification type and the non-certified group are indicated with * p < 0.01, ** p < 0.05, *** < 0.01.

§ Proportion of managed land owned or under agriculture: 1 if 0%; 2 if >1% and < 50%; 3 if 50%; 4 if >50% and < 100%; 5 if 100%.

collective certification under a group administrator with a formal Internal Management System (Rainforest Alliance, 2023). Capacity-building mechanisms such as training and technical support, which are central to third-party compliance strategies (Depoorter and Marx, 2024), are also typically delivered through farmer organizations, reinforcing the link between third-party certification and cooperative membership (Meemken et al., 2021). In contrast, under C.A.F.E. Practices the audited entity is the Producer Support Organization, which in Rwanda is the CWS, regardless of its ownership structure (Café Practices, 2016). Because in-house standards do not mandate farmer-level organization as a precondition for compliance, their adoption does not inherently correlate with higher cooperative membership.

Despite these distinctions, some characteristics remain consistent across all groups, with no statistically significant differences in gender composition, household size, non-coffee income, total land size, or the number of coffee trees per farm.

4.1.2. Good agricultural practices (GAPs) across certification groups

Certifications are expected to promote the uptake of farming practices, which will shape economic and ecological outcomes on the farm. To examine this, Fig. 1 presents adoption rates of Good Agricultural Practices (GAPs) across certification groups. GAPs here refer to a set of agronomically validated practices, including shade tree planting, mulching, organic input use, pruning, and pest and disease monitoring, that are promoted under certification schemes and are associated with improved farm management, input efficiency, and environmental stewardship.

Certified farmers adopt a significantly higher average number of GAPs than non-certified farmers (7.90 versus 7.23), with notably higher adoption of shade tree planting, organic practices, mulching, and monitoring and prevention strategies. This pattern is consistent with the capacity-building function of certification schemes, which use training and technical support to foster compliance with sustainability requirements (Depoorter and Marx, 2024).

Within the certified group, however, adoption profiles diverge in ways that reflect the underlying governance logic of each certification type. Third-party certified farmers show significantly higher adoption of organic practices (78% vs. 64% among non-certified), consistent with the environmental and social mandates of standards such as Rainforest Alliance and Fairtrade, which promote reduced agrochemical use and biodiversity-friendly management as core or scored requirements (Fairtrade, 2019; Rainforest Alliance, 2023). In-house certified farmers, by contrast, show significantly higher adoption of pruning (95%), a productivity-oriented practice that improves canopy renewal and cherry uniformity and directly serves the quality and supply objectives of C.A.F.E. Practices (Café Practices, 2016). Notably, in-house certified farmers do not show significantly higher organic practice adoption relative to non-certified farmers, suggesting that the environmental dimension of in-house standards does not translate into the same breadth of ecological practice change as third-party standards.

This divergence in GAP adoption profiles mirrors to some extent the structural differences in standard design identified in Section 2: third-party certifications promote practices that span productivity and conservation, while in-house certifications channel farmer behavior primarily toward practices that support quality outcomes. These practice-level differences foreshadow the divergent economic and ecological outcome patterns reported in the following sections.

4.1.3. Coffee prices across certification groups

Turning to coffee prices, an important contextual factor shapes the interpretation of Table 2. During the data collection period, a government zoning policy required CWSs to pay a fixed farmgate price, with any additional bonuses issued as second payments, limiting the ability of certifications to implement price competition across stations (Gerard, 2020; Gerard et al., 2022). This institutional constraint reduces price variation across groups and means that certification premiums operate within a regulated price environment rather than a freely competitive market.

Within this context, certified farmers receive a modest but significant premium over non-certified farmers (USD 0.009/kg), resulting in an average total price of USD 0.563/kg versus USD 0.547/kg for non-certified farmers. The premium is more pronounced among third-party certified farmers (USD 0.011/kg) than in-house certified farmers (USD

