Applied Economic Perspectives and Policy

WILEY | AAEA Agricultural & Applied Economics Association

SUBMITTED ARTICLE

Certified and Stable? Price and Yield Volatility Under Voluntary Sustainability Standards in Peru

Eva Boonaert[1] | Eva-Marie Meemken[2] | Miet Maertens[1]

[1]Division of Bioeconomics, Department of Earth and Environmental Sciences, KU Leuven, Leuven, Belgium | [2]Food Systems Economics and Policy, Department of Environmental Systems Science, ETH Zurich, Zurich, Switzerland

Correspondence: Eva Boonaert (eva.boonaert@kuleuven.be)

Received: 10 June 2025 | **Revised:** 12 January 2026 | **Accepted:** 24 April 2026

Keywords: certification | ecolabels | Fairtrade | GlobalGAP | Organic | private standards

ABSTRACT

Prior research analyzes the economic effects of Voluntary Sustainability Standards (VSS)—such as Fairtrade, Organic, and GlobalGAP—but little is known about the stability of these effects over time. Using a nationally representative farm survey of Peru (2015–2019), this study analyzes whether VSS certification is associated with reduced inter-annual price and yield volatility. Applying pooled OLS, matching, and internal instruments, we find that certification is associated with 27% lower price volatility and 17% lower yield volatility, particularly benefiting family farms, translating into an 81% reduction in their net farm revenue volatility. The results highlight VSS' potential to enhance revenue stability.

JEL Classification: C21, C26, C86, L11, L15, O54, Q02, Q11, Q13

1 | Introduction

The agri-food system faces numerous sustainability challenges that are increasingly difficult to address amidst rising price and yield uncertainty, exacerbated by climate change, the COVID-19 pandemic, and geopolitical instability (Diaz-Bonilla et al. 2023). Recent events, such as the 2022 Ukraine conflict, have revived concerns about food price spikes and unstable agricultural yields, reminiscent of the food crises of 2007–2008 and 2010–2011 (Goyal et al. 2024; Legrand 2023). While rising food prices dominated public and media discourse, political responses prioritized limiting price volatility, as reflected in SDG target 2.c (United Nations General Assembly 2015). Price volatility can have negative repercussions for producers and consumers, especially in globalized markets[1]: it can undermine producers' ability to plan and invest, thereby affecting revenue volatility, while also constraining consumers' capacity to ensure food security, especially in low- and middle-income countries (FAO et al. 2011; HLPE 2011). Similarly, yield volatility impairs farmers' capacity to plan production, invest in innovation, and manage risks, thereby hindering agricultural resilience (SDG target 2.4) and contributing to fluctuations in farm income and rural livelihoods (Reckling et al. 2021; Seufert and Ramankutty 2017; FAO et al. 2011; HLPE 2011). Understanding price, yield, and revenue volatility is therefore central to policy and industry strategies aimed at sustaining food production and food security under increasing economic and environmental uncertainty (Barrett et al. 2021).

Against this backdrop, various initiatives such as Voluntary Sustainability Standards (VSS) may mitigate volatility in agri-food systems, either directly or indirectly. VSS, such as Fairtrade,[2] Organic, and GlobalGAP, have become prominent market-based instruments to address sustainability challenges in the agri-food system. Certified production now covers approximately 10% of global cropland for the seven main certified commodities (cocoa, coffee, banana, palm oil, soy, sugarcane, and tea) (Kemper et al. 2025). While only a few VSS explicitly target price, yield, or revenue stability, many may influence volatility indirectly through their effects on market access, production practices, and trade relationships. Impact studies on VSS largely focus on level effects, such as average prices and yields (Oya et al. 2018; Traldi 2021; Meemken 2020). However, the question of whether certification also stabilizes prices and yields over time remains largely unanswered.

This study addresses this gap and provides empirical evidence on (i) the association between VSS and inter-annual producer price and yield volatility, (ii) how this links to volatility in net farm revenue, and (iii) how this relation varies across producers, VSS, and crops. We rely on nationally representative farm-household survey data from Peru, covering all years from 2015 to 2019. We calculate volatility as the coefficient of variation (CV) over the certified and non-certified periods to account for level differences across crops and certification status. Peru is an interesting case study due to its large geographic size, agro-diversity, and rapid expansion of certification coverage over the past decade, certifying between 37% and 89% of coffee production area and 5%–12% of banana production area in 2019 (Kemper et al. 2025). Additionally, Peru has witnessed considerable price and yield fluctuations over the 2015–2019 study period due to extreme weather events, such as the El Niño phenomenon in 2017, heightened political uncertainty since 2016, and global price fluctuations for key export commodities (World Food Programme 2025; Oxford Business Group 2019; Carranza and Gallo Gold 2019).

This paper contributes to the current literature on VSS by providing the first empirical study that examines the association between VSS and price volatility using producer-level data, as well as the link between VSS and yield volatility in Peru. Methodologically, we employ nationally representative longitudinal data and pooled OLS, matching methods, and internal instrument methods, strengthening both external and internal validity. Additionally, we explore heterogeneous effects among producer types and associated VSS and crops—a dimension often overlooked in VSS research, yet critical given the diversity of certified value chain structures (Lee et al. 2012; Meemken 2021). We find that VSS certification is associated with statistically and economically meaningful reductions in price and yield volatility—a reduction of 0.11 or 27% in the price CV, and a 0.06 or 17% reduction in the yield CV—with heterogeneity across producer types, VSS, and crops. These reductions translate into more stable net farm revenues for family farms only—a reduction of 2.58 or 0.81% in the CV of revenue—highlighting a relevant channel through which VSS may contribute to economic stability. Overall, the findings offer new evidence on the association between VSS and both price and yield volatility, which complements existing evidence on the implications of VSS for price and yield levels, and supports policy efforts to enhance economic performance and stability.

2 | Background

2.1 | Literature Review

A well-established body of empirical research assesses the effectiveness of VSS in the agricultural sector, primarily through cross-sectional case studies that focus on specific VSS, crops, and regions, yielding mixed evidence regarding their effects at the producer level (Traldi 2021). While most studies focus on economic outcomes, typically the levels of prices, yields, costs, and/or revenues in a specific year, reviews indicate that VSS generally bring no or only small, context-specific economic benefits for producers, with effects for price levels generally more positive than for yields (Oya et al. 2018; Traldi 2021; Meemken 2020). Some studies compare multiple VSS within the same setting, highlighting heterogeneous impacts across VSS, with those applying quality-based price differentiation systems and explicitly targeting production efficiency showing the largest price and yield effects (e.g., Akoyi and Maertens 2018; Boonaert and Maertens 2023; Chiputwa et al. 2015; Ruben and Zuniga 2011; Vanderhaegen et al. 2018). However, economic performance also depends on the stability of these outcomes over time, particularly in risk-prone agricultural settings, an aspect that remains largely unexplored in the VSS literature.

Few studies quantitatively analyze stability of prices and yields for certified crops over time. Notably, Rueda and Lambin (2013) find that Rainforest Alliance-certified coffee farmers in Colombia experience lower price volatility, based on mean comparison of aggregate spot market prices. A study by Knapp and van der Heijden (2018) finds that Organic is associated with higher inter-annual yield volatility compared to conventional agriculture based on a meta-analysis dominated by studies from the United States and, to a lesser extent, India, Canada, and a few other countries—highlighting the limited evidence from low- and middle-income contexts. The paucity of empirical evidence on this topic is largely attributable to the lack of longitudinal producer data on VSS, despite considerable academic and policy interest in the topic.

Another body of literature explores the factors influencing yield and price volatility in agricultural markets. Yield volatility is largely driven by climate, weather, and input use, while also being shaped by farm management practices, agro-ecological conditions, and crop and variety characteristics (Albers et al. 2017; Kukal and Irmak 2018; Ray et al. 2015). Price volatility, in turn, is shaped by short-run supply and demand shocks, storage levels, market structure, and policy-related factors. On the supply side, for domestically produced and consumed crops, price volatility is mainly influenced by local yield variability, fluctuations in input costs, and storage constraints, particularly in markets with limited infrastructure or under restricted trade conditions (FAO et al. 2011; Gilbert and Morgan 2010; Brümmer et al. 2013, 2016; Wright 2011). For internationally traded crops, global yield fluctuations and input cost variations play a more prominent role. Speculation and trade policies—such as biofuel mandates, export bans, and tariffs—also have a significant impact on price dynamics for these crops, as they are subject to global market fluctuations and geopolitical factors (HLPE 2011; Brümmer et al. 2013; FAO et al. 2011). On the demand side, factors such as income growth, population dynamics, and consumer preferences influence price movements for both types of crops (Brümmer et al. 2013). Market structure—including levels of concentration and price transmission—and policy interventions such as subsidies or exchange rate fluctuations further shape price dynamics across both domestic and international markets (FAO et al. 2011; HLPE 2011).

2.2 | Conceptual Background

To guide implementation and evaluation, many VSS articulate theories of change (ToCs) that specify how standard requirements are expected to translate into intermediate outcomes and longer-term impacts. We review the ToCs of 10 leading VSS according to Kemper et al. (2025) to create insights into how VSS can affect economic stability. Only a limited subset of VSS explicitly incorporate stability-oriented objectives in their ToCs. For instance, Fairtrade explicitly aims to stabilize prices through fair trading conditions, minimum price guarantees, and the promotion of long-term contracts. In addition, Fairtrade's premium mechanism is intended to support investments in farm management and climate-smart practices that may enhance resilience. Other standards, including Organic, UTZ, Rainforest Alliance, and Bonsucro, do not explicitly target volatility reduction as a primary objective, but their ToCs emphasize agronomic practices, resource efficiency, and resilience that may contribute to more stable yields or revenues over time.

