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Promoting Sustainable Coffee Production: A Comparison of Economic and Ecological Indicators Under In-House and Third-Party Sustainability Standards in Rwanda

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ABSTRACT

Voluntary sustainability standards (VSS) have gained prominence in the agri-food sector as market-based tools to address environmental and social concerns in global supply chains. While third-party certifications like Rainforest Alliance and Fairtrade have been extensively studied, company-led in-house certifications, such as Starbucks' C.A.F.E. Practices, remain underexplored. This paper examines the effects of in-house and third-party certifications on coffee farmers' economic and ecological outcomes in Rwanda. Using survey data from 842 coffee farmers and ecological data from a subsample of 99 farmers, we explore the association between certifications and coffee revenues, costs, yields, vegetation structure, and animal diversity. Our findings indicate that third-party certifications enhance economic performance without compromising ecological conditions, whereas in-house certifications improve economic indicators at the expense of biodiversity. These findings underscore the need for policy measures that not only support the economic benefits of certification but also address potential ecological trade-offs, ensuring that sustainable development strategies benefit both farmers and the environment.

Keywords: Sustainability standards; Third-party and in-house certifications; Economic outcomes; Ecological outcomes; Coffee; Rwanda.

JEL Code: Q01, Q56, Q57

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1. Introduction

Voluntary sustainability standards (VSS or certifications hereafter) have become increasingly important in the agri-food sector over recent years, due to growing consumer concerns in high-income countries about the sustainability of tropical commodities (Tscharntke et al. 2015; Meemken et al. 2021; Marx et al. 2024). VSS serve as market-based, private regulatory instruments that aim to mitigate social and environmental problems by implementing a set of criteria that promote environmental and social responsibility within production systems (Milder et al. 2015) . Companies and global buyers often use voluntary sustainability standards (VSS) as a corporate social responsibility strategy (Giuliani et al. 2017; Meemken et al. 2021). While most standards are led by third parties (e.g., Rainforest Alliance, Fairtrade, etc.), some companies have created their own certification schemes to address various price and market power concerns (Ruben and Zuniga 2011; Yenipazarli 2015; Lambin and Thorlakson 2018). These self-standard schemes, commonly known as in-house certification, have been widely implemented in the coffee sector, most notably by Starbucks (C.A.F.E. Practices) and Nespresso (AAA Sustainable Quality Program).

In-house schemes are usually different from third-party certifications because they are designed internally and have more flexibility to align with the company's business objectives (Ruben and Zuniga 2011; Giuliani et al. 2017; Panhuysen and Pierrot 2020). As a result, they are often viewed with skepticism, as they may contribute to private greenwashing mechanisms rather than genuinely improving farmers' livelihoods and the environmental conditions of production systems (Giovannucci et al. 2008; Giuliani et al. 2017). However, to date, most studies on certification have focused on third-party and NGO-led certifications, leaving in-house standards largely unexplored (Lambin and Thorlakson 2018; Panhuysen and Pierrot 2020; Dietz et al. 2020).

This paper addresses this research gap by investigating the relationship between the adoption of in-house and/or third-party certifications and the economic and ecological outcomes of coffee plots among farmers in Rwanda. First, we analyze whether adopting in-house and/or third-party certifications improves economic performance indicators at the coffee plot level. Specifically, we look at coffee gross revenue, net revenue, costs, and yield. Second, we examine whether certification adoption enhances ecological outcomes related to vegetation structure (shade tree count, tree species richness, and shade tree diversity) and animal diversity (bioacoustics index and predation rate) at the coffee plot level. Third, we discuss whether and under what circumstances VSS can help mitigate trade-offs between economic and ecological outcomes across certification schemes.

For the economic analysis, we use data from a farm household survey based on a stratified random sample of 515 certified and 327 non-certified coffee farmers in Rwanda, collected between November 2022 and January 2023 in five major coffee-producing districts: Rusizi, Nyamasheke, Rutsiro, Karongi, and Huye. Among the 515 certified farmers, 268 are certified only by third-party VSS (Rainforest Alliance, Fairtrade, Organic), 119 hold only a C.A.F.E. Practices certification, and the remaining 128 have both certifications. For the ecological analysis, we use data from ecological experiments conducted on a sub-sample of the socioeconomic survey, which includes 62 certified and 37 non-certified farmers. Among the 62 certified farmers, 27 hold only third-party VSS certifications, 15 are certified only by C.A.F.E. Practices, and the remaining 20 have both certifications.

Our paper makes two main contributions. First, while previous studies have assessed the effects of VSS, few have explicitly considered company-led certifications (Ruben and Zuniga 2011; Giuliani et al. 2017; Haggar et al. 2017; Dietz et al. 2020). As these certifications become increasingly central to sustainability efforts, it is critical to understand their effects. Thus, our first contribution is to expand the limited literature by examining the effects of in-house certifications.

Second, few studies have examined the trade-offs between economic and ecological outcomes associated with certification adoption (Haggar et al. 2017; Vanderhaegen et al. 2018; Gather and Wollni 2022; Paz et al. 2024; Wätzold et al. 2025). Among these, even fewer rely on actual ecological data rather than self-reported measures (Haggar et al. 2017; Vanderhaegen et al. 2018; Paz et al. 2024; Wätzold et al. 2025). Notably, Haggar et al. (2017) is the only study to compare the effects of in-house and third-party certification in this context. A deeper understanding of whether and under what circumstances VSS can help mitigate economic-ecological trade-offs is crucial for promoting more sustainable production systems. Our second contribution expands this limited literature by simultaneously evaluating economic and ecological indicators, a rarely adopted approach that enables us to assess potential economic-ecological trade-offs.

Our study concludes that third-party VSS can promote sustainable development by enhancing economic conditions without compromising ecological ones. In contrast, in-house VSS improve coffee economic indicators at the expense of ecological ones. These findings underscore the need for policy measures that not only support the economic benefits of certification but also address potential ecological trade-offs, ensuring that sustainable development strategies benefit both farmers and the environment.

The paper is organized as follows. Section 2 provides background on in-house and third-party certifications. Section 3 outlines the conceptual framework. Section 4 describes the methods and empirical approach, while Section 5 presents the results. Section 6 discusses our findings, and we conclude the paper in Section 7.

2. Background

On in-house and third-party standards

Standards have increased their number rapidly from just a few to several hundred in the past two decades (Marx et al. 2024). Currently, there are three main classifications for VSS: Government (e.g., USDA Organic, ISPO), NGO (e.g., Fairtrade or Rainforest Alliance), and Company-led standards (e.g., C.A.F.E. Practices) (Lambin and Thorlakson 2018). These groups of standards have also broadened their scope over time (Lambin and Thorlakson 2018; Meemken et al. 2021), creating a huge overlap across schemes. These issues combined have led to a duplication problem (Lambin and Thorlakson 2018) that has raised questions about the credibility of VSS, due to the wide range of claims they make and the potential confusion they can create for producers, buyers, and consumers (UNFS 2018).

Then the natural question is why do we need more standards, or more precisely, why do some companies need to develop their own standards when they are often seen as weaker governance instruments than NGO-led standards (Giovannucci et al. 2008; Giuliani et al. 2017)? One explanation is that in-house labeling is often preferred over third-party labels due to the high costs associated with licensing, initial participation fees, and auditing expenses, which frequently outweigh the short-term market benefits (Yenipazarli 2015). Additionally, premium or floor prices imposed by third-party certifications can be prohibitively high, reducing demand due to market distortions and, in turn, undermining the total profit from certified products (Yenipazarli 2015). In fact, the supply of certified coffee in the agri-food market often exceeds demand (Panhuysen and Vries 2023; Marx et al. 2024).

To mitigate market distortions, in-house certifications generally adopt a weaker price-driven scheme compared to third-party certifications. For example, Fairtrade mandates a minimum price and an additional premium differential for quality (Fairtrade 2019). Similarly, the Rainforest Alliance requires a quality-based premium differential, which must be paid in cash (Rainforest Alliance 2023). In contrast, C.A.F.E. Practices follows a similar approach to premium differentials based on quality but provides limited transparency regarding price mechanisms in its evaluation framework (Café Practices 2016).

Besides price and cost-related issues, in-house certifications are frequently a response to exclusion or direct competition from existing Voluntary Sustainability Standards (VSS) and serve as a strategy to capture market share (Reinecke et al. 2012; Potts et al. 2014; Lambin and Thorlakson 2018). For example, the private sector may introduce its own certifications to counter “defamation” campaigns by NGOs (Lambin and Thorlakson 2018) and to preserve autonomy and identity (Reinecke et al. 2012), contributing to the growth of in-house and industry-led standards. For example, the 4C certification, an industry-driven standard for coffee, was introduced as a response to the Rainforest Alliance certification (Lambin and Thorlakson 2018). This expansion of privately-led standards strengthens industry influence by capturing market share from NGO-led standards, but potentially creates confusion among consumers and producers, thereby weakening the credibility of VSS systems as a whole (Lambin and Thorlakson 2018).

3. Conceptual framework

Sustainability standards are designed to influence both the socioeconomic and ecological outcomes of coffee farm households through price, production, and environmental-related interventions (Meemken et al. 2021). In this section, we present a conceptual framework illustrating the potential pathways through which VSS may impact coffee-related economic and ecological indicators. Figure 1 provides a graphical representation of this framework.

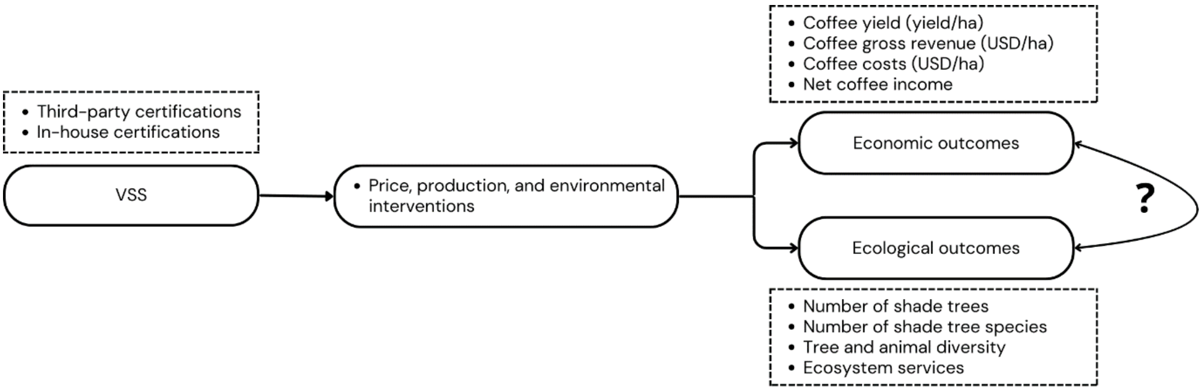

Figure 1: How VSS affect economic and ecological outcomes

Economic outcomes

Sustainability standards often implement price-related interventions, such as promoting quality-based price differentials, and thereby should enhance the prices farmers receive for their coffee (Café Practices 2016; Fairtrade 2019; Rainforest Alliance 2023). Moreover, certifications provide better access to agrochemicals when their availability is low (Jena et al. 2017), promote the adoption of new agricultural practices, and offer recurring training (Jena et al. 2017; Sellare et al. 2020), all of which should increase coffee productivity (Beuchelt and Zeller 2011; Paz et al. 2024).