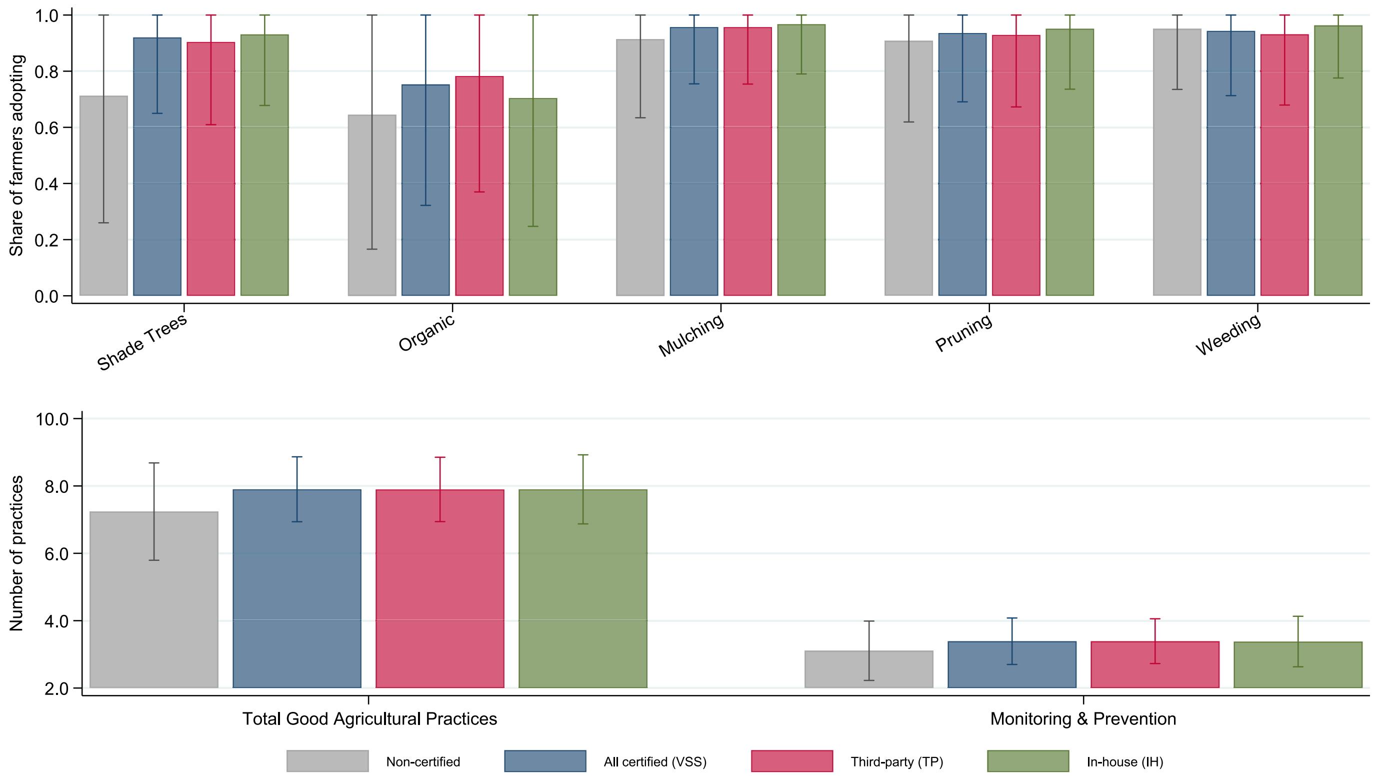

Fig. 1. Adoption of good agricultural practices by certification status.

Table 2
Coffee price by category received by each VSS group of farmers in Rwanda.

	Non-certified	VSS	Third-party VSS	In-house VSS
	mean (sd)	mean (sd)	mean (sd)	mean (sd)
Coffee price (USD/kg)	0.546 (0.004)	0.554 (0.003)	0.560** (0.004)	0.559* (0.006)
Premiums (USD/kg)	0.001 (0.000)	0.009*** (0.001)	0.011*** (0.001)	0.003*** (0.000)
Total Price (USD/kg)	0.547 (0.004)	0.563*** (0.003)	0.571*** (0.004)	0.562** (0.006)
Observations	**327**	**515**	**396**	**247**

Note: Third-party (TP) and In-house (IH) certifications are not mutually exclusive; therefore, farmers with both types of certifications are included in both groups. Significant differences in means for each certification type and the non-certified group are indicated with * $p < 0.01$, ** $p < 0.05$, *** < 0.01.