For other VSS, economic stability is not an explicit ToC outcome, but may arise indirectly through broader effects on market access, production practices, and trade relationships. For example, VSS like Organic and GlobalGAP may affect price stability more indirectly by improving access to market information, agricultural inputs, encouraging quality differentiation, or linking producers to more stable trade relationships. Similarly, yield volatility may be indirectly affected through the promotion of specific good agricultural practices, such as diversification or soil management, while in some contexts, restrictions on synthetic inputs may also increase short-term yield variability. Supporting Information Appendix Table A1 summarizes the key ToC elements of the VSS analyzed in this study.

3 | Methods

3.1 | Data

We use secondary data from Peru's nationally representative farm survey, *Encuesta National Agropecuaria* (ENA), collected by the *Instituto Nacional de Estadística e Informática* (INEI) and *Dirección Nacional de Censos y Encuestas* (DNCE). The ENA covers diverse agricultural topics, including crop choice, revenue determinants, good agricultural practices, and certification. The ENA is a repeated cross-section, sampling approximately 30,000 farms annually, of which around 9000 farms are included in multiple years.[3] We use the panel subsample from ENA covering the period for 2015–2019,[4] enabling to track price and yield levels over time.

The sample is selected using a two-stage sampling approach. In the first stage, 2086 conglomerates[5] are randomly selected and in the second stage, 14 farms are randomly selected from each conglomerate. The data distinguishes between small/medium-sized and large farms, using the definition of the Peruvian government, which defines large farms as commercial, agro-industrial companies typically farming more than 50 ha of land and small/medium-sized farms as family-operated farms with typically less than 50 ha. The data includes sampling weights and is representative at the departmental level for family farms and the national level for agro-industry. The survey has a low non-response rate of 4%, primarily due to farm inactivity (3.5%), with minimal refusal (0.2%) and absence (0.3%). We exclude observations related exclusively to livestock production, as these differ in important ways from crop-only or mixed farms in terms of production dynamics and market conditions. Given that fewer than 1% of livestock farms are certified, this exclusion primarily removes non-certified farms from the analysis. Additionally, we exclude non-certified crops grown on certified farms, as they may not serve as a suitable control group due to potential spillover effects.

The ENA includes self-reported data on crop-level producer prices[6] and yields, expressed as average unit values over the past 12 months.[7] Volatility encompasses multiple dimensions (Reckling et al. 2021). In this study, we focus on whether VSS are associated with inter-annual fluctuations around the mean price or yield for certified and non-certified producers. Since VSS may also affect price and yield levels—potentially inflating volatility when certification status changes—we isolate volatility within certified and non-certified periods separately and analyze between-effects. This approach avoids bias from level shifts during transition from non-certified to certified (or vice versa). Specifically, we calculate price and yield volatility for crop i of farm j under certification status c, denoted as $Volatility_{i,j,c}$, as the CV of annual price or yield levels $Level_{i,j,t}$ for crop i of farm j in year t in the set of years $T^{c}_{i,j}$ in which crop i was produced under certification status c on farm j (Equations 1–3):

$$Volatility_{i,j,c} = \frac{\sigma_{i,j,c}}{\mu_{i,j,c}} \tag{1}$$

where $\sigma_{i,j,c}$ is the standard deviation:

$$\sigma_{i,j,c} = \sqrt{\frac{\sum_{t \in T^{c}_{i,j}} \left(Level_{i,j,t} - \mu_{i,j,c}\right)^2}{\left(T^{c}_{i,j} - 1\right)}} \tag{2}$$

and $\mu_{i,j,c}$ is the mean level[8]:

$$\mu_{i,j,c} = \frac{\sum_{t \in T^{c}_{i,j}} Level_{i,j,t}}{T^{c}_{i,j}} \tag{3}$$

The standard deviation captures the absolute variability in prices or yields, while the CV expresses this variability relative to the mean, allowing comparison across crops and certification statuses.[9] It is a standard indicator in the price and yield volatility literature (d'Hôtel and Le Cotty 2018; Dalheimer and Bellemare 2025; Patel and Dahlin 2022; Knapp and van der Heijden 2018; Reckling et al. 2021). Since the ENA data spans full agricultural years, this approach also accounts for seasonal effects. We compute volatility metrics for the full sample as well as a subsample restricted to crop-farm observations with at least 4 years under the same certification status as sensitivity analysis. As robustness checks, we employ the high-low range as an alternative volatility measure, which captures extreme price fluctuations (Adjemian and Irwin 2018), and the adjusted CV for small sample sizes (Plavcan and Cope 2001). We do not employ rolling window-based indicators (e.g., the CV of returns) (Brümmer et al. 2013), as these are incompatible with our setup due to the potential overlap of transitions in certification status with the observation window.

The ENA also collects farm-level certification data for several VSS, including Organic, Fairtrade, GlobalGAP (and Tesco's Nurture add-on), and other certifications specified by farmers, such as Rainforest Alliance and various health and safety standards. Given that certification is relevant only for a handful of crops, we derive crop-level certification data assuming that farm-level certification primarily applies to crops contributing at least 50% of the net farm revenue or harvested area (Ruben 2017), or to crops for which at least 50% of the harvest is destined for export, Lima, or agroindustry, where demand for certified produce is high (Schuster and Maertens 2013; UNFSS 2022). We verified these assumptions during stakeholder interviews in Peru in spring 2022, where informed consent was obtained, and using department-level certification data from Fairtrade International and Fair Trade USA for 2015–2019 (family farms) and 2025 (agro-industry) and from Organic for 2019, and crop-specific certification data from GlobalGAP for 2021. Across the full sample, we observe 1153 certified farms (Table 1).

3.2 | Estimation Approach

To compare price and yield volatility between certified and non-certified farms, we start by using a pooled OLS model at the crop level (Equation 4):

$$Volatility_{i,j,c} = \alpha + \beta VSS_{i,j,c} + \theta C_{j,c} + \vartheta_d + \sigma_i + \varphi_{i,j,c} + \delta_{i,j,c} + \varepsilon_{i,j,c} \tag{4}$$

where $Volatility_{i,j,c}$ denotes the price or yield volatility for crop i of farm j under certification status c. $VSS_{i,j,c}$ is a dummy variable indicating the certification status of crop i on farm j in certification status c. $C_{j,c}$ includes time-variant observable farm-level control variables, comprising total harvested area (level and squared), tropical livestock units,[10] proportion of irrigated fields, and, for family farms, farm-household characteristics (number of household laborers, years of farming experience, off-farm employment, gender, education level, language, and ethnicity of the head of the household) based on previous work on VSS adoption characteristics (Marx et al. 2022) and economic outcomes (Meemken 2020; Traldi 2021). ϑ_d represents department fixed effects to control for departmental-specific characteristics (e.g., infrastructure, policies, climate conditions), and σ_i denotes crop fixed effects to account for differences between crops (e.g., differences in supply chains, buyers, or weather sensitivity). $\varphi_{i,j,c}$ controls for the number of years the farm-crop pair remained under the same certification status as volatility might depend on the temporal scale (Pimm and Redfearn 1988). $\delta_{i,j,c}$ are year dummies to account for the specific years on which the volatility metric is calculated, and $\varepsilon_{i,j,c}$ is the error term. Since the volatility indicator captures volatility over the certification period, the data collapses to a cross-sectional dataset for all observations that do not change certification status, and to a panel dataset with two data points for observations that switch certification status. This structure renders the use of panel estimators infeasible, thus motivating the use of pooled OLS.[11] To complement the price and yield volatility analysis and understand how these relate to revenue volatility, we additionally compare cost and revenue volatility between certified and non-certified farms. We therefore use a similar pooled OLS model at the farm level (Equation 5):

$$Volatility_{j,c} = \alpha + \beta VSS_{j,c} + \theta C_{j,c} + \vartheta_d + \varphi_{j,c} + \delta_{j,c} + \varepsilon_{j,c} \tag{5}$$

To facilitate interpretation of the estimated effects of VSS on relative price and yield volatility, measured by the CV as changes in price and yield variability relative to changes in their levels, we also estimate the effect of VSS on price and yield levels using the following fixed effects model at the crop level (Equation 6):

$$Level_{i,j,t} = \alpha + \beta VSS_{i,j,t} + \theta C_{j,t} + \mu_{i,j} + \tau_t + \vartheta_d + \sigma_i + \varepsilon_{i,j,t} \tag{6}$$

where $Level_{i,j,t}$ represents the price or yield level for crop i of farm j in year t. μ_i captures crop-farm fixed effects, accounting for time-invariant unobserved confounders such as geographical, economic, technological, or cultural factors. τ_t represents year dummies, capturing temporal variation across years (e.g., climate, policy, or economic shocks), and the other variables are similar as in Equations (4) and (5). Similarly, we estimate the effect of VSS on cost and net farm revenue levels using a fixed effects model at the farm level (Equation 7):

$$Level_{j,t} = \alpha + \beta VSS_{j,t} + \theta C_{j,t} + \mu_j + \tau_t + \vartheta_d + \varepsilon_{j,t} \tag{7}$$

All economic variables, including prices, are adjusted to constant 2019 Peruvian soles (PEN) using the consumer price index (The World Bank 2025). We apply the inverse hyperbolic sine transformation to the lognormally distributed outcome variables in Equations (6) and (7) and the total area in Equations (4–7) to reduce skewness. To analyze heterogeneous effects by VSS, we replace the variable $VSS_{i,t}$ in Equations (4–7) with a vector of VSS. We hereby account for multiple certifications, which apply to 26% of the sample and reflect the common practice in Peru's agricultural sector. To analyze heterogeneity across crops, we re-estimate Equations (4–7) for a subsample of the four main certified crops: banana, coffee, grape, and avocado.