Since certifications influence both yield and price through production and price-related interventions, they are expected to increase gross coffee income. However, their impact on net coffee income, whether positive or negative, depends on production costs. Sustainability standards are associated with various costs. Farmers typically bear fixed costs (e.g., protective gear for pesticide application) and variable costs (e.g., hired labor, fertilization, and other inputs) required to transition their production systems, obtain, and maintain certifications (Meemken et al. 2021). Consequently, the extent to which certifications enhance the economic viability of coffee plots depends on the interplay of three key factors: coffee price, production, and costs.

Ecological outcomes

Moreover, we hypothesize that VSS also contribute to improving the ecological conditions of the coffee plots because most VSS target, along with socioeconomic improvements, ecological and environmental improvements. For example, they promote an increase in tree cover and vegetation density on and around the coffee plots, having minimum requirements for the proportion of shade trees in the coffee plots while prohibiting deforestation in their surrounding areas (Café Practices 2016; Rainforest Alliance 2023). Additionally, the training on good agricultural practices that we hypothesized to affect coffee yield should also be relevant for ecological indicators on the coffee plot because they reduce agrochemicals application (due to recurrent monitoring of pests) and increase natural control agents by maintaining bush and habitats for beneficial predators (Rainforest Alliance 2023). Therefore, we expect that certifications improve vegetation structural complexity and animal diversity indicators at the coffee plot level.

4. Methods

Data

We conducted a stratified random selection of certified and non-certified coffee washing stations (CWSs) across five major coffee-producing districts in Rwanda (Rusizi, Nyamasheke, Karongi, Rutsiro, and Huye). We identified the CWSs from a list provided by local authorities. Next, we randomly chose farmers from a full list provided by each selected CWS. During the data collection period, a zoning policy[1] was in effect, which assigned each farmer to a specific CWS based on their geographical location. As certification is granted at the CWS level, the certification status of each farmer depends on the CWS allocation and is exogenously assigned to the farmer.

Our socioeconomic data derive from a farm household survey collected between November 2022 and January 2023. Our sample covers 842 coffee farm households, and we captured information on household demographics, coffee production in the most productive coffee plot, agricultural production, and general household welfare and socioeconomic conditions. The sample includes 327 non-certified farmers, 268 farmers certified only by third-party standards (Rainforest Alliance, Fairtrade, or Organic), 119 certified only by in-house standards (C.A.F.E. Practices), and 128 certified by both.

[1] The zoning policy was implemented in June 2016 and lifted in June 2023

Our ecological data derive through ecological assessments at the coffee plot level on a subsample of 99 farmers. The subsample was defined by randomly selecting farmers whose plots contain at least 100 coffee trees. We collected information on the number of shade trees, shade tree species, bioacoustics index, and predation rate. The full protocol for collecting our ecological data is provided in Appendix A1. The subsample includes 37 non-certified farmers, 27 farmers certified only by third-party standards, 15 certified only by in-house standards, and the remaining 20 certified by both.

Economic and ecological indicators

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 in 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 all expenses associated with producing coffee on the most productive coffee plot, represented as a variable in USD per hectare. *Net coffee income* is calculated by subtracting *coffee production costs* from *gross coffee income* and is expressed in USD per hectare.

The ecological performance indicators relate to vegetation structure and animal diversity. Indicators for vegetation structure 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 structure is expected to enhance animal diversity and ecosystem functioning (Tscharntke et al. 2011). Second, our 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. 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. A detailed explanation of the calculation methods is provided in Appendix A1.

Predation rate is the proportion of fake plasticine caterpillars deployed in each coffee plot that are attacked by predators (Schwab et al. 2021), serving as an indicator of the ecosystem service provided by biological control. 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 community (Boelman et al. 2007).

Estimation strategy

Endogenous Switching Regression (ESR) for estimating economic outcomes

Voluntary sustainability standards (VSS) are typically considered a farmer's choice, influenced by both observable and unobservable characteristics (Meemken et al. 2021). Consequently, certified and non-certified farmers often differ systematically, with certified farmers generally willing to incur costs in exchange for associated benefits. However, in 2016, the Rwandan government implemented a zoning policy that reshaped certification dynamics. The zoning policy aimed to strengthen relationships between farmers and coffee washing stations (CWSs) while reducing the role of middlemen (Gerard et al. 2017). It established geographic zones, restricting CWSs to purchasing coffee cherries only from farmers within their designated areas and requiring farmers to sell exclusively to their assigned CWS (Gerard et al. 2017). Nevertheless, due to the close proximity of some CWSs, overlapping zones emerged, making the system more flexible than strictly independent geographical assignments. Although side-selling was prohibited, farmers faced no direct penalties; instead, traders risked coffee confiscation and fines, while CWSs purchasing outside their designated zones were similarly sanctioned (Gerard 2020; Gerard et al. 2022).

When estimating the effects of certification on economic outcomes, a typical concern is that the certification status is potentially endogenous to the outcome variables. For example, suppose certification is an individual choice at the farmers' level. In that case, unobserved farmer characteristics, such as management skills or wealth, may influence both the decision to pursue certification and the way farms are managed. These characteristics can directly impact economic outcomes, making it challenging to separate the true effect of certification on variables like yield, costs, and income per hectare. The Rwanda zoning policy, in effect during our data collection, helps mitigate some individual-level selection bias, but due to its imperfect implementation, it does not fully address this issue. Moreover, selection bias may still arise at the CWS level. For example, CWS managers with a strong focus on environmental sustainability may already promote farming practices that influence both yield and the likelihood of obtaining certification.

To address potential endogeneity bias, we employ the endogenous switching regression approach (Maddala 1983) to estimate the effect of in-house and third-party certifications on economic outcomes. The endogenous switching regression (ESR) method is a two-stage parametric approach commonly used in impact assessments (Abdulai 2016), including studies on certifications (Kleemann et al. 2014; Wätzold et al. 2025). In the first stage, a probit model estimates the selection into treatment. In the second stage, outcome equations are estimated separately for the treatment and control groups, incorporating the inverse Mills ratios from the first stage as additional covariates.

We estimate the endogenous switching regression (ESR) model three times to evaluate the effects of in-house and third-party certifications, which are not mutually exclusive. In the first estimation, we use the full sample to compare certified farmers, under any scheme, to non-certified farmers. In the second estimation, we exclude certified farmers who have not adopted third-party certifications to isolate the effect of third-party schemes. Similarly, in the third estimation, we exclude certified farmers without in-house certifications to assess the effect of private schemes.

To estimate a farmer's probability of being certified, we use a utility maximization framework and employ a probit model in the first stage:

$$CERT_i = Z_i\gamma + n_i \qquad (1)$$

Where $CERT_i$ can be represented as VSS_i, TP_i, and IH_i, corresponding respectively to certification under any voluntary sustainability standard (VSS), a third-party (TP), or an in-house (IH) scheme. Equation 1 is run separately for each treatment: one run for VSS, one for TP, and one for IH. 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. Specifically, we conduct three separate estimations to assess the impact of different certification schemes:

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

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

- The corresponding equation for non-certified farmers ($CERT_i = 0$)
    - $Y_{i,N} = X_{i,N}\beta_N + \sigma_{N,n}\lambda_{i,N} + \vartheta_{i,N} \qquad (2.2)$

Like in Equation 1, $CERT_i$ can be represented as VSS_i, TP_i, and IH_i, corresponding respectively to certification under any voluntary sustainability standard (VSS), a third-party (TP), or an in-house (IH) scheme. 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 equation

(1), denoted as λ_i. The covariance terms σ_n represent the error terms, which have conditional means of zero.

Our control variables include the demographic characteristics of the household head, such as gender, age, literacy level, farming experience, primary occupation, and household size. We also control for economic factors, including non-coffee income, access to a financial institution, and cooperative membership. Additionally, we incorporate land and agricultural characteristics such as land size, number of coffee trees on the plot, proportion of owned land, proportion of agricultural land, and distance to the nearest agricultural market. We include district-fixed effects to control for regional heterogeneity. To account for the fact that third-party and in-house certifications are not mutually exclusive, we include the alternative certification as a control variable in Equations 2.1 when estimating the effect for TP or IH.

Although the variables used in the first stage can overlap with those in the second stage, the model requires at least one variable to be present in Z_i but not in X_i for proper identification. In other words, the sample selection equation is estimated using the control variables along with at least one additional instrument (Abdulai 2016). To satisfy this requirement, we include an instrument in our selection model that meets the exclusion restriction, meaning it influences the probability of certification but does not directly affect the outcome variable (Wooldridge 2014).

We use the ownership of coffee washing stations (CWSs) as an instrument. In Rwanda, CWSs can be owned by cooperatives, exporters, or individuals. We hypothesize that cooperative-owned and exporter-owned CWSs are more likely to obtain certifications than individually owned ones, as cooperatives are driven to pursue high-value market opportunities that benefit their farmers (Wollni and Zeller 2007), while exporters have greater access to global markets. As a result, CWSs with these ownership types are more likely to be certified compared to CWSs owned by individuals. Note that farmers who sell coffee to a cooperative-owned CWS are not necessarily members of the cooperative.

To test the exclusion restriction of our instrument, we conducted a falsification test following Di Falco and Veronesi (2013). This approach examines whether the instrument is strongly correlated with the treatment but not with the outcome variables and suggests that our instrument fulfills the exclusion restriction for all our economic outcomes (Appendix A2).