0.003/kg), resulting in a higher total price for the former (USD 0.571/kg vs. USD 0.562/kg). These differences are consistent with the structural price mechanisms embedded in each certification type: Fairtrade and Rainforest Alliance establish binding price floors or mandatory sustainability differentials paid in cash (Fairtrade, 2019; Rainforest Alliance, 2023), while C.A.F.E. Practices conditions price incentives on quality scores without guaranteeing minimum premiums (Café Practices, 2016; Dietz et al., 2018).

Fig. 2 illustrates the kernel density distributions of the total price (USD) per kilogram of fresh coffee cherries for non-certified (gray), third-party certified (red), and in-house certified (green) groups. The horizontal axis represents price levels, while the vertical axis shows the density of observations, with each curve starting at the group's minimum price (non-certified: USD 0.131; third-party: USD 0.152; in-house: USD 0.253). Although the curves overlap, both third-party and in-house VSS groups tend to shift toward higher prices compared to non-certified farmers. Summary statistics support this observation: the mean prices are USD 0.547 for non-certified, USD 0.571 for third-party, and USD 0.562 for in-house, with all groups sharing a maximum price of USD 0.769. Finally, price distribution for in-house certified farmers is bimodal. The first peak encompasses most farmers (166 across several districts), with roughly half holding double certification and half not. The second peak reflects a smaller group of 30 farmers from Nyamasheke (21 of whom are double certified), supplying only two washing stations. Their higher prices stem primarily from the coffee price offered by these specific washing stations rather than from certification premiums alone.

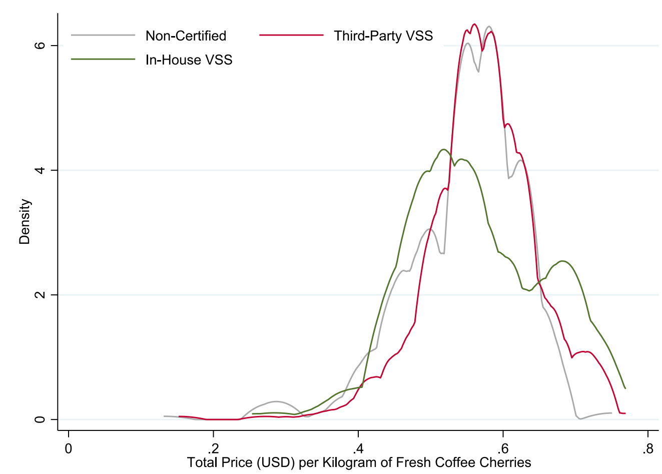

Fig. 2. Total coffee price (USD/kg) distribution.

4.2. *Endogenous Switching Regression: associations with economic outcomes*

Table 3 presents the expected Average Treatment Effect on the Treated (ATT) of the group of all certified (VSS), third-party certified

Table 3
Expected ATT for economic outcomes for VSS, TP-VSS, and IH-VSS.

	VSS		Third-party		In-house	
	ESR	OLS	ESR	OLS	ESR	OLS
Log(yield) (kg/ha)	0.21*** (0.01)	0.17*** (0.07)	0.23*** (0.01)	0.18*** (0.07)	0.21*** (0.02)	0.18 (0.12)
Log(Gross coffee income) (USD/ha)	0.35*** (0.01)	0.22*** (0.07)	0.34*** (0.01)	0.26*** (0.07)	0.36*** (0.02)	0.17 (0.11)
Log(Costs) (USD/ha)	0.36*** (0.02)	0.20 (0.16)	0.20*** (0.03)	0.22 (0.19)	0.47*** (0.04)	0.27 (0.23)
Net coffee income (USD/ha)	198*** (34)	655** (266)	443*** (38)	670** (284)	−55 (70)	685 (506)
Observations	**842**	**842**	**723**	**842**	**574**	**842**

Note: ***, **, * means significant at the 1%, 5%, and 10% level, respectively. Robust standard errors in parentheses.

(TP-VSS), and in-house certified (IH-VSS) farmers on four economic outcome indicators, estimated using Endogenous Switching Regression (ESR). The full ESR results are provided in Appendix A4, A5, and A6 for the full model, third-party, and in-house certifications respectively. To evaluate the magnitude of potential unobserved selection bias under the zoning policy, we compare the ESR results with OLS estimates (Appendix A7). Both approaches yield similar directional effects and overall conclusions, suggesting that selection bias is not large. While the ESR model refines effect sizes and significance levels, we acknowledge its limitations and interpret the estimated effects as associations rather than strictly causal inferences.