Both models (Equations 4–7) assume a linear relationship between VSS and the outcome variables, which is sensible given that the main independent variable of interest is a dummy. Additionally, the models assume the absence of multicollinearity, which we verify through inspection of correlation coefficients. To address arbitrary serial correlation and heteroskedasticity, we use clustered standard errors at the crop-farm level in both models, and additionally at the farm and conglomerate levels to account for the sampling design and treatment level (Abadie et al. 2023; Wooldridge 2010). Finally, while the fixed effects model (Equations 6 and 7) assumes strict exogeneity between the explanatory variables and the error term but allows for correlation of time-invariant unobservables at the crop-farm level, the pooled OLS model (Equations 4 and 5) assumes contemporaneous exogeneity between explanatory variables and the error term. Potential sources of endogeneity in Equations (4–7) include: (1) reverse causality, (2) measurement error, and (3) omitted variable bias. We consider reverse

TABLE 1 | Descriptive statistics by certification status.

Sample	**All farms**		**Family farms**		**Agro-industry**	
Certification status	**NC**	**C**	**NC**	**C**	**NC**	**C**
N	29,667	1153	26,326	238	3341	915
Farm characteristics						
Total harvested area (ha)	2.349 (0.199)	24.019*** (7.431)	1.800 (0.178)	2.739*** (0.750)	127.248 (16.985)	318.871*** (43.985)
Experience in farming (years)	26.454 (0.283)	25.887* (1.544)	26.469 (0.286)	25.890* (1.553)	24.726 (0.573)	24.785 (2.958)
Tropical livestock units	3.198 (0.188)	5.118** (2.063)	2.794 (0.177)	0.859** (0.285)	87.695 (12.378)	62.180 (21.898)
Advanced irrigation techniques (% of area)	0.378 (0.020)	0.657 (0.125)	0.377 (0.021)	0.637 (0.140)	0.537 (0.023)	0.942 (0.017)
Part of a producer organization (0/1)	0.052	0.903***	0.052	0.969***	0.012	0.016
Land title (0/1)	0.130	0.228**	0.128	0.201	0.407	0.558***
Production characteristics						
Annual net farm revenue (2019 PEN/ha)	2530.792 (189.324)	14,719.950 (2331.840)	2399.154 (188.246)	12,050.330 (2216.977)	31,017.490 (8061.571)	51,347.050*** (20,502.200)
Annual production costs (2019 PEN/ha)	3545.969 (208.558)	6854.888*** (1362.112)	3291.272 (205.086)	5548.09*** (1548.903)	56,839.380 (11,344.950)	24,370.410*** (4621.433)
Production sold to a collector, wholesaler or retailer (%)	43.898 (1.950)	31.334*** (6.717)	43.956 (2.004)	29.994*** (7.065)	30.452 (1.608)	49.901*** (3.744)
Production sold to a farmer organization or agribusiness (%)	2.561 (0.431)	81.910*** (7.572)	2.525 (0.442)	82.554*** (8.147)	10.638 (0.922)	72.991*** (2.445)
Production sold to final consumer (%)	7.881 (0.417)	0.802 (0.445)	7.896 (0.427)	0.736 (0.476)	4.465 (0.495)	1.715 (0.609)
Local market as production destination market (%)	34.734 (1.218)	16.569*** (2.470)	34.790 (1.251)	15.628*** (2.560)	21.953 (1.218)	29.603 (2.398)
Export market as production destination market (%)	2.258 (0.397)	71.900*** (6.549)	2.243 (0.408)	71.981*** (7.142)	5.606 (0.717)	70.780*** (2.566)
Regional, Lima or agro-industry as production destination market (%)	14.688 (1.104)	20.353 (5.176)	14.664 (1.134)	18.806 (5.338)	20.193 (1.315)	41.794 (2.972)
Farm support services						
Training (0/1)	0.009	0.101***	0.009	0.091***	0.037	0.245***
Technical assistance (0/1)	0.008	0.144***	0.008	0.138***	0.032	0.226***
Market information (0/1)	0.145	0.251**	0.145	0.240**	0.260	0.400**
Access to credit when demanded for (0/1)	0.100	0.389**	0.100	0.379**	0.282	0.510***

Note: Statistics are based on the panel of the ENA data with sampling weights applied. Standard errors for continuous variables are shown in parentheses. Differences between certified and noncertified farms are tested using Mann–Whitney or χ^2 tests. Statistically significant differences are indicated by $^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
Abbreviations: C, certified; NC, non-certified.

causality unlikely, as farmers are generally unable to anticipate future price or yield changes, which are largely driven by external factors (Bazzi and Blattman 2014). To mitigate concerns about measurement error,[12] we validate producer price and yield data against FAOSTAT data,[13] use alternative volatility indicators as robustness checks, and exclude outliers identified via z-scores exceeding three. Omitted variable bias remains a concern due to unobserved (time-varying) confounders. Although we lack strong external instruments, we assess the robustness of the results using various matching and reweighting

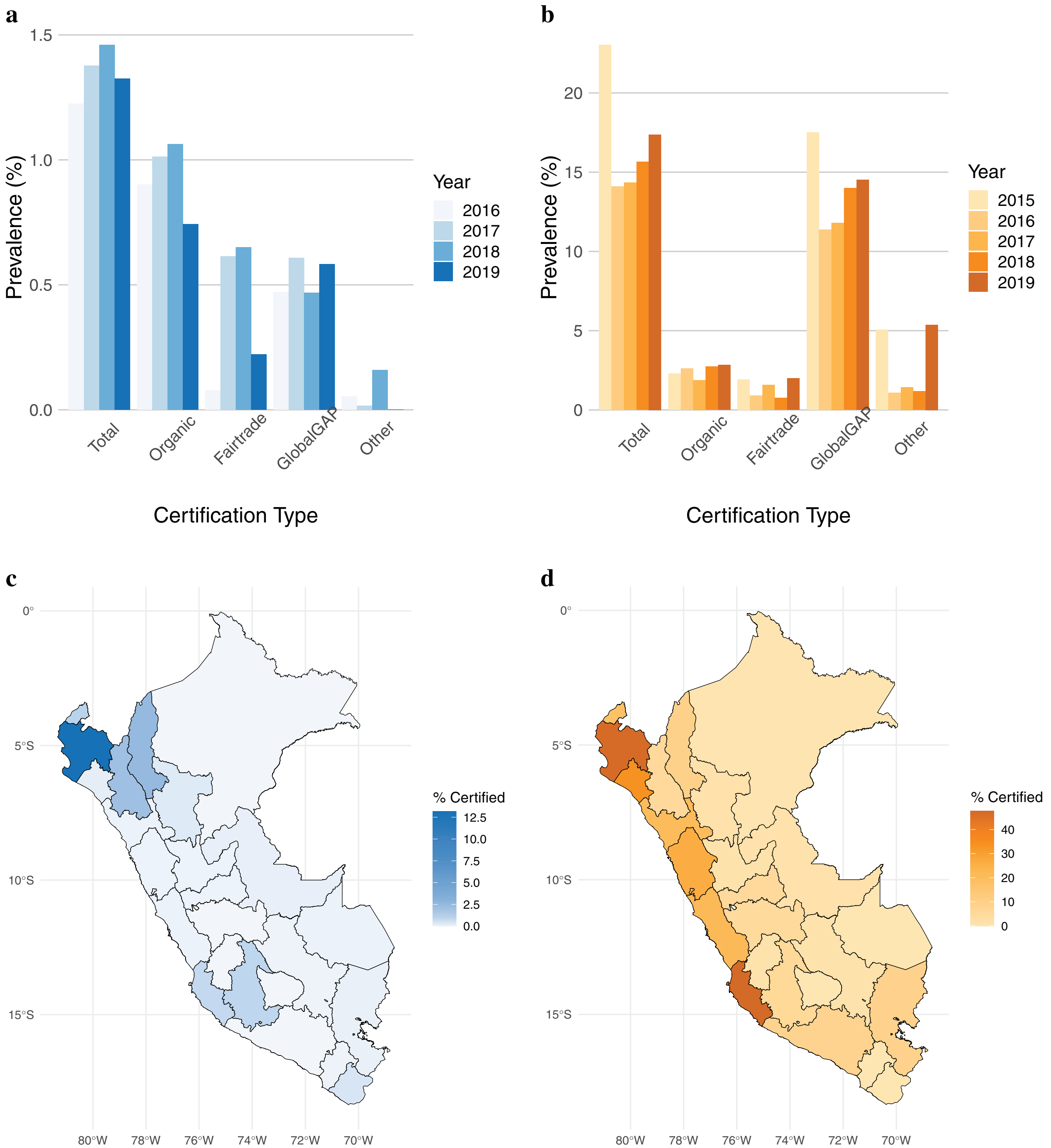

FIGURE 1 | Temporal and geographical distribution of VSS. Share of certified farms among the total number of sampled farms over the period 2015–2019 (a, b), and department-level distribution of certification, measured as the share of certified farms among sampled farms over the period 2015–2019 (c, d), disaggregated by family farms ($N = 27{,}194$) (a, c) and agro-industrial farms ($N = 4486$) (b, d). Figures are based on the panel of the ENA data with sampling weights applied.

methods (regression adjustment, inverse probability-weighting, augmented inverse-probability weighting, nearest-neighbor matching, and propensity-score matching). Additionally, we use an internal instrument method following the approach of Lewbel (2012). This method creates instrumental variables by exploiting information contained in the heteroscedasticity of the first-stage residuals.