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. Clustering standards errors at the CWS level accounts for potential correlation among farmers delivering to the same CWS, ensuring that our standard errors are robust to within-CWS dependencies. Next, we compute the average treatment effect on the treated (ATT) separately for each certification type. The ATT represents the expected impact of certification and is derived by measuring the difference between the observed outcomes of certified farmers and their hypothetical counterfactual outcomes had they not been certified. It is estimated as follows:

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

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

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

Generalized linear mixed models for estimating ecological outcomes

We rely on ecological and survey data from a subsample of 99 coffee plots to assess the association between different VSS schemes and ecological outcomes. Following Vanderhaegen et al. (2018), we employ generalized linear models and, for consistency with our economic analysis, specify our model as follows:

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

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

The outcome variable Y_i for equations 4.1 and 4.2 includes *shade trees*, *shade tree species*, *Shannon index*, *Simpson index*, *bioacoustics index*, and *predation rate*. The primary difference between these equations lies in the treatment variable. In equation 4.1, *VSS* is a binary variable, set to 1 if farmer *i* is certified under any certification scheme and 0 otherwise. The variables *TP* and *IH* are also binary, assigned a value of 1 if farmer *i* is certified under a third-party or in-house scheme, respectively, and 0 otherwise. The vector *X* encompasses variables related to coffee production and household characteristics, including the number of coffee trees per plot, the age of the coffee trees, the size (in hectares) of the most productive coffee plot, the household head's gender, age, literacy, main occupation, household size, income from sources other than coffee production, the proportion of land under agriculture, and whether farmers are members of a cooperative. Vector E includes three relevant environmental indicators that may affect our outcomes: the proportion of tree cover within a 1-kilometer radius of the coffee plot, the distance to the nearest primary forest, and the altitude of the coffee plot. We use a Poisson distribution for shade tree species and a Gaussian distribution for the remaining outcome variables.

Similar to Wätzold et al. (2025), we argue that our ecological outcomes are less influenced by selection bias than socioeconomic indicators, as farmers' unobserved characteristics associated with certification are more likely to be correlated with farmers' welfare rather than the vegetation structure and animal diversity in their plots. However, we acknowledge that certification may still be partially influenced by environmental factors. For instance, CWSs located in greener areas might have a higher likelihood of certification, as meeting VSS requirements may be easier in these environments. Following Paz et al. (2024), we examined the enhanced vegetation index within a 500-meter radius of each coffee plot before certification activities began to address this potential issue. Our analysis confirmed that, prior to the start of certification, certified farmers were not located in greener areas than non-certified farmers in our sample (Appendix A3).

Finally, farmers within the same CWS may share similar environmental conditions, agricultural practices, and resource access through their respective CWS. This clustering could introduce similarities within groups independent of certification status, leading to correlation in the error term. Therefore, following Krumbiegel et al. (2018), we use random effects for coffee washing stations (CWS) to account for these within-cluster dependencies and obtain more reliable estimates of the certifications' impact on ecological outcomes.

5. RESULTS

Sample characteristics

Table 1 presents summary statistics of the explanatory variables for non-certified farmers, all VSS certified farmers, third-party certified farmers, and in-house certified farmers. We compare each of the three certified groups to non-certified farmers. VSS-certified farmers exhibit 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. Given these differences, it is important to control for potential selection bias due to unobservable factors that may influence both certification adoption and economic outcomes. To address this, we employ the Endogenous Switching Regression (ESR) model, which accounts for selection on unobservables and provides a more reliable estimation of certification effects.

Third-party certified farmers (TP-VSS) differ significantly from non-certified farmers in several key characteristics, including age, farming experience, financial access, cooperative membership, market distance, and association with well-structured coffee washing stations (CWSs). In-house certified farmers (IH-VSS) 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. 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.

Table 1: Descriptive statistics of socioeconomic variables

	Non-certified mean (sd)	VSS mean (sd)	TP-VSS mean (sd)	IH-VSS 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-kilometer 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 and In-house certifications are not mutually exclusive; therefore, farmers with both types of certifications are included in both groups. Significant differences in means for each certification category and the control 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%.

Good agricultural practices (GAPs) and coffee prices across certification groups

To deepen our understanding of our conceptual framework within the context of our study, we examine the proportion of farmers adopting Good Agricultural Practices (GAPs) in their coffee production systems across different groups. Additionally, we explore the coffee prices received by each group.

Table 2 presents the proportion of farmers adopting various sustainability-related agricultural practices across four groups: non-certified farmers, all certified farmers, third-party certified (TP), and in-house certified (IH) farmers. Each certified group is compared to non-certified farmers to highlight differences in adoption rates. The results indicate that certified farmers adopt a higher number of GAPs on average compared to non-certified farmers. Certified farmers also exhibit significantly higher adoption rates of specific practices such as shade tree planting, organic practices, mulching, and monitoring, suggesting that certification may play a key role in promoting sustainable farming practices. The differences between TP-certified and non-certified farmers, as well as IH-certified and non-certified farmers, follow a similar pattern to the overall certified versus non-certified comparison. However, TP-certified farmers have a higher proportion of organic practice adoption compared to non-certified farmers, while IH-certified farmers do not. In contrast, IH-certified farmers show a higher adoption rate of pruning practices, a pattern not observed among TP-certified farmers.

Table 2: Proportion of farmers adopting GAPs

	Non-VSS mean (sd)	VSS mean (sd)	TP-VSS mean (sd)	IH-VSS mean (sd)
GAP	7.23 (1.44)	7.90*** (0.96)	7.90*** (0.95)	7.89*** (1.02)
Shade trees	0.71 (0.45)	0.92*** (0.27)	0.91*** (0.29)	0.93*** (0.25)
Organic (yes/no)	0.64 (0.48)	0.75*** (0.43)	0.78*** (0.41)	0.70 (0.45)
Mulching (yes/no)	0.91 (0.28)	0.96*** (0.20)	0.96** (0.20)	0.97*** (0.17)
Pruning (yes/no)	0.91 (0.29)	0.94 (0.24)	0.93 (0.26)	0.95* (0.21)
Weeding (yes/no)	0.95 (0.22)	0.94 (0.23)	0.93 (0.25)	0.96 (0.19)
Monitoring and prevention (number of strategies)	3.10 (0.88)	3.39*** (0.69)	3.39*** (0.66)	3.38*** (0.75)
Observations	**327**	**515**	**396**	**247**

Note: Certification groups are not mutually exclusive; therefore, farmers with both types of certifications are included in both groups. Significant differences in means for each certification category and the control are indicated with * p < 0.01, ** p < 0.05, *** < 0.01. Monitoring and prevention involve activities such as removing dead branches, unharvested cherries, infested materials, and planting bushes that attract beneficial insects.

Table 3 shows the average coffee price, premiums, and total price per kilogram of fresh coffee cherries for non-certified, VSS, TP-VSS, and IH-VSS farmers. Prior to receiving any premiums, certified farmers obtain similar prices for their produce as non-certified farmers. However, certified farmers receive a modest premium of USD 0.01 per kilogram, which results in a total coffee price that is USD 0.01 higher on average. While both TP-VSS and IH-VSS farmers follow this pattern, the difference between certified and non-certified farmers is more pronounced among TP-VSS farmers.

Table 3: Coffee price by category received by each VSS group of farmers in Rwanda

	Non-certified mean (sd)	VSS mean (sd)	Third-party VSS mean (sd)	In-house VSS mean (sd)
Coffee price (USD/kg)	0.55 (0.00)	0.55 (0.00)	0.56** (0.00)	0.56* (0.01)
Premiums (USD/kg)	0.00 (0.00)	0.01*** (0.00)	0.01*** (0.00)	0.00*** (0.00)
Total Price (USD/kg)	0.55 (0.00)	0.56*** (0.00)	0.57*** (0.00)	0.56** (0.01)
Observations	**327**	**515**	**396**	**247**

Note: Certification groups are not mutually exclusive; therefore, farmers with both types of certifications are included in both groups. Significant differences in means for each certification category and the control are indicated with * p < 0.01, ** p < 0.05, *** < 0.01.

Figure 2 illustrates the kernel density distributions of the total price (USD) per kilogram of fresh coffee cherries for non-certified (red), third-party VSS (blue), and in-house VSS (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 0.13; third-party: USD 0.15; in-house: USD 0.25). Although the curves overlap, both third-party and in-house VSS groups tend to shift toward higher prices compared to non-certified farmers. This observation is supported by summary statistics: the mean prices are USD 0.55 for non-certified, USD 0.57 for third-party, and USD 0.56 for in-house, with all groups sharing a maximum price of USD 0.77. Finally, in-house VSS exhibits a bimodal shape of the distribution. The first peak encompases the majority of the farmers (166 across several districts) cluster around the first peak, with roughly half holding double certification and half not.

Finally, the in-house VSS distribution 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.

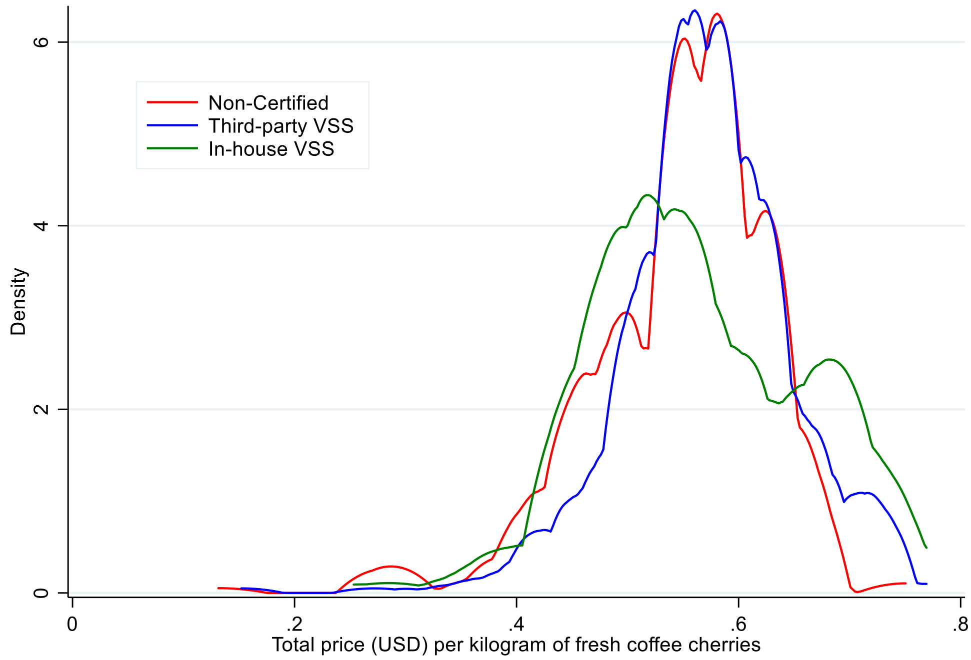

Figure 2: Total coffee price (USD/kg) distribution

Effects on economic outcomes

Table 4 presents the expected Average Treatment Effect on the Treated (ATT) of Voluntary Sustainability Standards (VSS), Third-Party VSS (TP-VSS), and In-House VSS (IH-VSS) on various economic outcome indicators, estimated using Endogenous Switching Regression (ESR). The full ESR results are provided in Appendix A4, Appendix A5, and Appendix A6 for the full model (VSS), third-party, and in-house certifications, respectively. Moreover, to evaluate the magnitude of potential unobserved selection bias under the zoning policy, we compare our ESR results with OLS estimates (Appendix A7). We find that both approaches yield similar directional effects and overall conclusions, suggesting that selection bias is not large. However, the ESR model refines the effect sizes and significance levels, indicating that unobserved factors still play a minor role in shaping the main results.