On average, certifications are associated with significant increases in yields, gross coffee income, and production costs, ultimately leading to higher net coffee income. However, the estimates vary considerably across certification types, revealing important differences in the economic pathways through which each governance model operates.

Both third-party and in-house certifications are associated with significant yield gains and higher gross coffee income, suggesting that the productivity-oriented components of both certification types generate comparable output improvements. These yield associations are consistent with prior evidence from Rwanda and the broader region (Haggar et al., 2017; Akoyi and Maertens, 2018; Gather and Wollni, 2022) and reflect the GAP adoption patterns, where both certification types promote shade tree planting, mulching, and monitoring practices that support productive coffee systems.

The two certification types diverge considerably, however, on production costs and net income, the dimensions most directly relevant to farmer welfare. Both certification types are associated with higher production costs, but the cost increase for in-house certifications is substantially larger. To understand these cost dynamics, Appendix 8 presents ESR results of production costs disaggregated into their two main components: agrochemicals and labor. Both certification types are associated with lower agrochemical costs. However, in-house certifications are associated with an 87% increase in labor costs compared to 43% for third-party certifications. Higher costs under certifications more generally stem from the greater labor demands of intensified good agricultural practices (Qiao et al., 2016; Haggar et al., 2017; Ingram et al., 2018; Meemken et al., 2021), and this is particularly pronounced for in-house certifications, consistent with their stricter quality protocols, enhanced monitoring, and traceability requirements that demand greater labor inputs and farm-level oversight (Renard, 2010; Giuliani et al., 2017; Dietz et al., 2020).

In this case study, third-party certifications are more strongly associated with translating productivity gains into tangible welfare improvements for farmers than in-house certifications. Third-party certified farmers show a significant and positive association with net coffee income, while in-house certified farmers do not, as the revenue increases generated by higher yields are fully offset by the disproportionate rise in labor costs. Third-party certifications combine binding price mechanisms, such as Fairtrade's price floor and Rainforest Alliance's mandatory sustainability differential (Fairtrade, 2019; Rainforest Alliance, 2023), with capacity-building support, including training and technical assistance, embedded in their institutional design (Depoorter and Marx, 2024). For smallholders, group certification and associated support services can reduce the compliance cost burden, creating conditions in which revenue gains outpace cost increases (Meemken et al., 2021). In-house certifications impose compliance costs driven by corporate quality and traceability requirements without guaranteeing price premiums that would allow farmers to recover those costs (Renard, 2010; Dietz et al., 2018).

Haggar et al. (2017) report similarly higher costs for in-house certified farmers, though they find positive net income associations, likely because in-house certified farmers in their study benefited from higher productivity and prices in a more competitive market context. By contrast, coffee price differences across certified and non-certified farmers in Rwanda are minimal due to the fixed farmgate price structure established under the government zoning policy (Gerard et al., 2022), limiting the potential for net income gains particularly under in-house certifications, which do not guarantee premiums (Café Practices, 2016; Dietz et al., 2018). This finding echoes Meemken et al. (2021), who show that the net welfare effects of certification depend critically on whether price and cost mechanisms are jointly favorable, and Giuliani et al. (2017), who find that in-house programs improve environmental conduct without triggering equivalent social upgrading. For smallholder farmers, net income is a critical measure of economic well-being; yield or revenue gains alone do not necessarily translate into improved livelihoods if costs rise faster than earnings.

4.3. Generalized linear models: associations with ecological outcomes

Fig. 3 presents the GLMM estimated effects of certifications on various ecological indicators, including shade trees per hectare, shade tree species, biodiversity indices (Shannon and Simpson), bioacoustics index, and arthropod predation rate. We present the full regression results for the full model (VSS) in Appendix A9 and for third-party and in-house certifications in Appendix A10.