3.3 | Descriptive Statistics

Overall, the prevalence of certification among Peruvian farms is 1.4%.[14] However, adoption is substantially higher among agro-industry (16.7%) compared to family farms (1.3%) (Figure 1a,b). These two producer types also differ markedly in terms of the VSS adopted, geographical distribution, and crop choices. GlobalGAP certification is most prevalent among agro-industry, while Organic certification dominates among family farms. Geographically, certified agro-industry is concentrated in the coastal region of Peru, whereas certified family farms are primarily located in the Andean region (Figure 1c,d). In addition, while many agro-industrial companies grow fruits and vegetables (e.g., avocado, grapes, mandarin, beans, or banana), family farms often grow traditional cash crops (e.g., banana, coffee, or cocoa) or traditional staple crops (e.g., maize, or potato), where certified small and large producers are more likely to produce the aforementioned cash crops compared to their non-certified counterparts (Supporting Information Appendix Table A2).

Certified agro-industry and family farms also differ from non-certified farms across a range of socioeconomic characteristics (Table 1). On average, certified farms have a larger farm size, more livestock units, and are more likely to be members of producer organizations and to hold land titles. Certified family farms report higher per-hectare production costs, while certified agro-industrial farms report lower per-hectare production costs and higher net farm revenues. The large differences in mean values among agro-industrial farms partly reflect the highly skewed distribution of farm sizes and production systems. Marketing channels and market orientation also vary: certified farms are more likely to sell to farmer organizations or agribusinesses and less likely to sell to collectors, wholesalers, or retailers. They are also significantly more export-oriented and less focused on local markets. Moreover, certified producers are more likely to receive various forms of capacity building, including training, technical assistance, market information, and access to credit. Additionally, family farms differ on a range of household characteristics (Table 2). Certification adoption is more skewed toward male operators, those speaking Spanish as their first language, and non-indigenous groups compared to non-certified family farms. Finally, certified family farms tend to rely less on family labor and are less likely to engage in off-farm employment.

TABLE 2 | Descriptive statistics of farm household characteristics by certification status.

Sample	**Family farms**	
Certification status	**NC**	**C**
N	26,326	238
Household size	3.562 (0.036)	4.001 (0.208)
Number of household laborers on the farm	2.310 (0.017)	2.185** (0.130)
Self-reported distance to the capital district (hours)	1.483 (0.088)	1.365 (0.503)
Age of the household head (years)	53.100 (0.309)	51.721 (1.466)
Off-farm employment by household head (0/1)	0.544	0.462**
Female-headed household (0/1)	0.279	0.078***
Secondary or tertiary education of the household head (0/1)	0.326	0.330
Spanish as first language of the household head (0/1)	0.567	0.945***
Indigenous ethnic group of the household head (0/1)	0.528	0.111***

Note: Comparable household and workforce data are unavailable for agro-industrial farms, for which only labor cost information is collected. Statistics are based on the panel of the ENA data with sampling weights applied. Standard errors for continuous variables are shown in parentheses. Differences between certified and non-certified farms are tested using Mann–Whitney or χ^2 tests. Statistically significant differences are indicated by $^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$.
Abbreviations: C, certified; NC, non-certified.

Descriptive figures of price and yield levels for the four main certified crops—banana, coffee, avocado, and grape—show higher average prices and yields among both certified family farms and agro-industrial producers (Figure 2). Price variability is lower for banana and coffee, while yield variability is lower only for banana, and no clear differences are observed for the other crops. Substantial variation across years suggests that analyzing price and yield volatility is relevant. Descriptive figures of price and yield volatility highlight that, on average, certified farms exhibit lower price volatility than non-certified farms, with a mean CV of 0.13 compared to 0.40 (Figure 3a), suggesting that certification is generally associated with more stable prices. Certified farms also show a smaller range of price volatility (0–1.48) relative to non-certified farms (0–1.86), indicating fewer extreme fluctuations. However, the highest density of price volatility values for certified farms occurs at higher values of the CV (0.24) than for non-certified farms (0.17), implying more frequent moderate volatility spikes. A similar pattern is observed for yield volatility (Figure 3b). Certified farms again show lower average volatility (mean CV of 0.26 compared to 0.33 for non-certified farms), as well as a smaller range (0–0.94 vs. 0–1.60). Yet, the highest density of yield volatility also lies at slightly higher values of the CV for certified farms (0.22) than for non-certified ones (0.18), indicating more common mid-level fluctuations. Taken together, these patterns suggest that certification is associated with reduced average volatility and fewer extreme fluctuations in both price and yield. However, it may also be linked to a greater concentration of moderate volatility levels.

Descriptive statistics of production costs and net farm revenue suggest that certification is associated with more stable production costs and net farm revenues (Figure A1). Certified farms exhibit lower average cost volatility (mean CV of 0.67) compared to non-certified farms (0.85), along with a slightly narrower range (0–1.96 vs. 0–2.00). However, the highest density of cost volatility values is observed at higher values of the CV for certified farms (0.40) than for non-certified ones (0.34), indicating more frequent moderate fluctuations. A similar pattern is found for net farm revenue volatility, where certified farms show a substantially lower average volatility (mean CV of 0.84 compared to 6.10 for non-certified farms) and a more narrow range (0–1742 vs. 0–2273). Yet, the highest density of volatility values again lies at slightly higher values for certified

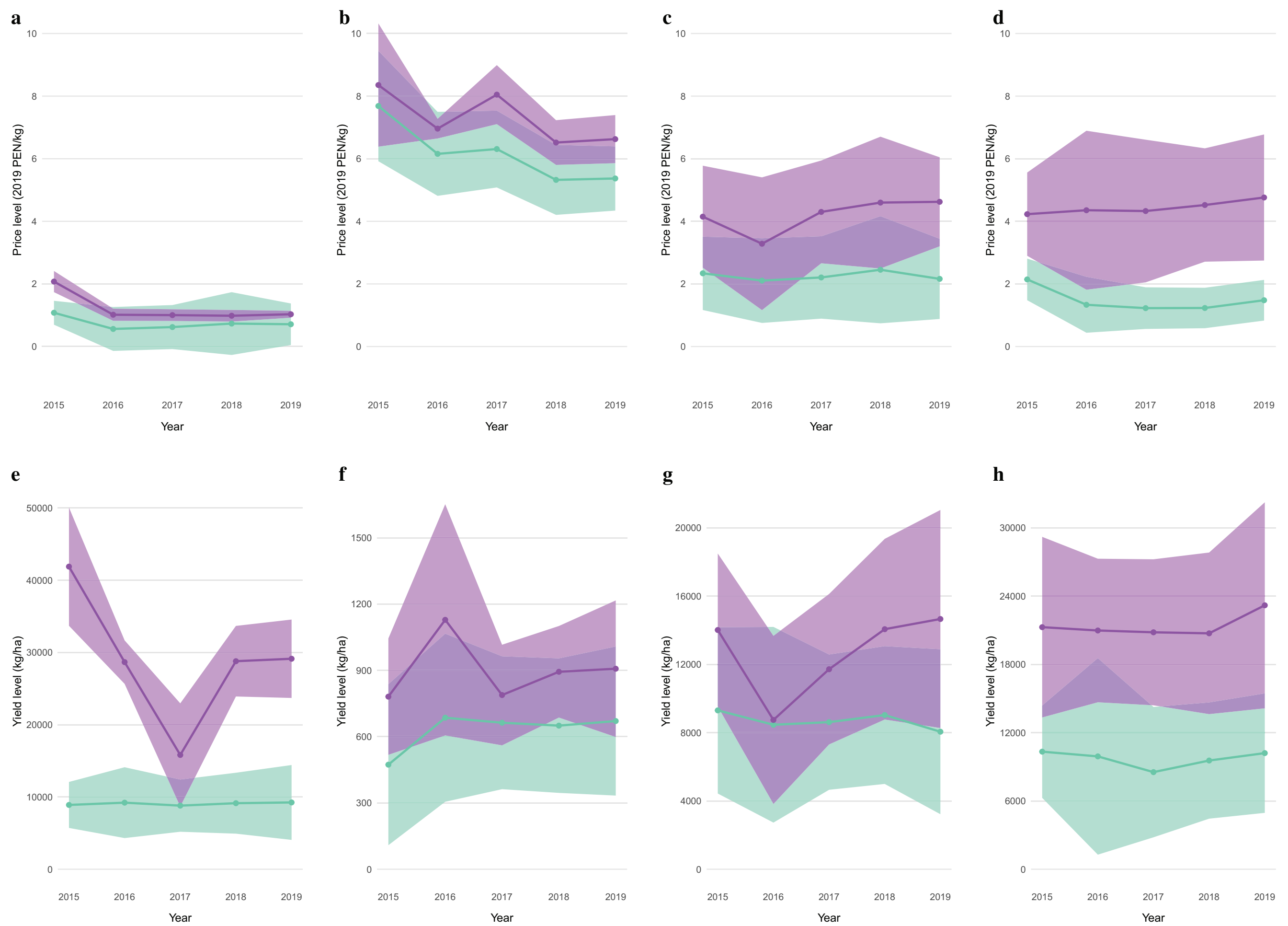

FIGURE 2 | Price and yield levels for the four main certified crops. Mean price (a–d) and yield (e–h) levels, with standard deviations, for certified (purple) and non-certified (green) crops: (a, e) banana, (b, f) coffee, (c, g) avocado, and (d, h) grape. Based on ENA data with sampling weights applied.

farms (0.08) than for non-certified farms (0.11), suggesting that although extremes are reduced, mid-level fluctuations remain relatively common.