Table 4: Expected ATT for socioeconomic 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.

The results show that, on average, VSS are associated with significant increases in yields, gross coffee income, and production costs, ultimately leading to higher net coffee income. However, the effects vary across certification schemes. Both TP-VSS and IH-VSS contribute to the observed increases in yield and gross coffee income under VSS. However, TP-VSS show a comparatively larger effect on yield, while IH-VSS show a comparatively larger effect on gross coffee income, which results from the combination of yield and price. Although both certification types lead to higher coffee production costs, the cost increase for IH-VSS is higher than that of TP-VSS. These differences translate into a significant and positive effect on net coffee income (NCI) for TP-VSS farmers but not for IH-VSS farmers. These findings suggest that while all certification types improve economic outcomes, third-party certification offers the strongest economic benefits, particularly in terms of net coffee income.

Association between certifications and ecological outcomes

Table 5 presents the GLMM estimated effects of Voluntary Sustainability Standards (VSS) on various ecological indicators, including shade trees per hectare, species, biodiversity indices (Shannon and Simpson), bioacoustics index, and predation rate. We present the full regression results for the full model (VSS) in Appendix A8 and for third-party and in-house certifications in Appendix A9.

Table 5: Association between VSS and ecological outcomes

	VSS	TP-VSS	IH-VSS	CONTROLS
Shade trees per hectare	57 (52)	85 (57)	-45 (62)	YES
Shade tree species	0.15 (0.16)	0.28* (0.16)	-0.01 (0.17)	YES
Shannon index	-0.01 (0.13)	0.05 (0.13)	0.01 (0.14)	YES
Simpson index	-0.07 (0.07)	-0.04 (0.07)	-0.03 (0.08)	YES
Bioacoustics index	0.12 (0.19)	0.23 (0.19)	-0.20 (0.21)	YES
Predation rate	-4.16 (2.56)	0.68 (2.56)	-8.05*** (2.71)	YES
Observations	**99**	**99**	**99**	

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

The results show that, on average, VSS have no significant association with ecological outcomes, which may be partly due to the divergent effects observed between third-party and in-house certifications. For TP-VSS, the results suggest a tendency toward positive association with shade tree density and species richness, with a clear stronger association with the number of shade tree species. The Shannon index shows a small positive association and the Simpson index a small negative one, reflecting subtle shifts in diversity patterns. In terms of animal diversity, TP-VSS is associated with higher values of the bioacoustics index and predation rates. The relationships between TP-VSS with broader ecological indicators are minimal. In contrast, the effects of in-house certifications are generally small or negative, with IH-VSS notably negatively associated with predation rates.

Discussion

VSS and Economic outcomes

Our results suggest that both third-party and in-house certifications increase coffee yield, aligning with the broader literature on coffee production and certification (Arnould et al. 2009; Beuchelt and Zeller 2011; Jena et al. 2017; Akoyi and Maertens 2018; Paz et al. 2024). Specifically, third-party certifications increase land productivity by 25.9%, while in-house certifications increase it by 23.4%. This effect may stem from a higher intensity of good agricultural practices (GAP) among certified farmers compared to non-certified farmers as shown in Table 2, including the use of shade trees, combining inorganic and organic fertilization, mulching, and regular monitoring for pests.

Moreover, participation in either third-party or in-house schemes increases gross coffee income by 40.5% and 43.3%, respectively. The larger increase in gross coffee income relative to yield suggests that income gains are driven not only by improved yields but also by higher prices, with the price effect likely being more pronounced among in-house certified farmers.

On average, third-party certified farmers receive 2 cents USD more per kilogram of fresh coffee cherries than non-certified farmers, while in-house certified farmers receive 1 cent USD more per kilogram compared to non-certified farmers (Table 3). The slightly higher increase in coffee prices among third-party certifications compared to in-house certifications is not surprising because large coffee companies generally argue that output price interventions may promote market inefficiencies (Ruben and Zuniga 2011). Consequently, in-house certifications typically emphasize yields and quality over price, in contrast to third-party certifications (Lambin and Thorlakson 2018). Additionally, the small increase in average price for both groups is expected in the Rwandan context. First, a significant portion of certified coffee is sold as non-certified coffee due to lower international demand relative to supply (Marx et al. 2024). Second, premium prices in Rwanda are neither common nor high, consistent with findings from a survey of the Ethiopian coffee industry (Minten et al. 2018), which reported that farmers receive only a small share of the total premium paid by consumers. Third, during the implementation of the zoning policy, the Rwandan Government introduced incentives to reduce price competition among CWSs, as such competition could encourage farmer side-selling and undermine the zoning system (Gerard et al. 2022).

Finally, the lowest price paid to farmers is 10 cents USD higher for in-house certified farmers compared to third-party certified farmers (Figure 2). This implies that in-house certifications may be linked to market mechanisms that secure a higher minimum price for coffee more effectively than, for example, Fairtrade regulatory mechanisms in Rwanda. This difference in pricing may help explain the slightly higher coffee income estimates for in-house VSS farmers despite their slightly lower yield estimates compared to third-party certifications. However, previous research has shown that C.A.F.E. Practices are associated with higher annual price volatility than non-certified farmers (Snider et al. 2017), suggesting that further research into this issue is warranted.

Our results also indicate that VSS certification is associated with a 43.2% increase in coffee costs. Although both third-party and in-house standards raise costs, in-house certifications primarily drive this effect, with third-party certifications increasing costs by 22.1% and in-house certifications by 59.9%. These increases are linked to production costs rather than direct VSS fees, as farmers in Rwanda do not pay for their certifications; instead, coffee washing station owners incur these costs, sometimes subsidized by international non-governmental organizations.

To understand the cost dynamics under VSS, Appendix A10 presents endogenous switching regression results, which break down coffee production costs into two main components: agrochemicals and labor. It reveals that both third-party and in-house certifications are associated with significant reductions in agrochemical-related costs. In contrast, labor costs increase by 43% under third-party certifications and 87% under in-house certifications, primarily due to greater labor input rather than higher wages. A plausible explanation is that the increased intensification of good agricultural practices requires more labor for their implementation (Qiao et al. 2016; Haggar et al. 2017; Ingram et al. 2018; Meemken et al. 2021).

Finally, VSS certification leads to higher net coffee income compared to non-certified farmers. However, this effect is primarily driven by third-party VSS, which increase net coffee income by 443 USD/ha, while in-house certifications do not show a statistically significant effect. The difference in profit appears to be linked to the varying increases in coffee production costs observed between the two groups.

In summary, our findings indicate that VSS certifications increase coffee yield, gross coffee income, and costs. However, the effect on net coffee income varies by certification type: third-party certifications boost net coffee income, whereas in-house certifications do not, largely due to higher production costs.

VSS and Ecological Outcomes

The estimates for our ecological outcomes suggest that VSS may be positively associated with the number and diversity of shade trees while having a low association with biodiversity indices. They also indicate a slight positive association with bioacoustics activity and a potential negative association with predation rates. However, the positive association with shade tree-related indicators appears to be driven primarily by third-party certifications, whereas the reduction in predation rates is largely associated with in-house certifications.

Our findings are consistent with Haggar et al. (2017), who suggest that third-party certifications enhance vegetation structure, whereas in-house certifications do not. Although third-party VSS are positively associated with shade trees, the bioacoustics index estimate is not significant. Similarly, Philpott et al. (2007) found that, although organic farms had greater tree diversity than non-certified farms, they did not meet the Bird Friendly shade-certification criteria. Furthermore, Vanderhaegen et al. (2018) also observed both positive and negative associations between third-party certification and tree diversity in Eastern Uganda, highlighting variability depending on the specific certification scheme. Moreover, in our analysis, most ecological indicators for in-house certifications showed negative, non-significant associations; however, the predation rate had a notably negative coefficient and was significant at the 1 percent level. This pattern suggests that reduced biological activity under in-house certifications may be reflected in lower predation rates.

Taken together, these studies indicate that certain certifications may improve aspects of biodiversity, such as tree diversity, but their overall effect on broader ecological metrics, such as vegetation structure or animal diversity, is limited and inconsistent. These findings challenge our conceptual framework, which suggests that certifications in Rwanda should improve broader ecological conditions at the coffee plot level by promoting the adoption of environmentally friendly practices (Gather and Wollni 2022).

Several factors may explain this discrepancy. First, ecological improvements may require longer timeframes to materialize compared to socioeconomic outcomes. Second, ecological conditions within coffee plots are also influenced by the surrounding landscape (Tscharntke et al. 2015; Wollni et al. 2025). For instance, the Rwanda Forestry Policy, launched in 2010 (Ministry of Lands and Forestry of Rwanda 2018), has aimed to reduce deforestation and promote reforestation nationwide. The policy’s positive impacts may obscure the specific ecological effects of certifications. Moreover, suppose a certified farm is surrounded by many non-certified farms or other types of land use that are less beneficial to biodiversity. In that case, these surrounding influences may confound the overall effect of certification, as many species, especially birds, depend on larger landscapes rather than individual plots. New species can only establish themselves if they have suitable habitats from which to migrate. These landscape-level effects are not considered in our study.

Third, although certifications encourage good agricultural practices, such practices are already widely implemented in Rwanda (Gather and Wollni 2022), largely due to ongoing governmental initiatives to increase coffee productivity (AgriLogic 2018). Finally, compared to our socioeconomic sample, the relatively small sample size for our ecological indicators may limit our ability to detect significant effects.

Trade-offs

Our results indicate positive effects of the adoption of VSS on coffee economic indicators, with a stronger effect observed among third-party certified farmers. However, the findings suggest that VSS are weakly or not associated with improved ecological conditions at the coffee plot level compared to non-certified farms and that the impact on ecological metrics varies by certification scheme. The full model shows that VSS adoption results in economic gains without compromising ecological indicators at the plot level. These results align with those of Wätzold et al. (2025) in Ghana.