Across the pooled certification group (VSS), no significant associations with ecological outcomes are observed relative to the control group, underscoring the importance of disaggregating the analysis by certification type. Third-party certifications show a significant positive association with shade tree species richness (coefficient: 0.28, $p < 0.10$). Point estimates for shade trees per hectare and other diversity indices are positive in direction but not statistically significant. Given the limited statistical power of the 99-farm ecological subsample, the directional consistency across indicators nonetheless suggests a genuine, if modest, positive ecological signal. This pattern aligns with the environmental mandate of third-party standards such as Rainforest Alliance, which require minimum shade cover, prohibit deforestation, and promote biodiversity-friendly management as binding compliance criteria (Rainforest Alliance, 2023). These results are consistent with Haggar et al. (2017), who find that third-party certifications are associated with higher vegetation diversity. The modest significance levels may also reflect the temporal dynamics of agroforestry systems, where ecological benefits of shade tree establishment accumulate gradually and cross-sectional data will tend to underestimate long-run effects.

In-house certifications show a significant negative association with arthropod predation rate (coefficient: −8.05, $p < 0.01$). These rates reflect the functional ecosystem service of biological pest control,

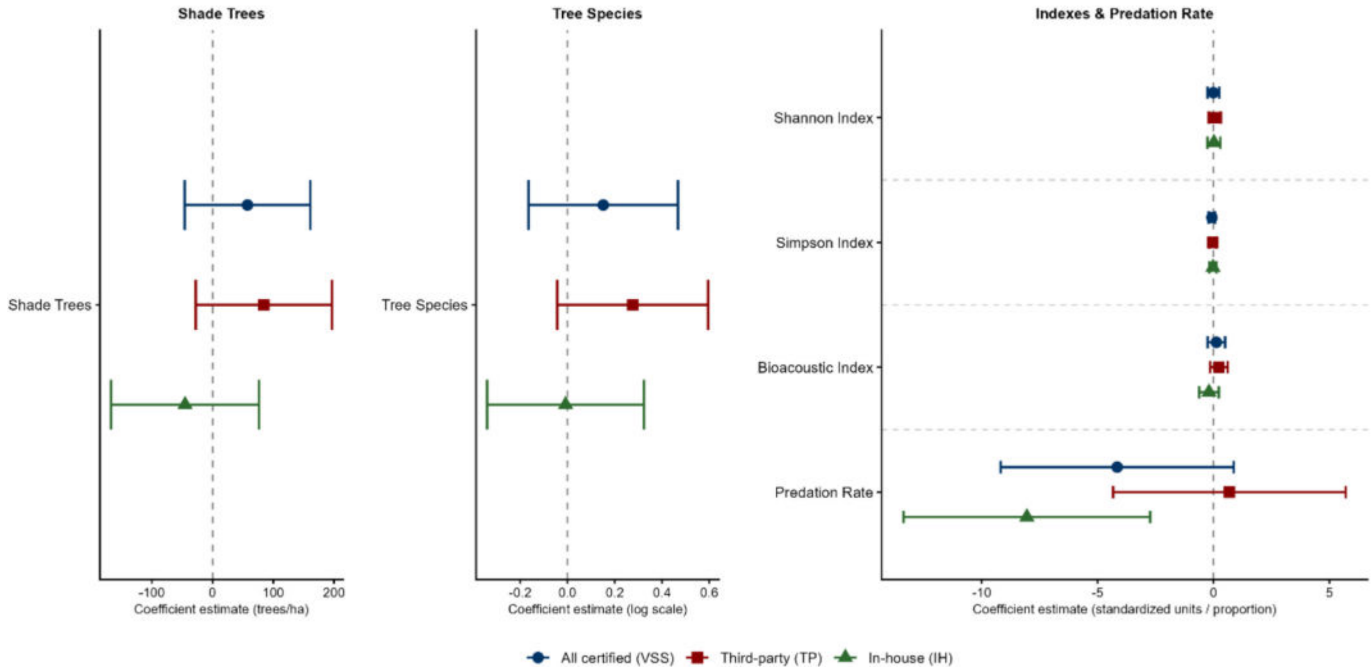

Fig. 3. Ecological estimates compared to non-certified farmers.

provided by predator communities that depend on habitat complexity and vegetation structure (Low et al., 2014). Our results also show that in-house certifications have negative and non-significant point estimates for shade tree density and species richness, which indicates that vegetation structure is not improving or becoming more complex as a result of these certifications, and therefore likely not providing enough resources for predator communities to remain in the coffee farms. These results are consistent with Haggar et al. (2017), who find no vegetation diversity gains on in-house certified farms. Moreover, they likely reflect the focus of corporate supply chains on quality and yield-oriented standards, rather than ecological ones.