4 | Results

4.1 | Price and Yield Volatility

The econometric results (Figures 4 and 5; Supporting Information Appendix Tables A4–A6) indicate that certification is generally associated with lower volatility in both prices and yields. In real terms, certification corresponds to a reduction in the CV by 0.11 for prices and 0.06 for yields. This translates to a 27% drop in the CV for prices or a drop in the standard deviation from 0.93 to 0.70 PEN/kg (based on an average crop price of 2.15 PEN/kg) and a drop of 17% in the CV for yields or from 3406 to 2764 kg/ha (based on an average yield of 10,708 kg/ha). However, the results reveal substantial heterogeneity across producer types, certification schemes, and crops. Certification is associated with reduced price volatility particularly among family farms, across all VSS, and for banana and coffee. Certification is also associated with lower yield volatility for both family farms and agro-industrial producers, specifically under GlobalGAP, and for banana and grape production. Additionally, we find that the yield volatility reductions associated with VSS certification are stronger if the duration of certification, in years, increases.

4.2 | Price and Yield Level

To better interpret the relative volatility findings, we additionally estimate the effect of VSS on price and yield levels (Figures 4 and 5; Supporting Information Appendix Tables A7–A9). The regression results indicate that VSS are associated with a 6% increase in price levels. We take this price level increase into account in our volatility indicator by using a relative measure to the mean of the price levels. This price level increase is, particularly the case for family farms, for Organic and GlobalGAP certification, and for coffee and grapes. In contrast, Fairtrade and avocado certification are associated with lower price levels. For Fairtrade, this may be explained by structural factors such as cooperative deductions to cover operational costs, oversupply resulting from limited demand or processing capacity, farmers' lack of awareness about their certification status, or periods of high commodity prices that render the Fairtrade minimum price largely irrelevant.

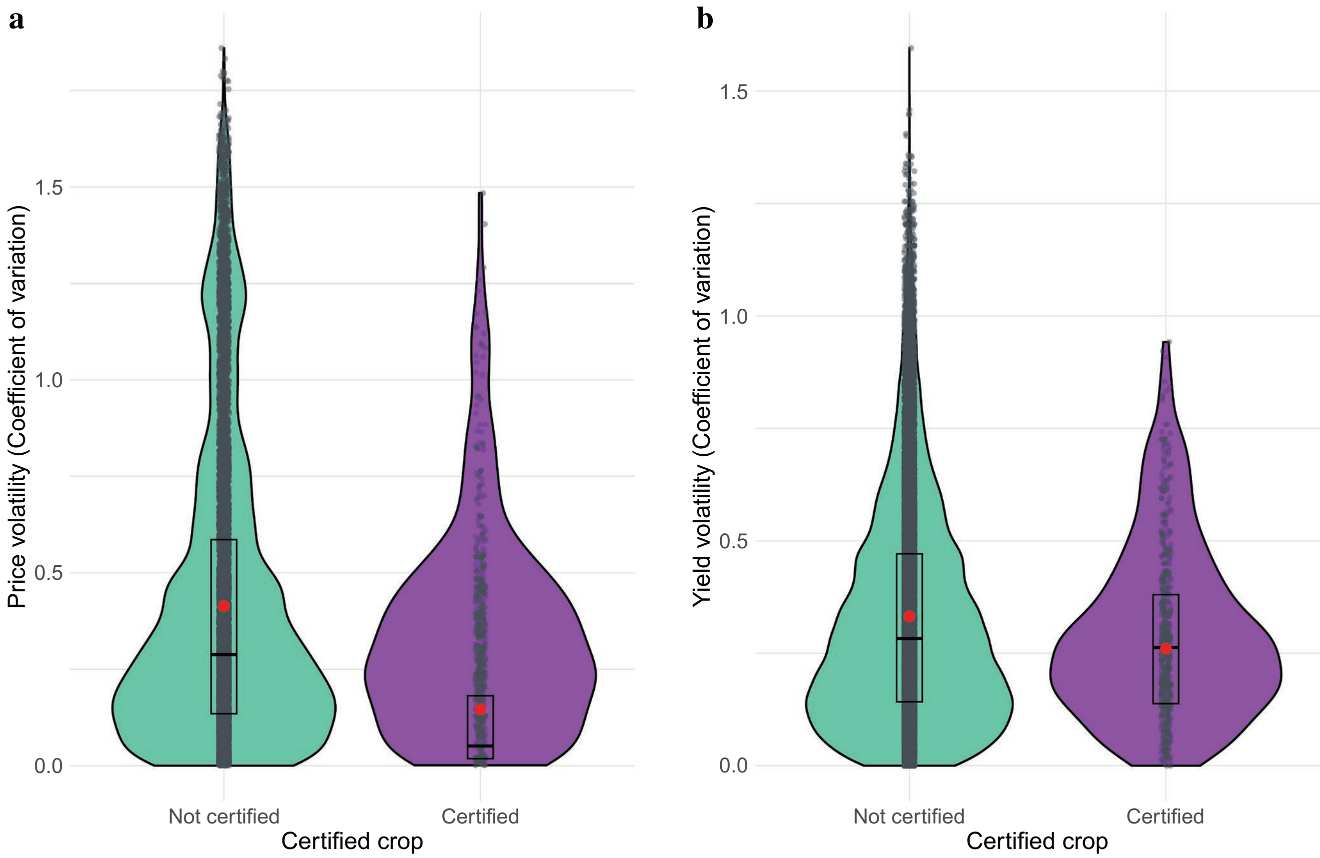

FIGURE 3 | Distribution of price and yield volatility by certification status. Violin plots showing the distribution of (a) price volatility and (b) yield volatility for certified and non-certified crops. Individual observations are shown as black dots; boxplots indicate the median and interquartile range, and the red dot denotes the mean. Based on ENA data with sampling weights applied.

At the same time, methodological issues may also play a role. Fairtrade certification is always held by cooperatives, which typically provide partial advance payments and a final payment at the end of the year. Cooperatives may also distribute part of the social premium as additional payments. However, farmers may not perceive these transfers as part of the product price, leading to underreporting of the actual price received. Additionally, certification is not significantly associated with higher yield levels, except for a positive association in the case of avocado.

4.3 | Production Cost and Net Farm Revenue Volatility and Level

To understand how price and yield volatility affect revenue volatility, we additionally compare cost and revenue volatility between certified and non-certified farms. The econometric results (Figures 6 and 7; Supporting Information Appendix Tables A10 and A11) show that certification is associated with lower volatility in costs. Specifically, certified farms experience a 17% drop in cost volatility, particularly those in the agro-industrial sector and those certified under GlobalGAP or Fairtrade. For net farm revenue volatility, the stabilizing effect of certification is more limited, with a reduction in the CV observed only among family farms (81% reduction), especially those certified under Organic. Volatility further decreases with the duration of certification.

Despite the reduction in cost volatility, certification is associated with higher production costs across both family farms and agro-industrial producers (Figures 6 and 7; Supporting Information Appendix Tables A12 and A13). This effect is, particularly, pronounced for farms certified under Organic and GlobalGAP. Additionally, certification does not lead to higher net farm revenues on average and is linked to lower net farm revenues for Fairtrade-certified family farms and GlobalGAP-certified agro-industrial farms.