However, when we examine our analysis by certification type, a different trend emerges. In-house certifications show trade-offs between coffee economic improvements and ecological indicators, particularly in terms of predation rates. These trade-offs are consistent with the findings of Haggar et al. (2017) in Nicaragua and Vanderhaegen et al. (2018) in Uganda, who documented economic and ecological trade-offs under different certification schemes. In contrast, third-party certifications positively influence both coffee economic indicators and shade tree–related metrics, although this benefit does not extend to broader ecological indicators.

Overall, our results suggest that VSS prioritize enhancing farmers' well-being over ecological improvements at the coffee plot level in Rwanda. Although in-house certifications are not significantly associated with shade tree-related ecological indicators, Table 1 indicates that this scheme has notably decreased the number of coffee trees per hectare, allowing for potential increases in number of shade trees and species, similar to what third-party certified farmers have done. In our study context, VSS can still foster sustainable development by enhancing farmers' coffee performance without major detriment to environmental indicators at the coffee plot level.

6. Conclusion

This study examines the effects of third-party and in-house certifications on both the economic performance and ecological indicators of coffee plots among Rwandan farmers. We first use endogenous switching regression (ESR) to analyze the effect of certifications on economic outcomes. We then use Generalized Linear Mixed Models (GLMM) to explore the association between these standards and ecological indicators at the coffee plot level. Our study concludes that third-party VSS positively influence economic and ecological outcomes and can promote sustainable development by enhancing economic conditions without compromising ecological ones. In contrast, in-house VSS improve coffee economic indicators at the expense of ecological ones.

Our paper comes with several limitations. The zoning policy that was in place in Rwanda during our data collection creates a unique study context where the certification status is less dependent on farmers' characteristics, minimizing the risk of self-selection bias. However, this may result in farmers with low levels of compliance being certified, potentially leading to an underestimation of the true effects of VSS. Additionally, our ecological indicators are inherently linked to landscape conditions, which are often influenced by various stakeholders, making it challenging to isolate the true effects of VSS on ecological outcomes. Finally, evidence on price dynamics (Snider et al. 2017) suggests that price effects of VSS may vary from year to year. Consequently, our study does not capture the long-term perspective of price dynamics across certification types because of the nature of our data.

Considering these limitations, our study provides valuable insights for evidence-based policymaking for sustainable development in tropical regions. It highlights distinct dynamics affecting farmers' economic outcomes depending on the type of certification. While both in-house and third-party VSS are associated with higher yield and gross coffee income, in-house VSS do not translate into higher net coffee income due to the higher costs they incur. In our conceptualization, certifications have the potential to contribute to rural development by influencing coffee prices. However, we note a positive but small correlation between VSS and higher coffee prices in Rwanda, which is of limited practical significance. It is possible to boost gross coffee revenue without a corresponding increase in costs by allowing the price mechanisms associated with certifications, ultimately resulting in higher net income from coffee production.

In our study context, government mechanisms designed to reduce market competition have limited VSS's ability to implement price-related interventions. For instance, under the zoning policy, coffee washing stations were required to pay a fixed farmgate price, with any additional bonuses issued as second payments (Gerard 2020). Although the zoning policy was revoked in June 2023, the government has retained the fixed price per fresh coffee cherry system (Jenkins et al. 2023). These price-related findings highlight the complex interplay between certification schemes and government policies in shaping rural development outcomes. While certifications can potentially enhance economic benefits for farmers, their capacity is sometimes constrained by regulatory frameworks that limit market competition and price flexibility. Future policies should aim to balance market regulation with mechanisms that allow certification schemes to fully realize their potential in supporting sustainable development and improving farmer livelihoods in tropical regions.

In addition to the findings discussed above, our study shows that while third-party certifications positively influence economic performance and specific shade tree metrics, these benefits do not translate into broader ecological improvements. Coupled with the economic-ecological trade-offs observed under in-house certifications, these results yield two main insights. First, it is crucial to strongly promote sustainable practices whenever possible. For example, in-house certified farmers, like their third-party counterparts, have reduced the number of coffee trees per hectare to allow more space for shade trees without affecting productivity, yet this has not translated into an increase in the actual planting of shade trees. Second, our findings and prior evidence indicate that certifications alone may not reliably ensure environmental protection, particularly when conflicts of interest are present, as is often the case with in-house certifications. Therefore, at its best, certifications can support and complement centralized governance of common pool resources but certainly not replace them, as in the case of Rwanda and the National Forestry Plan (Garrett et al. 2021; Paz et al. 2024).

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A1: Ecological data collection protocol

Number of shade trees and shade tree species

We recorded all non-coffee trees with a diameter at breast height (dbh) greater than 10 cm following the methods of Hoover and Smith (2020). For each tree, we recorded its species, and if there was any doubt about the identification, we photographed the tree to later verify its species using resources such as PlantNet (Yang et al. 2022) and local expertise. This approach allowed us to compile a complete data set of all trees and their species for each plot.

Shannon and Simpson Index

We quantified shade tree diversity in the plots using two indices. The first, the Shannon diversity index, is calculated as $H = -\sum_{i=1}^{S} log_b(p_i)$, and the second is the Simpson diversity index, defined as $D = 1 - \sum_{i=1}^{S} p_i^2$. Here, p_i represents the proportion of species i, and S is the total number of species in the cocoa plot (Magurran 2003).

Bioacoustics Index (BI)

Audio data was gathered using two recorders per plot. Due to the steep slopes and limited plot sizes, recorders were strategically positioned on opposite sides of each plot, in the middle of the slope and facing each other, to ensure adequate spacing—at least 20 meters apart—and to minimize overlapping recording areas, while keeping them within the interior of the plot (no further to the edge than the second to last row of coffee). Each recorder was mounted on a tree at a height of 1.5 m. The AudioMoth logger by Open Acoustic Devices was used, which can capture frequencies from 8 to 348 kHz and record continuously for days. The devices, equipped with a 64-gigabyte microSD card and secured using a case and an old bicycle tire, were configured via computer applications to set parameters like sample rate and recording schedule (Open Acoustic Devices 2022). Running on firmware 1.8.1 with a sample rate of 48 kHz and medium gain—and operating continuously without a sleep cycle—they provided a cost-effective and high-quality data collection method (Hill et al. 2019). For acoustic analysis, the Bird Index (BI) was employed as a simple analytical technique to estimate the relative abundance of the avian community, rather than to count species. Recordings were examined within the frequency range of 2,000 to 8,000 kHz to exclude most man-made sounds (typically found between 1,000 and 2,000 kHz), and the mean spectral power was calculated to represent the average amount of ecological acoustic energy (Villanueva-Rivera and Pijanowski 2022; Mitchell et al. 2020).

Predation rate

To measure predation rates, we used dummy caterpillars following Howe et al. (2009), although recent work suggests that shape may be less critical (Weissflog et al. 2022). The dummies were made from green plasticine (Pelikan Nakiplast®, Colour: 681/"green") with a mechanical clay extruder, chosen because different green hues do not affect predation in tropical regions (Sam et al. 2015). Sized at 35 x 5 mm to match similar tropical studies, the dummies were prepared a day in advance—cut, smoothed with a thin plastic card, and transported in insulated boxes to prevent damage and temperature effects. Surgical gloves were used during handling to avoid leaving additional scents. In a cluster plot design on farms with at least 100 coffee trees, 40 dummies were deployed per plot for 24 hours. Each plot featured five clusters (one central and four cardinal points) with dummies placed on coffee trees at various levels (ground, trunk, branch, leaf) and spaced at least 15 cm apart. Ground dummies were attached to sticks or local leaves, and others were fixed at an average height of 1.5 m using a neutral-scent superglue. Bite marks were documented using reference images (Tvardikova and Novotny 2012; Low et al. 2014; Nurdiansyah et al. 2016; Schwab et al. 2021) and were further validated with test marks from field-caught insects. Any ambiguous marks were photographed and later categorized as "morphobites" for detailed analysis using magnifying glasses.

A2: Falsification test of the instrument

Table A2: Falsification test

	Model 1 VSS	Model 1 TP	Model 1 IH	Model 2A Log(yield)	Model 2B Log(GCI)	Model 2C Log(Costs)	Model 2D Log(NCI)
IV (CWS Strong Ownership)	0.50*** (0.03)	0.68*** (0.03)	0.40*** (0.04)	-0.12 (0.12)	-0.05 (0.12)	0.18 (0.24)	-500 (382)
N	**842**	**723**	**573**	**327**	**327**	**327**	**327**

***Note:* ***, **, *** means significant at the 1%, 5%, and 10% level, respectively.

A3: EVI values before certification period

Table A3: EVI values before certification period across groups

	Non-certified	VSS	Third-party VSS	In-house VSS
Vegetation values before VSS	0.43 (0.00)	0.41*** (0.00)	0.42 (0.00)	0.41*** (0.00)
N	**327**	**515**	**396**	**247**

Note: Certification groups are not mutually exclusive; therefore, farmers with both types of certifications are included in both groups. Significant differences in means for each certification category and the control are indicated with * p < 0.01, ** p < 0.05, *** < 0.01.