The C.A.F.E. Practices framework emphasizes cherry uniformity and processing efficiency (Café Practices, 2016), incentivizing practices such as intensive pruning that can reduce canopy complexity, as evidenced by the significantly higher pruning adoption rates shown in Fig. 1. With environmental criteria largely non-obligatory for certification (Dietz et al., 2018), farmers face little institutional incentive to invest in ecological complexity beyond what quality production requires. This, however, is known to come at the expense of crop health on the long term, with higher densities of pests and lower availability of pest control ecosystem services under more intensive farm management (Shimales et al., 2023).

Finally, the results show no significant effects of certifications on mobile animals as birds, assessed through the bioacoustics index. This reflects the inherent spatial limitations of plot-level interventions. In highly fragmented landscapes with average farm sizes of approximately 0.14 ha (Table 1), bird and insect communities respond more strongly to landscape-level factors such as proximity to forest fragments and neighboring farm practices than to individual plot management (Tscharntke et al., 2011; Rocha et al., 2019; Bennett et al., 2022).

5. Conclusion

Taken together, the empirical results of this study reveal two distinct patterns of sustainability governance within the Rwandan coffee sector. Third-party certifications exhibit a pattern of synergy, where economic and ecological outcomes are jointly positive relative to non-certified farms. Farmers under these independent schemes experience significantly higher net coffee income alongside higher shade tree species richness. In contrast, in-house certifications exhibit a pattern of trade-off. For these farmers, higher productivity levels are offset by increased labor costs, resulting in stagnant net incomes, and ecological outcomes do not show equivalent improvements, with arthropod predation rates significantly lower than among non-certified farmers.

We interpret these differences in outcomes as reflecting the distinct institutional designs of the two types of standards. Third-party certifications that are characterized by binding environmental requirements, independent accountability, and mandatory premium mechanisms seem to create structural conditions favorable to the generation of positive sustainability outcomes. The weaker institutional design of in-house programs, by contrast, which prioritizes corporate supply chain reliability and quality over strict environmental conservation and guaranteed price floors, appears to limit their capacity to deliver positive ecological and livelihood outcomes that go beyond productivity improvements (Giuliani et al., 2017).

These findings carry important implications for the credibility and design of private sustainability governance. At the farm level, the results demonstrate that the institutional structure of a certification, rather than the mere presence of a sustainability label, is what ultimately shapes outcomes. At the standard-setting level, the results empirically support calls for corporate programs to integrate mandatory price mechanisms and binding environmental thresholds (Dietz et al., 2018; Depoorter and Marx, 2024). Without these structural reforms, the continued proliferation of corporate programs risks displacing more rigorous, independent third-party standards from the market, potentially exacerbating the relative race to the bottom observed in global certified agricultural markets (Dietz et al., 2018).

At the policy level, these findings highlight the limitations of relying solely on voluntary, private governance. National authorities such as Rwanda's National Agricultural Export Development Board (NAEB), alongside international regulatory frameworks like the EU Deforestation Regulation, which requires importers to conduct due diligence on deforestation risks for coffee and other commodities, possess the necessary leverage to mandate minimum ecological and livelihood standards across all certification schemes operating in producer countries.

While this cross-sectional study provides evidence of these divergent associations, future research using longitudinal panel data across different geographical contexts would be valuable to further untangle the long-term temporal dynamics of agroecological investments and corporate compliance costs. The relatively small ecological subsample of 99 farms also constrains statistical power for some indicators, and future studies with larger ecological samples would allow more precise estimation of certification effects on functional biodiversity metrics.

Disclosure of AI use

During the preparation of this work, the authors used ChatGPT (OpenAI) in order to improve readability and language clarity. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Bruno Paz: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Meike Wollni:** Writing – review & editing, Validation, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Miet Maertens:** Writing – review & editing, Validation, Supervision, Conceptualization. **Carolina Ocampo-Ariza:** Writing – review & editing, Validation, Methodology, Data curation, Conceptualization. **Arne Wenzel:** Writing – review & editing, Validation, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This research was financially supported by the German Research Foundation (DFG) through the Sustainable Food Systems Research Training Group (RTG2654). We are grateful to our research assistants, Kolja Wächter and Damian Bernzen, for their outstanding support in the field, and we sincerely appreciate the farmers who generously took the time to answer our questions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2026.104835.

Data availability

Data will be made available on request.

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