4.4 | Sensitivity Analyses

A series of robustness checks confirm the main findings (Table 3). Restricting the sample to observations with at least 4 years of data in the same certification status does not alter the results. Alternative volatility measures, such as the high-low range and adjusted CV for small sample sizes, yield consistent results for all outcomes. Excluding outliers based on z-scores above three also leaves the main conclusions unchanged. Additionally, we estimate the average treatment effect using a range of matching estimators (regression adjustment, inverse probability-weighting, augmented inverse-probability weighting, nearest-neighbor

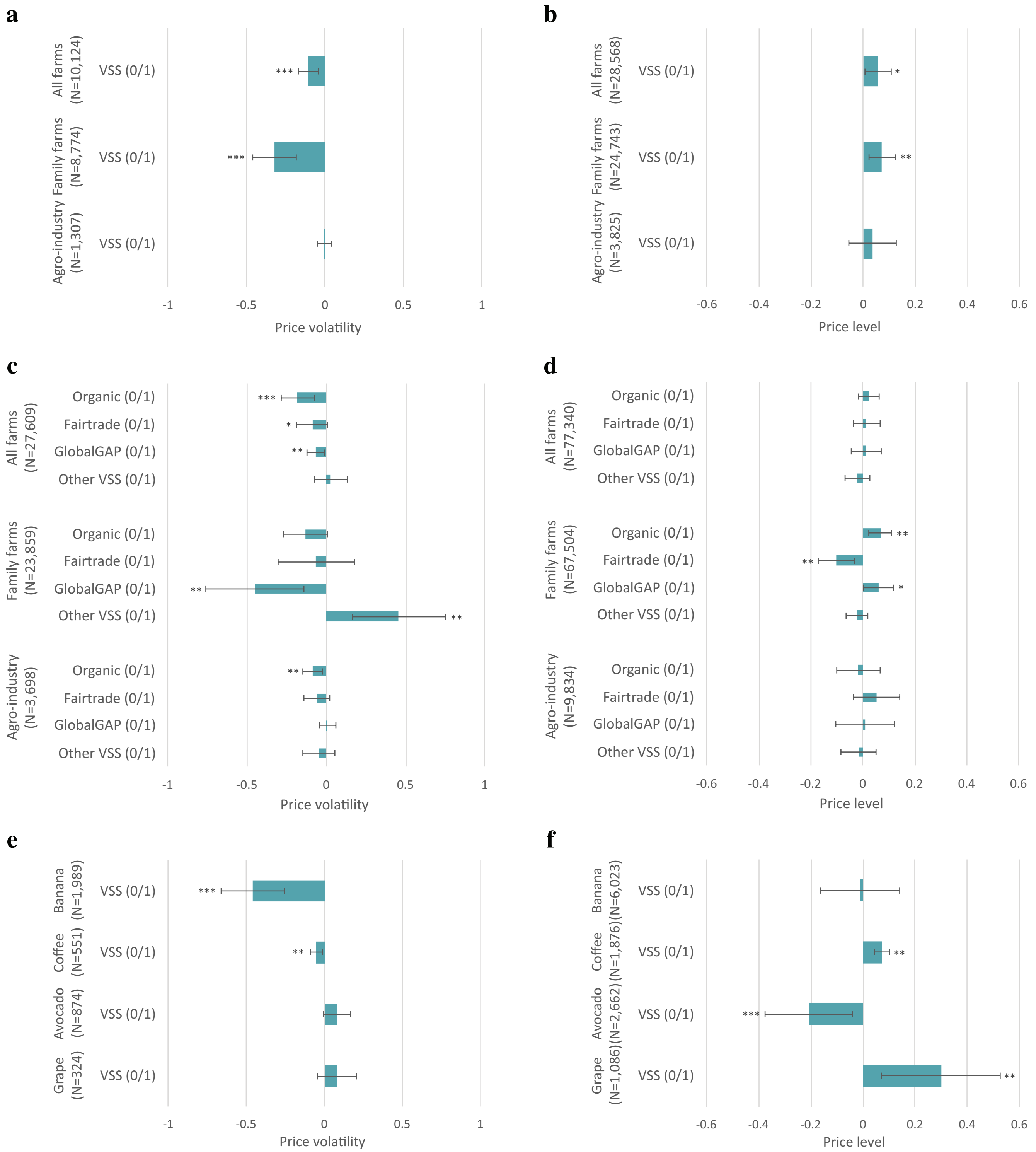

FIGURE 4 | Estimated effects of VSS on price volatility and levels. Estimated effects of VSS adoption on price volatility (a, c, e) and levels (b, d, f). Heterogeneity in effects is shown across producer types (a, b), VSS (c, d), and crops (e, f). Abbreviation: VSS–voluntary sustainability standards.

matching, and propensity-score matching) instead of pooled OLS. All estimators yield qualitatively similar results, with the doubly robust inverse-probability-weighted regression adjustment (IPWRA) estimator reported as the main specification. Finally, employing internal instruments via the Lewbel approach produces similar results, though the overidentification test for yield volatility is only borderline non-significant at the 5% level, warranting cautious interpretation.

5 | Discussion

Previous research on VSS has largely focused on their economic effects, generally pointing toward moderately positive price effects and mixed effects on yields (Oya et al. 2018; Traldi 2021; Meemken 2020). In line with these studies, we observe that VSS adoption is associated with higher prices but no significant differences in yield levels in Peru. Beyond

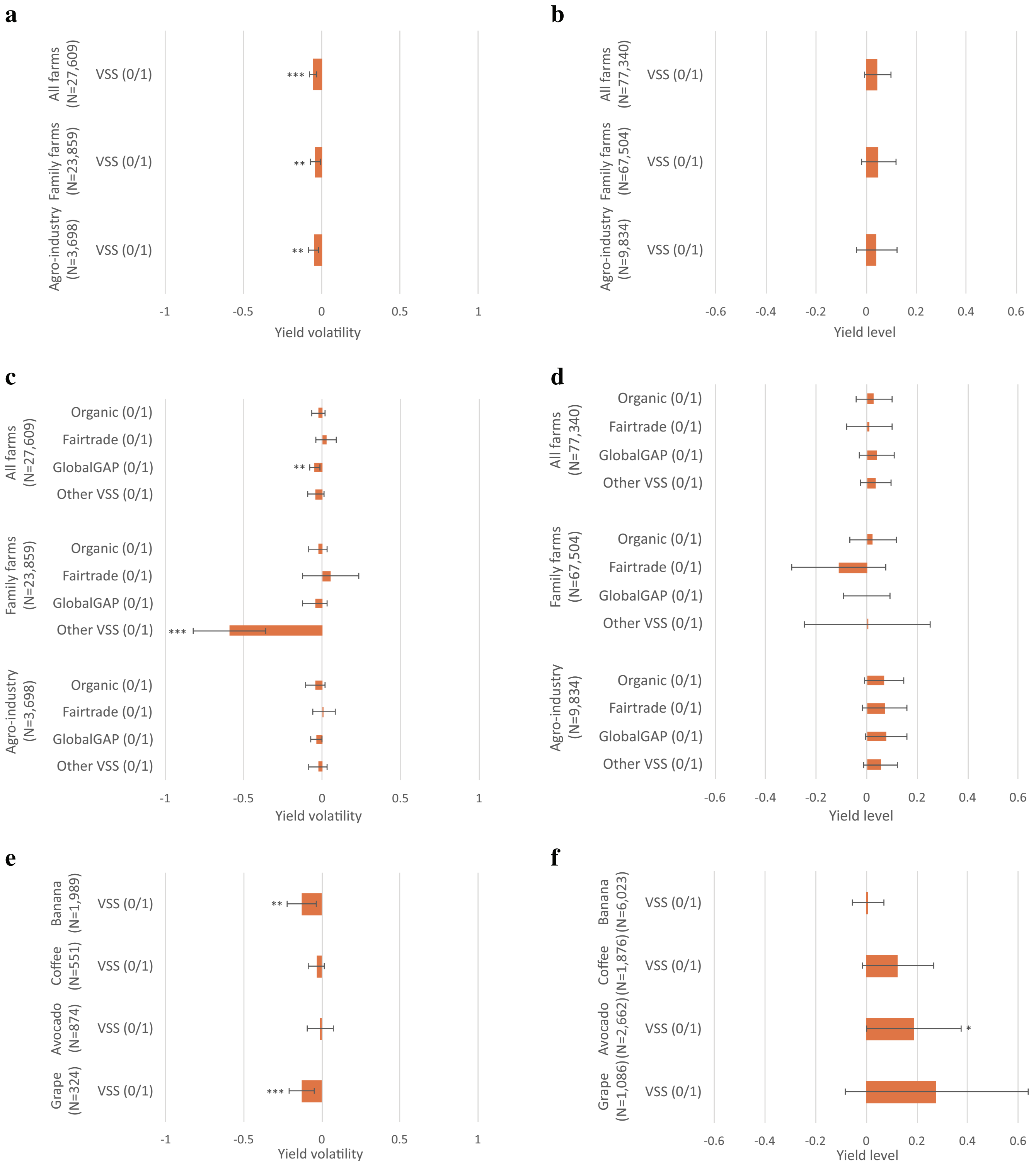

FIGURE 5 | Estimated effects of VSS on yield volatility and levels. Estimated effects of VSS adoption on yield volatility (a, c, e) and levels (b, d, f). Heterogeneity in effects is shown across producer types (a, b), VSS (c, d), and crops (e, f). Abbreviation: VSS–voluntary sustainability standards.

level effects, however, we find that certification is associated with greater stability in both prices and yields. This supports earlier evidence on price volatility reduction in Rainforest Alliance certified coffee markets in Colombia (Rueda and Lambin 2013) but contrasts with findings of higher yield volatility under Organic certification in the United States, India, and other predominantly high-income countries (Knapp and van der Heijden 2018). Extending the analysis to a wider range of crops and VSS and focusing on a middle-income country, Peru, we find that certification is associated with a decrease of 0.11 in the CV of price and a decrease of 0.06 in the CV of yield, reflecting substantial reductions in price and yield volatility. Price volatility reductions are most pronounced among family farms, for Organic, Fairtrade, and GlobalGAP certification, and for banana and coffee certification. Yield volatility reductions are observed across both family farms and agro-industry,