A4: Full ESR output: Pooled model (VSS)

Table A4_1: Results of selection and outcome equations for coffee yield

	Log(Yield/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
Rusizi		-0.45*** (0.04)	-0.26*** (0.06)
Nyamasheke		-0.45*** (0.07)	-0.11 (0.14)
Karongi		-0.25*** (0.06)	-0.25** (0.10)
Huye		-0.50** (0.20)	-0.17* (0.09)
Gender (1 = male)	-0.09 (0.16)	0.08 (0.11)	0.11 (0.07)
Age (years)	-0.01 (0.01)	-0.01 (0.00)	-0.01** (0.00)
Density (trees/ha)	-0.00** (0.00)	0.00*** (0.00)	0.00*** (0.00)
Literacy (1 = yes)	0.33* (0.19)	-0.15 (0.11)	0.15* (0.08)
Farming experience (years)	0.01 (0.01)	0.00 (0.00)	0.01** (0.00)
Main occupation (1 = farmer)	0.25 (0.18)	0.23 (0.17)	0.07 (0.17)
Household size (number)	0.02 (0.03)	-0.03 (0.02)	-0.01 (0.01)
Non-coffee income (USD/year)	-0.00 (0.00)	0.00* (0.00)	0.00 (0.00)
Financial account (1 = yes)	0.35* (0.18)	-0.10 (0.08)	0.10 (0.08)
Proportion of owned land	0.09 (0.09)	0.03 (0.03)	0.14** (0.06)
Proportion of land under agriculture	0.12 (0.08)	-0.17 *** (0.05)	0.06 (0.05)
Cooperative membership (1 = yes)	0.31 (0.23)	-0.04 (0.11)	0.02 (0.06)
Distance to market (km)	0.03 (0.03)	0.00 (0.01)	-0.00 (0.01)
CWS strong ownership (1 = yes)	1.44*** (0.49)		
CONSTANT	-1.77* (0.99)	8.93*** (0.38)	7.50*** (0.36)
Observations	**842**	**842**	**842**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A4_2: Results of selection and outcome equations for gross coffee income

	Log(GCI/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
Rusizi		-0.35*** (0.05)	-0.20*** (0.08)
Nyamasheke		-0.36*** (0.05)	0.07 (0.16)
Karongi		-0.17** (0.08)	-0.16 (0.15)
Huye		-0.44*** (0.16)	-0.08 (0.11)
Gender (1 = male)	-0.09 (0.16)	0.12 (0.11)	0.09 (0.07)
Age (years)	-0.01 (0.01)	-0.01 (0.00)	-0.01** (0.00)
Density (trees/ha)	-0.00** (0.00)	0.00*** (0.00)	0.00*** (0.00)
Literacy (1 = yes)	0.33* (0.19)	-0.15 (0.09)	0.10 (0.09)
Farming experience (years)	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)
Main occupation (1 = farmer)	0.25 (0.18)	0.21 (0.17)	0.05 (0.17)
Household size (number)	0.02 (0.03)	-0.03 (0.02)	-0.01 (0.01)
Non-coffee income (USD/year)	-0.00 (0.00)	0.00* (0.00)	0.00 (0.00)
Financial account (1 = yes)	0.35* (0.18)	-0.09 (0.08)	0.10 (0.09)
Proportion of owned land	0.09 (0.09)	0.05* (0.03)	0.13*** (0.05)
Proportion of land under agriculture	0.12 (0.08)	-0.22*** (0.06)	0.00 (0.05)
Cooperative membership (1 = yes)	0.31 (0.23)	-0.10 (0.11)	0.00 (0.07)
Distance to market (km)	0.03 (0.03)	-0.01 (0.01)	-0.00 (0.01)
CWS strong ownership (1 = yes)	1.44*** (0.49)		
CONSTANT	-1.77* (0.99)	8.18*** (0.36)	7.10*** (0.37)
Observations	**842**	**842**	**842**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A4_3: Results of selection and outcome equations for coffee costs

	Log(Costs/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
Rusizi		0.64* (0.33)	-0.48*** (0.17)
Nyamasheke		0.02 (0.28)	-0.06 (0.20)
Karongi		0.25 (0.32)	-0.44* (0.25)
Huye		-0.01 (0.38)	-0.28* (0.14)
Gender (1 = male)	-0.09 (0.16)	-0.08 (0.23)	0.07 (0.18)
Age (years)	-0.01 (0.01)	-0.01 (0.01)	-0.00 (0.01)
Density (trees/ha)	-0.00** (0.00)	0.00*** (0.00)	0.00*** (0.00)
Literacy (1 = yes)	0.33* (0.19)	-0.16 (0.23)	-0.16 (0.13)
Farming experience (years)	0.01 (0.01)	-0.01 (0.00)	-0.01 (0.01)
Main occupation (1 = farmer)	0.25 (0.18)	0.09 (0.24)	-0.33*** (0.13)
Household size (number)	0.02 (0.03)	-0.05 (0.04)	-0.04 (0.03)
Non-coffee income (USD/year)	-0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)
Financial account (1 = yes)	0.35* (0.18)	-0.10 (0.17)	-0.08 (0.15)
Proportion of owned land	0.09 (0.09)	0.05 (0.07)	-0.04 (0.11)
Proportion of land under agriculture	0.12 (0.08)	-0.08 (0.09)	0.14 (0.09)
Cooperative membership (1 = yes)	0.31 (0.23)	0.01 (0.24)	-0.14 (0.16)
Distance to market (km)	0.03 (0.03)	0.01 (0.02)	-0.04*** (0.01)
CWS strong ownership (1 = yes)	1.44*** (0.49)		
CONSTANT	-1.77* (0.99)	6.60*** (0.65)	7.44*** (0.76)
Observations	**842**	**842**	**842**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A4_4: Results of selection and outcome equations for net coffee income

	Log(NCI/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
Rusizi		-1,135.69*** (324.99)	-527.01* (302.58)
Nyamasheke		-477.52 (364.44)	648.67 (640.02)
Karongi		-44.30 (365.33)	51.99 (458.62)
Huye		-717.66 (690.69)	-266.93 (437.37)
Gender (1 = male)	-0.09 (0.16)	232.52 (395.35)	254.06 (353.05)
Age (years)	-0.01 (0.01)	-9.35 (12.62)	-34.28** (17.03)
Density (trees/ha)	-0.00** (0.00)	0.41*** (0.13)	0.67*** (0.19)
Literacy (1 = yes)	0.33* (0.19)	-369.14 (294.18)	20.65 (478.61)
Farming experience (years)	0.01 (0.01)	5.56 (7.07)	10.87 (9.46)
Main occupation (1 = farmer)	0.25 (0.18)	769.75 (507.05)	286.47 (761.00)
Household size (number)	0.02 (0.03)	-32.11 (66.89)	5.69 (73.78)
Non-coffee income (USD/year)	-0.00 (0.00)	0.19 (0.16)	0.14 (0.10)
Financial account (1 = yes)	0.35* (0.18)	-75.48 (263.18)	390.41 (326.61)
Proportion of owned land	0.09 (0.09)	33.36 (99.71)	507.31** (220.54)
Proportion of land under agriculture	0.12 (0.08)	-620.49*** (183.62)	-216.82 (211.79)
Cooperative membership (1 = yes)	0.31 (0.23)	-358.29 (408.60)	298.99 (480.29)
Distance to market (km)	0.03 (0.03)	-26.54 (35.27)	12.85 (34.92)
CWS strong ownership (1 = yes)	1.44*** (0.49)		
CONSTANT	-1.77* (0.99)	3,400.48*** (1,180.92)	-645.61 (1,791.24)
Observations	**842**	**842**	**842**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

A5: Full ESR output: Third-party (TP)

Table A5_1: Results of selection and outcome equations for coffee yield

	Log(Yield/ha)		
Variables	(1) First stage: Selection into VSS	(2) Outcome equation for non-VSS farmers	(3) Outcome equation for VSS farmers
In-house VSS			-0.11* (0.06)
Rusizi		-0.45*** (0.04)	-0.19** (0.09)
Nyamasheke		-0.46*** (0.07)	0.21 (0.17)
Karongi		-0.25*** (0.06)	-0.16* (0.09)
Huye		-0.51** (0.20)	-0.15 (0.11)
Gender (1 = male)	-0.23* (0.13)	0.08 (0.11)	0.07 (0.06)
Age (years)	0.00 (0.01)	-0.01 (0.00)	-0.01** (0.00)
Density (trees/ha)	-0.00 (0.00)	0.00*** (0.00)	0.00*** (0.00)
Literacy (1 = yes)	0.46*** (0.15)	-0.15 (0.11)	0.17** (0.08)
Farming experience (years)	0.01 (0.01)	0.00 (0.00)	0.00* (0.00)
Main occupation (1 = farmer)	0.07 (0.22)	0.23 (0.17)	0.16 (0.17)
Household size (number)	0.02 (0.03)	-0.03 (0.02)	-0.01 (0.02)
Non-coffee income (USD/year)	-0.00 (0.00)	0.00* (0.00)	0.00 (0.00)
Financial account (1 = yes)	0.59*** (0.21)	-0.10 (0.08)	0.18* (0.09)
Proportion of owned land	0.07 (0.10)	0.03 (0.03)	0.10 (0.07)
Proportion of land under agriculture	0.09 (0.07)	-0.17*** (0.05)	0.02 (0.05)
Cooperative membership (1 = yes)	0.15 (0.31)	-0.05 (0.10)	0.11* (0.06)
Distance to market (km)	0.03 (0.03)	0.00 (0.01)	-0.00 (0.01)
CWS strong ownership (1 = yes)	2.01*** (0.55)		
CONSTANT	-2.76*** (0.88)	8.94*** (0.39)	7.42*** (0.44)
Observations	**723**	**723**	**723**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A5_2: Results of selection and outcome equations for gross coffee income

	Log(GCI/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
In-house VSS			-0.17*** (0.07)
Rusizi		-0.35*** (0.05)	-0.19 (0.13)
Nyamasheke		-0.35*** (0.05)	-0.19 (0.13)
Karongi		-0.17** (0.08)	-0.14 (0.13)
Huye		-0.44*** (0.17)	-0.13 (0.14)
Gender (1 = male)	-0.23* (0.13)	0.12 (0.11)	0.06 (0.07)
Age (years)	0.00 (0.01)	-0.01 (0.00)	-0.01* (0.00)
Density (trees/ha)	-0.00 (0.00)	0.00*** (0.00)	0.00*** (0.00)
Literacy (1 = yes)	0.46*** (0.15)	-0.15 (0.09)	0.14 (0.09)
Farming experience (years)	0.01 (0.01)	0.00 (0.00)	0.00* (0.00)
Main occupation (1 = farmer)	0.07 (0.22)	0.22 (0.17)	0.16 (0.17)
Household size (number)	0.02 (0.03)	-0.03 (0.02)	-0.01 (0.02)
Non-coffee income (USD/year)	-0.00 (0.00)	0.00 (0.00)	0.00* (0.00)
Financial account (1 = yes)	0.59*** (0.21)	-0.09 (0.08)	0.18* (0.10)
Proportion of owned land	0.07 (0.10)	0.05* (0.03)	0.11* (0.06)
Proportion of land under agriculture	0.09 (0.07)	-0.22*** (0.06)	-0.02 (0.05)
Cooperative membership (1 = yes)	0.15 (0.31)	-0.10 (0.11)	0.08 (0.05)
Distance to market (km)	0.03 (0.03)	-0.00 (0.01)	-0.00 (0.01)
CWS strong ownership (1 = yes)	2.01*** (0.55)		
CONSTANT	-2.76*** (0.88)	8.20*** (0.36)	6.93*** (0.42)
Observations	**723**	**723**	**723**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A5_3: Results of selection and outcome equations for coffee costs