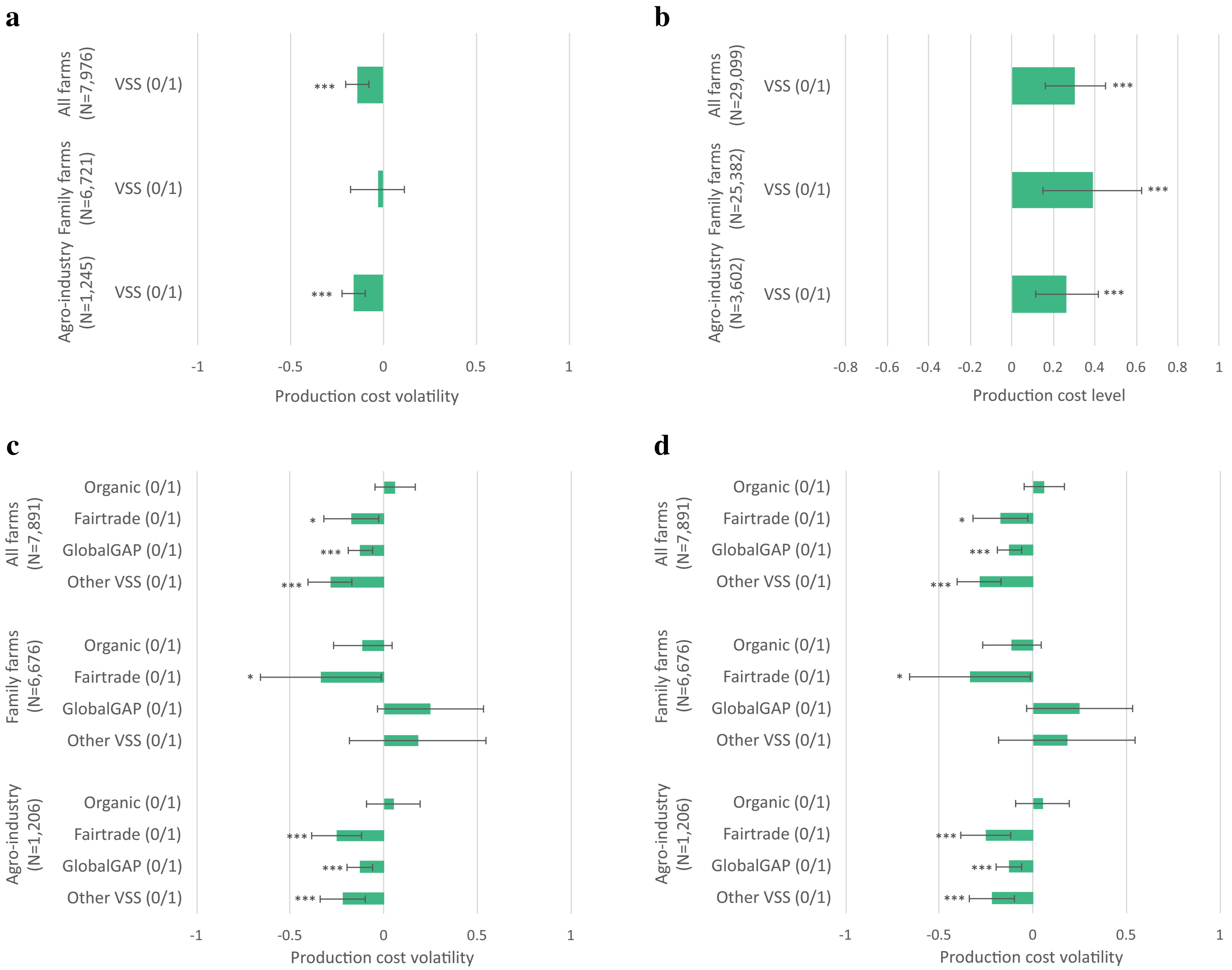

FIGURE 6 | Estimated effects of VSS on production cost volatility and levels. Estimated effects of VSS adoption on production volatility (a, c) and levels (b, d). Heterogeneity in effects is shown across producer types (a, b) and VSS (c, d). Abbreviation: VSS–voluntary sustainability standards.

especially under GlobalGAP certification and for banana and grape certification.

The observed reduction in yield volatility is strongest under GlobalGAP certification, next to the group of VSS consisting of Rainforest Alliance, SMETA, and various health and safety certifications, such as HACCP, BASC, and BRC. This might relate to the schemes' focus on good agricultural practices—including soil health, pest and disease control, and farm management protocols—which may enhance crop resilience to environmental shocks (Supporting Information Appendix Table A1). GlobalGAP is also associated with higher access to training and extension services in Peru (Supporting Information Appendix Table A15), which might further contribute to stabilizing yields. In contrast, Organic and Fairtrade certification are not associated with significant reductions in yield volatility. This suggests that the switching to new practices under Fairtrade and Organic, as well as input restrictions under Organic, do not lead to temporary yield fluctuations. The effect varies across crops: yield volatility reductions are seen for banana and grape certification but not for coffee and avocado certification. These differences may be linked to the main VSS certifying these crops (GlobalGAP), crop characteristics, and value chain dynamics. Bananas and grapes, typically grown in more intensive systems and with shorter production cycles than coffee and avocado, may respond more quickly to improvements in practices. They are also more frequently integrated into vertically coordinated supply chains or contract farming arrangements (Lee et al. 2012), which often include technical support and stricter quality controls—factors that can enhance yield stability.

The reduction in price volatility holds under Organic, Fairtrade, and GlobalGAP certification. Several mechanisms may underlie the reduced price volatility. On the supply side, this might relate to improved access to market information and agricultural inputs, and horizontal coordination among certified family farms, which can enhance bargaining power and collective responses to market changes (Bray and Neilson 2017; Oya et al. 2018). Additionally, Organic and GlobalGAP rely on a quality-based price differentiation system and may adjust price premiums in response to international price spikes (Rueda and Lambin 2013). Fairtrade relies on minimum price guarantees, the promotion of long-term contracts, and the promotion of fair trading conditions which might help stabilize prices. The observed reduction

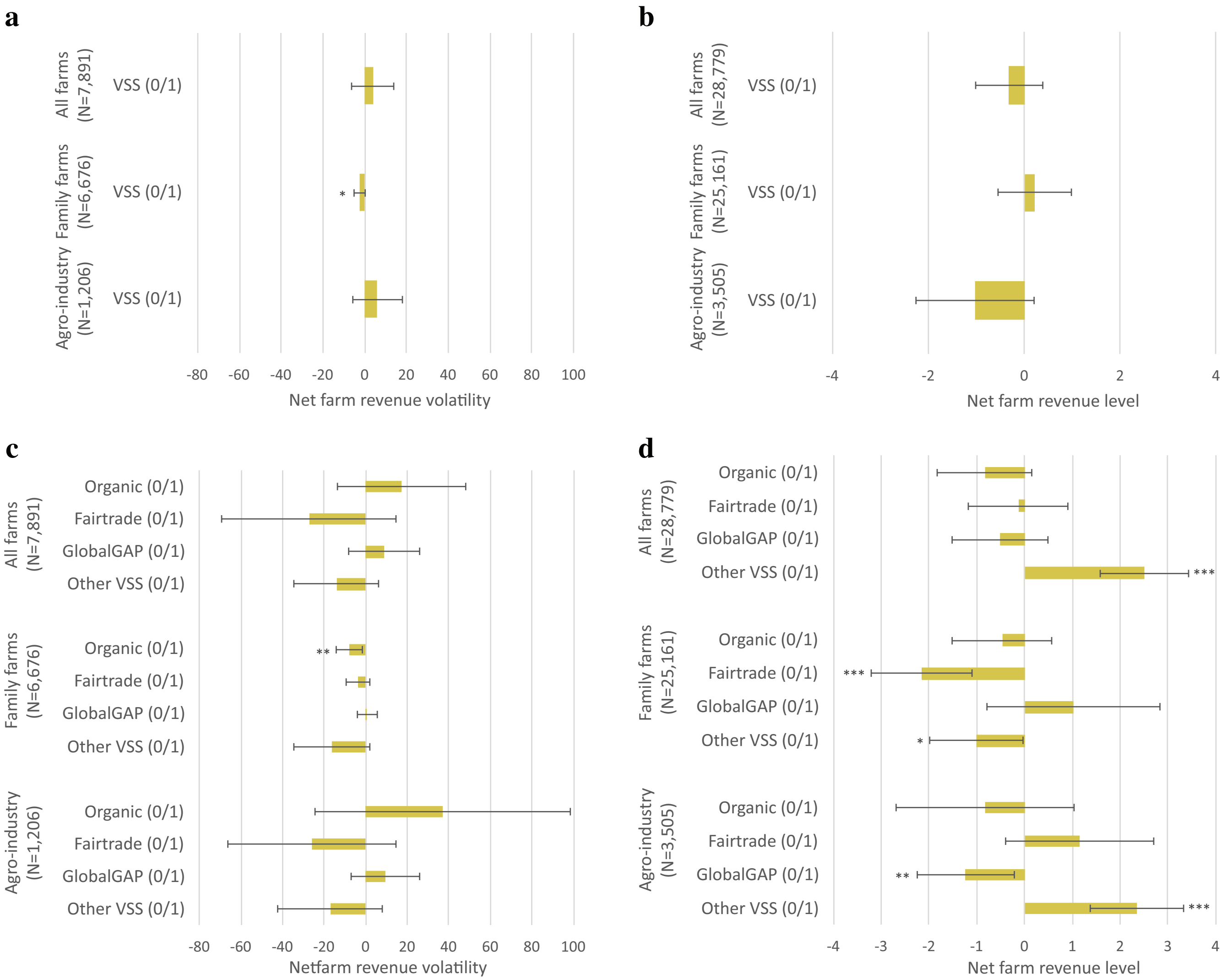

FIGURE 7 | Estimated effects of VSS on net farm revenue volatility and levels. Estimated effects of VSS adoption on net farm revenue volatility (a, c) and levels (b, d). Heterogeneity in effects is shown across producer types (a, b) and VSS (c, d). Abbreviation: VSS–voluntary sustainability standards.