	Log(Costs/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
In-house VSS			-0.35 (0.23)
Rusizi		0.64* (0.33)	-0.27 (0.23)
Nyamasheke		0.01 (0.27)	0.61** (0.24)
Karongi		0.25 (0.32)	-0.23 (0.22)
Huye		-0.02 (0.37)	-0.21 (0.18)
Gender (1 = male)	-0.23* (0.13)	-0.07 (0.23)	0.12 (0.21)
Age (years)	0.00 (0.01)	-0.01* (0.01)	0.00 (0.01)
Density (trees/ha)	-0.00 (0.00)	0.00*** (0.00)	0.00*** (0.00)
Literacy (1 = yes)	0.46*** (0.15)	-0.15 (0.23)	-0.20 (0.17)
Farming experience (years)	0.01 (0.01)	-0.01 (0.00)	-0.01 (0.01)
Main occupation (1 = farmer)	0.07 (0.22)	0.11 (0.25)	-0.27* (0.16)
Household size (number)	0.02 (0.03)	-0.05 (0.04)	-0.05 (0.04)
Non-coffee income (USD/year)	-0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)
Financial account (1 = yes)	0.59*** (0.21)	-0.11 (0.17)	-0.15 (0.18)
Proportion of owned land	0.07 (0.10)	0.06 (0.07)	-0.08 (0.14)
Proportion of land under agriculture	0.09 (0.07)	-0.07 (0.09)	0.20** (0.09)
Cooperative membership (1 = yes)	0.15 (0.31)	0.03 (0.23)	-0.03 (0.22)
Distance to market (km)	0.03 (0.03)	0.01 (0.02)	-0.04*** (0.02)
CWS strong ownership (1 = yes)	2.01*** (0.55)		
CONSTANT	-2.76*** (0.88)	6.65*** (0.64)	7.28*** (0.95)
Observations	**723**	**723**	**723**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A5_4: Results of selection and outcome equations for net coffee income

	Log(NCI/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
In-house VSS			-330.01 (328.54)
Rusizi		-1,133.92*** (323.50)	-479.17 (480.69)
Nyamasheke		-470.12 (364.43)	1,289.87 (873.48)
Karongi		-46.18 (363.72)	41.95 (451.70)
Huye		-713.25 (699.46)	-158.55 (395.52)
Gender (1 = male)	-0.23* (0.13)	216.01 (392.94)	-138.85 (329.36)
Age (years)	0.00 (0.01)	-6.79 (12.90)	-30.38* (17.95)
Density (trees/ha)	-0.00 (0.00)	0.42*** (0.13)	0.56*** (0.13)
Literacy (1 = yes)	0.46*** (0.15)	-379.67 (283.15)	509.90 (344.14)
Farming experience (years)	0.01 (0.01)	4.59 (7.06)	19.31* (10.14)
Main occupation (1 = farmer)	0.07 (0.22)	713.25 (504.89)	670.09 (801.37)
Household size (number)	0.02 (0.03)	-32.57 (67.40)	-24.66 (76.47)
Non-coffee income (USD/year)	-0.00 (0.00)	0.20 (0.16)	0.21* (0.11)
Financial account (1 = yes)	0.59*** (0.21)	-68.82 (260.89)	609.58 (412.14)
Proportion of owned land	0.07 (0.10)	23.06 (100.24)	440.87 (271.18)
Proportion of land under agriculture	0.09 (0.07)	-639.69*** (186.24)	-215.13 (195.81)
Cooperative membership (1 = yes)	0.15 (0.31)	-415.16 (385.26)	248.61 (512.39)
Distance to market (km)	0.03 (0.03)	-30.74 (32.41)	44.36 (39.72)
CWS strong ownership (1 = yes)	2.01*** (0.55)		
CONSTANT	-2.76*** (0.88)	3,299.83*** (1,167.69)	-1,469.48 (2,396.37)
Observations	**723**	**723**	**723**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

A6: Full ESR output: In-house (IH)

Table A6_1: Results of selection and outcome equations for coffee yield

	Log(Yield/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
Third-party VSS			0.36** (0.15)
Rusizi		-0.45*** (0.05)	-0.35 (0.21)
Nyamasheke		-0.45*** (0.08)	0.07 (0.17)
Karongi		-0.25*** (0.07)	-0.47** (0.22)
Rutsiro			0.31** (0.16)
Huye		-0.50** (0.20)	
Gender (1 = male)	-0.04 (0.22)	0.08 (0.11)	0.13 (0.11)
Age (years)	-0.01 (0.01)	-0.01 (0.00)	-0.02*** (0.01)
Density (trees/ha)	-0.00** (0.00)	0.00*** (0.00)	0.00*** (0.00)
Literacy (1 = yes)	0.26 (0.24)	-0.15 (0.11)	0.17 (0.13)
Farming experience (years)	0.01 (0.01)	0.00 (0.00)	0.01*** (0.00)
Main occupation (1 = farmer)	0.28 (0.20)	0.24 (0.17)	-0.14 (0.30)
Household size (number)	0.03 (0.04)	-0.03 (0.02)	0.02 (0.02)
Non-coffee income (USD/year)	-0.00 (0.00)	0.00* (0.00)	-0.00 (0.00)
Financial account (1 = yes)	0.38 (0.23)	-0.10 (0.09)	0.04 (0.13)
Proportion of owned land	0.04 (0.10)	0.03 (0.03)	0.10 (0.09)
Proportion of land under agriculture	0.12 (0.10)	-0.17*** (0.06)	0.08 (0.07)
Cooperative membership (1 = yes)	0.11 (0.23)	-0.04 (0.11)	0.02 (0.09)
Distance to market (km)	0.03 (0.03)	0.00 (0.01)	-0.01 (0.01)
CWS strong ownership (1 = yes)	1.17** (0.57)		
CONSTANT	-1.23 (1.15)	8.93*** (0.37)	7.54*** (0.62)
Observations	**574**	**574**	**574**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A6_2: Results of selection and outcome equations for gross coffee income

	Log(GCI/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
Third-party VSS			0.41** (0.17)
Rusizi		-0.36*** (0.05)	-0.54** (0.23)
Nyamasheke		-0.36*** (0.06)	0.05 (0.17)
Karongi		-0.17** (0.08)	-0.70*** (0.23)
Rutsiro			0.13 (0.17)
Huye		-0.44*** (0.17)	
Gender (1 = male)	-0.04 (0.22)	0.12 (0.11)	0.13 (0.09)
Age (years)	-0.01 (0.01)	-0.01 (0.00)	-0.02*** (0.01)
Density (trees/ha)	-0.00** (0.00)	0.00*** (0.00)	0.00*** (0.00)
Literacy (1 = yes)	0.26 (0.24)	-0.14 (0.09)	0.09 (0.14)
Farming experience (years)	0.01 (0.01)	0.00 (0.00)	0.01** (0.00)
Main occupation (1 = farmer)	0.28 (0.20)	0.21 (0.16)	-0.16 (0.31)
Household size (number)	0.03 (0.04)	-0.03 (0.02)	0.02 (0.02)
Non-coffee income (USD/year)	-0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)
Financial account (1 = yes)	0.38 (0.23)	-0.09 (0.08)	0.06 (0.14)
Proportion of owned land	0.04 (0.10)	0.05* (0.03)	0.10 (0.07)
Proportion of land under agriculture	0.12 (0.10)	-0.22*** (0.06)	0.00 (0.06)
Cooperative membership (1 = yes)	0.11 (0.23)	-0.09 (0.11)	-0.00 (0.07)
Distance to market (km)	0.03 (0.03)	-0.00 (0.01)	-0.01 (0.01)
CWS strong ownership (1 = yes)	1.17** (0.57)		
CONSTANT	-1.23 (1.15)	8.15*** (0.36)	7.36*** (0.59)
Observations	**574**	**574**	**574**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A6_3: Results of selection and outcome equations for coffee costs

	Log(Costs/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
Third-party VSS			0.55*** (0.20)
Rusizi		0.63* (0.33)	-0.64*** (0.23)
Nyamasheke		0.05 (0.29)	0.21 (0.29)
Karongi		0.24 (0.32)	-0.96*** (0.21)
Rutsiro			0.44** (0.18)
Huye		0.01 (0.38)	
Gender (1 = male)	-0.04 (0.22)	-0.08 (0.23)	0.10 (0.19)
Age (years)	-0.01 (0.01)	-0.01 (0.01)	-0.02** (0.01)
Density (trees/ha)	-0.00** (0.00)	0.00*** (0.00)	0.00 (0.00)
Literacy (1 = yes)	0.26 (0.24)	-0.14 (0.23)	-0.36** (0.15)
Farming experience (years)	0.01 (0.01)	-0.01 (0.00)	0.01 (0.01)
Main occupation (1 = farmer)	0.28 (0.20)	0.09 (0.25)	-0.41** (0.18)
Household size (number)	0.03 (0.04)	-0.06 (0.04)	-0.01 (0.02)
Non-coffee income (USD/year)	-0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)
Financial account (1 = yes)	0.38 (0.23)	-0.11 (0.17)	0.19 (0.17)
Proportion of owned land	0.04 (0.10)	0.06 (0.06)	0.02 (0.16)
Proportion of land under agriculture	0.12 (0.10)	-0.08 (0.09)	0.15 (0.13)
Cooperative membership (1 = yes)	0.11 (0.23)	0.04 (0.24)	-0.24 (0.20)
Distance to market (km)	0.03 (0.03)	0.01 (0.02)	-0.03 (0.02)
CWS strong ownership (1 = yes)	1.17** (0.57)		
CONSTANT	-1.23 (1.15)	6.52*** (0.66)	6.89*** (1.07)
Observations	**574**	**574**	**574**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A6_4: Results of selection and outcome equations for net coffee income

	Log(NCI/ha)		
	(1)	(2)	(3)
Variables	First stage: Selection into VSS	Outcome equation for non-VSS farmers	Outcome equation for VSS farmers
Third-party VSS			377.71 (736.97)
Rusizi		-1,135.44** (479.85)	-1,043.66 (1,032.33)
Nyamasheke		-498.60 (444.48)	504.64 (845.26)
Karongi		-40.95 (433.42)	-845.26 (1,213.52)
Rutsiro			441.72 (823.76)
Huye		-738.29 (466.34)	
Gender (1 = male)	-0.04 (0.22)	240.99 (366.96)	749.25 (578.66)
Age (years)	-0.01 (0.01)	-11.53 (16.16)	-57.97* (34.03)
Density (trees/ha)	-0.00** (0.00)	0.40*** (0.08)	0.94*** (0.18)
Literacy (1 = yes)	0.26 (0.24)	-383.08 (364.31)	-227.73 (640.81)
Farming experience (years)	0.01 (0.01)	6.08 (12.69)	24.40 (26.93)
Main occupation (1 = farmer)	0.28 (0.20)	782.56 (507.30)	-233.92 (981.25)
Household size (number)	0.03 (0.04)	-29.40 (71.88)	43.10 (111.89)
Non-coffee income (USD/year)	-0.00 (0.00)	0.19 (0.13)	0.10 (0.22)
Financial account (1 = yes)	0.38 (0.23)	-57.68 (342.90)	-48.17 (686.94)
Proportion of owned land	0.04 (0.10)	22.17 (159.58)	512.29* (303.57)
Proportion of land under agriculture	0.12 (0.10)	-619.94*** (207.72)	-424.86 (368.06)
Cooperative membership (1 = yes)	0.11 (0.23)	-414.03 (302.86)	441.58 (463.37)
Distance to market (km)	0.03 (0.03)	-26.87 (36.71)	-37.11 (56.77)
CWS strong ownership (1 = yes)	1.17** (0.57)		
CONSTANT	-1.23 (1.15)	3,589.85** (1,453.35)	1,031.74 (2,968.95)
Observations	**574**	**574**	**574**

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

A7: Robustness check: OLS estimates

Table A7: Robustness check using OLS estimates

	VSS	Third-party	In-house	Interaction[2]	CONTROLS
Log(yield) (kg/ha)	0.17*** (0.07)	0.18*** (0.07)	0.18 (0.12)	-0.19 (0.18)	YES
Log(GCI) (USD/ha)	0.22*** (0.07)	0.26*** (0.07)	0.17 (0.11)	-0.20 (0.18)	YES
Log(Costs) (USD/ha)	0.20 (0.16)	0.22 (0.19)	0.27 (0.23)	-0.37 (0.38)	YES
NCI (USD/ha)	655** (266)	670** (284)	685 (506)	-751 (721)	YES
Observations	**842**	**842**	**842**	**842**	

***Note:* ***, **, *** means significant at the 1%, 5%, and 10% level, respectively.

A8: Full ecological output: VSS

Table A8: Full ecological output for VSS farmers

Variable	**Number of shade trees** Mean (sd)	**Number of tree species** Mean (sd)	**Shanon Index** Mean (sd)	**Simpson Index** Mean (sd)	**Acoustics Index** Mean (sd)	**Predation rate** Mean (sd)
CONSTANT	-226.44 (524.50)	209.40 (135.80)	2.70** (1.26)	-0.71 (0.70)	3.33** (1.41)	53.74** (25.18)
VSS	**66.67 (53.97)**	**0.15 (0.16)**	**-0.01 (0.13)**	**0.07 (0.07)**	**0.12 (0.19)**	**-4.16 (2.56)**
Age of coffee trees	5.20 (5.90)	-0.00 (0.02)	-0.02 (0.01)	0.02** (0.01)	0.00 (0.01)	-0.27 (0.29)
Age of coffee trees[2]	-0.05 (0.09)	0.00 (0.00)	0.00 (0.00)	-0.00** (0.00)	0.00 (0.00)	0.00 (0.00)
Tree density	0.01 (0.02)					
Land		1.48*** (0.59)	0.73 (0.49)	-0.09 (0.27)	-0.75 (0.57)	-7.98 (9.73)
Coffee trees per plot		-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Gender	25.27 (58.66)	0.03 (0.18)	0.02 (0.14)	-0.09 (0.08)	0.06 (0.16)	0.86 (2.83)
Age	-2.68 (2.31)	0.00 (0.01)	0.00 (0.00)	-0.00 (0.00)	-0.01* (0.01)	0.04 (0.11)
Literacy	-78 (65)	0.48*** (0.21)	0.39*** (0.16)	-0.21** (0.09)	0.22 (0.18)	-1.92 (3.15)
Main occupation	93 (104)	0.27 (0.33)	0.22 (0.25)	-0.04 (0.14)	0.46* (0.25)	9.53* (5.10)
Household size	10.29 (11.78)	0.05 (0.03)	0.04 (0.03)	-0.14 (0.16)	-0.30 (0.03)	-0.51 (0.57)
Non-coffee income	-0.02 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Financial account	5.60 (66)	-0.07 (0.20)	0.05 (0.16)	-0.05 (0.09)	-0.32* (0.18)	-4.87 (3.24)

Proportion of land under agriculture	167.05 (115.61)	-0.43 (0.27)	-0.60*** (0.28)	0.28* (0.16)	0.12 (0.29)	-1.76 (5.63)
Cooperative membership	-27.18 (67.73)	0.00 (0.19)	-0.06 (0.16)	-0.04 (0.09)	0.07 (0.20)	7.25** (3.20)
Altitude	-0.06 (0.17)	-0.00 (0.00)	-0.00 (0.00)	0.00** (0.00)	-0.00 (0.00)	-0.02* (0.01)
Distance to national forest	0.93 (6.95)	-0.01 (0.01)	0.00 (0.02)	0.00 (0.01)	0.03 (0.02)	-0.05 (0.32)
Total covered area in 1 kilometer	-2.76 (3.75)	-0.01 (0.02)	-0.00 (0.01)	-0.00 (0.00)	-0.01 (0.01)	-0.02 (0.17)
Nyamasheke	-60.56 (85.93)	-0.27 (0.22)	-0.20 (0.19)	0.04 (0.11)	-0.84** (0.29)	20.50*** (3.95)
Karongi	-211.54* (107.21)	-0.34 (0.31)	-0.14 (0.25)	-0.30** (0.14)	-0.77** (0.34)	12.30** (4.99)
Rutsiro	-13.43 (83.97)	-0.01 (0.22)	0.04 (0.19)	-0.07 (0.11)	-0.27 (0.29)	6.79* (3.89)
Huye	-34.84 (158.97)	0.16 (0.44)	0.03 (0.37)	-0.13 (0.21)	-1.12** (0.52)	-4.64 (7.44)
Random effects: CWS = 28	YES	Yes	YES	YES	YES	YES
Observations	**99**	**99**	**99**	**99**	**99**	**99**

Note: *****, **, *** means significant at the 1%, 5%, and 10% level, respectively.

A9: Full ecological output: TP and IH

Table A9: Full ecological output for TP and IH farmers

Variable	**Number of shade trees** Mean (sd)	**Number of tree species** Mean (sd)	**Shanon Index** Mean (sd)	**Simpson Index** Mean (sd)	**Acoustics Index** Mean (sd)	**Predation rate** Mean (sd)
CONSTANT	-23 (536)	1.90 (1.40)	2.50* (1.30)	1.66** (0.72)	3.62** (1.44)	66*** (24)
TP	**85 (57)**	**0.28* (0.16)**	**0.05 (0.13)**	**-0.04 (0.07)**	**0.23 (0.19)**	**0.68 (2.56)**
IH	**-45 (62)**	**-0.01 (0.17)**	**0.01 (0.14)**	**-0.03 (0.08)**	**-0.20 (0.21)**	**-8.05*** (2.71)**
Age of coffee trees	63 (57)	-0.001 (0.02)	-0.02 (0.01)	-0.02** (0.01)	0.00 (0.01)	-0.26 (0.28)
Age of coffee trees^2	-0.08 (0.09)	0.00 (0.00)	0.00 (0.00)	0.00** (0.00)	-0.00 (0.00)	0.00 (0.00)
Tree density	0.01 (0.02)					
Land		1.34** (0.59)	0.69 (0.50)	0.08 (0.28)	-0.80 (0.57)	-12.76 (9.55)
Coffee trees per plot		-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00* (0.00)
Gender	37 (59)	0.06 (0.02)	0.03 (0.14)	0.08 (0.08)	0.08 (0.16)	1.70 (2.79)
Age	-2.67 (2.26)	0.00 (0.07)	0.00 (0.00)	0.00 (0.00)	-0.01* (0.00)	0.01 (0.10)

Literacy	-104 (65)	0.45** (0.22)	0.39** (0.16)	0.21** (0.09)	0.18 (0.18)	-3.25 (3.09)
Main occupation	87 (103)	0.21 (0.34)	0.23 (0.26)	0.05 (0.14)	0.43* (0.25)	8.94* (4.94)
Household size	9.09 (11)	0.06* (0.03)	0.05 (0.03)	0.01 (0.02)	-0.03 (0.31)	-0.44 (0.56)
Non-coffee income	-0.01 (0.02)	0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Financial account	22 (65)	-0.07 (0.20)	0.05 (0.16)	0.05 (0.09)	-0.29 (0.18)	-4.20 (3.15)
Proportion of land under agriculture	145 (115)	-0.40 (0.28)	-0.57** (0.28)	-0.28 (0.16)	0.10 (0.29)	-2.83 (5.46)
Cooperative membership	-58 (72)	-0.11 (0.22)	-0.91 (0.18)	0.03 (0.10)	-0.01 (0.21)	4.10 (3.40)
Altitude	-0.15 (0.17)	-0.00 (0.00)	-0.00 (0.00)	-0.00** (0.00)	-0.00 (0.00)	-0.02** (0.01)
Distance to national forest	0.30 (6.91)	-0.00 (0.02)	0.01 (0.02)	0.00 (0.01)	0.03 (0.02)	-0.16 (0.32)
Total covered area in 1 kilometer		-0.01 (0.01)	-0.00 (0.01)	0.00 (0.00)	-0.01 (0.01)	-0.02 (0.17)
Nyamasheke	-34 (90)	-0.27 (0.23)	-0.21 (0.20)	-0.05 (0.01)	-0.74** (0.29)	22.30*** (3.88)
Karongi	-199* (108)	-0.37 (0.31)	-0.17 (0.25)	0.29** (0.14)	-0.75** (0.34)	12.80*** (4.82)
Rutsiro	15 (86)	0.06 (0.24)	0.05 (0.20)	0.06 (0.11)	-0.21 (0.29)	7.07* (3.80)
Huye	17 (162)	0.18 (0.44)	-0.02 (0.37)	0.10 (0.21)	-0.97* (0.52)	-2.12 (7.18)
Random effects: CWS = 28	YES	Yes	YES	YES	YES	YES
Observations	**99**	**99**	**99**	**99**	**93**	**99**

Note: *****, **, *** means significant at the 1%, 5%, and 10% level, respectively.

A10: ESR estimates of coffee production costs: agrochemicals and labor

Table A11: ESR estimates of coffee production costs: agrochemicals and labor

	VSS	Third-party	In-house	CONTROLS
Log(ChemCosts)	-5.59*** (0.04)	-4.45*** (0.07)	-4.86*** (0.08)	YES
Log(LabourCosts)	0.48*** (0.02)	0.36*** (0.02)	0.63*** (0.03)	YES
Observations	**842**	**723**	**574**	

Note: *****, **, *** means significant at the 1%, 5%, and 10% level, respectively.

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