in price volatility may also partly reflect more stable local supply through improved yield stability, as discussed above. Since we do not find significant differences in yield levels between certified and non-certified farms, the effect is unlikely to be explained by market failures to correct for localized yield changes. On the demand side, certification may reduce information asymmetries, resulting in a more stable demand that is driven by ethical or environmental considerations rather than cost (Bissinger and Leufkens 2020; Vellema et al. 2015). Furthermore, VSS might relate to reduced transaction costs, potentially affecting price transmission (Swinnen 2016; Wang et al. 2024). Crop-level effects suggest that price volatility reductions are most substantial for banana and coffee, where horizontal coordination mechanisms are common, and where Organic and Fairtrade certification is well established (Lee et al. 2012). Bananas, in particular, are often subject to multiple certification schemes, which may enhance flexibility in accessing different markets and reduce dependence on a single buyer.

The reduction in price and yield volatility translates into lower volatility in net farm revenue—but only for family farms. Among VSS, Organic certification shows the strongest association with reduced volatility in net farm revenue, likely due to its pronounced effect on price stability. In contrast, we observe no significant reduction in revenue volatility under Fairtrade or GlobalGAP, possibly because their effects on price and yield volatility are either more limited or concentrated in different producer types. In particular, Fairtrade is associated with reduced price volatility for family farms, and GlobalGAP is associated with reduced yield and production cost volatility in agro-industrial farms, but this is not sufficient to significantly affect overall net revenue volatility.

Our findings have several implications for policymakers and certification bodies. First, we find that VSS are associated with higher price levels and reduced price and yield volatility—effects that translate into more stable net farm revenues, but primarily for family farms. This is particularly relevant in the current context of increasing uncertainty due to climate change, geopolitical instability and deregulation, where many producers in low- and middle-income countries lack access to formal risk management tools (García-Machado et al. 2024). By stabilizing prices, yields, and revenues, VSS can serve as a market-based instrument to

TABLE 3 | Robustness checks for the regression results of the association between VSS and price, yield, cost, and net farm revenue volatility.

	Price volatility	Yield volatility	Cost volatility	Net farm revenue volatility
Outcome indicator	**All farms**	**All farms**	**All farms**	**All farms**
Main effects				
VSS (0/1)	−0.108***	−0.057***	−0.139***	−3.814
	(0.039)	(0.015)	(0.038)	(6.026)
N total	10,124	27,609	7956	7891
Robustness checks				
Subsample of observations that occur at least 4 years in the certification status				
VSS (0/1)	−0.244***	−0.065**	−0.144*	−2.245
	(0.085)	(0.025)	(0.077)	(1.927)
N total	3906	6896	6363	6353
Coefficient of variation adjusted for small sample sizes				
VSS (0/1)	−0.119***	−0.061***	−0.151***	4.373
	(0.042)	(0.017)	(0.041)	(6.763)
N total	10,124	27,609	7976	7891
High-low range relative to the mean as alternative volatility indicator				
VSS (0/1)	−0.164**	−0.117***	−0.238***	−10.488
	(0.073)	(0.027)	(0.070)	(8.829)
N total	10,124	27,609	7976	7981
Removing potential outliers with z-scores above 3				
VSS (0/1)	−0.101***	−0.048***	−0.139***	−0.431
	(0.037)	(0.015)	(0.038)	(1.131)
N total	10,063	27,313	7956	7875
Inverse-probability weighted regression adjustment (IPWRA) instead of pooled OLS				
VSS (0/1)	−0.112***	−0.102**	−0.334***	10.590
	(0.047)	(0.041)	(0.057)	(8.642)
N total	10,166	27,538	6789	6743
Internal instrument method (Lewbell) instead of pooled OLS				
VSS (0/1)		−0.033***	−0.150***	−0.395
		(0.008)	(0.026)	(0.966)
N total		27,655	7977	7892
Breusch–Pagan test (*p*)		0.000	0.000	0.000
Pagan–Hall test (*p*)		0.000	0.000	0.000
Hansen's *J* statistic (*p*)		0.050	0.124	0.865
Kleibergen–Paap rk Wald *F* statistic		3075.670	546.192	546.005
Kleibergen–Paap rk LM statistic		108.996	166.556	168.866

Note: Control variables are included but estimated coefficients not shown for brevity. For IPWRA: The covariates in the outcome model and in the treatment-assignment model are the same as in the regression models. For the internal instrument method: We report the Breusch–Pagan test for heteroscedasticity of the first stage residuals, Pagan–Hall and Hansen's *J* test for instrument validity, Kleibergen-Paap rk Wald statistic for weak instruments and the Kleibergen–Paap rk LM statistic for under-identification. Included instruments are (a subset of) the control variables used in the main analysis on the paper. No valid internal instruments were found for price volatility and hence results are not reported. Statistically significant differences are indicated by $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
Abbreviations: ENA-Encuesta Nacional Agropecuaria; VSS-voluntary sustainability standards.

strengthen resilience among family farms. However, this also implies a shift in responsibility for economic sustainability management from the public to the private sector—raising questions about the adequacy and fairness of relying on voluntary initiatives to deliver stability in agricultural livelihoods. Moreover, certified producers are often relatively better off, with, for example, greater access to trainings, information, and markets. This highlights the need for complementary instruments—such as inclusive finance, extension services, or targeted subsidies—that can help extend the benefits of volatility reduction to less advantaged farmers who are unlikely to certify on their own.

Second, we find that VSS are associated with volatility reductions for some producer types, crops, and VSS, but not for all. Our results emphasize that the volatility reductions are contingent upon crop characteristics, value chain structures, and VSS design—echoing prior findings on the heterogeneous outcomes of VSS (Meemken 2020; Oya et al. 2018). During stakeholder interviews, the importance of long-term contracts for stabilizing producer incomes was frequently mentioned. Yet, only Fair Trade USA currently promotes such contracts—and even then, without enforceable compliance mechanisms. This highlights that through strengthening design features within certification schemes, VSS could more effectively contribute to price, yield, and revenue stability, and thereby create benefits that go beyond sustainability, improving the resilience of farm-based livelihoods.

6 | Conclusion

This study analyzes the association between certification to VSS and crop-level price and yield volatility. Focusing on inter-annual price, yield, and net farm revenue volatility and using producer-level data from a nationally representative survey in Peru over several years, crops and VSS, we find that certification is generally associated with lower price and yield volatility, particularly among family farms and for certain crops like banana, coffee, and grapes. These effects translate into greater net farm revenue stability, particularly for family farms, but not for agro-industry. Findings are particularly relevant as price and yield uncertainty are expected to rise due to climate change and geopolitical instability, underscoring the potential role of certification in enhancing economic stability and resilience for certain producers, while also highlighting the need for additional policies to support less favored producers and tailor certification design to different crop and farm types.

The study has several limitations that could be addressed in future research. First, while we analyze net farm revenue and its volatility as economic performance indicators, the dataset does not include household-level income or poverty measures, preventing us from examining broader welfare outcomes. Second, limited by the dataset that spans a maximum of 5 years, we focus on short-term volatility and on inter-annual, rather than intra-annual, volatility. We focus exclusively on crop-level yield volatility, without examining volatility at broader spatial scales, where factors such as farm-level diversification strategies could influence aggregate food supply stability. A third limitation is the lack of strong external instruments for the price volatility analysis to fully control for time-varying unobserved heterogeneity. Fourth, the number of certified family farms is relatively small, but comparable to sample sizes typically seen in surveys specifically designed to analyze the impact of VSS (Meemken 2020). However, this limits the extent to which we can disentangle the effect by VSS given small sub-sample sizes. Fifth, the dataset does not provide information on whether certified products were actually sold as certified. This is a common limitation in farm-level surveys, as farmers are often unaware of how their products are marketed downstream in the value chain.

Future research could extend this analysis to other countries and institutional contexts to assess the external validity of the findings. While the data used here are nationally representative—an exception in this literature—the analysis focuses on Peru, and the extent to which the results generalize to other regions or continents remains an open question. In addition, future research could explore how different types of value chains mediate the effects of certification on price and yield volatility. For example, bargaining power dynamics among producers, intermediaries, and buyers may influence price stability outcomes. Moreover, future research could examine whether certified farms adopt different risk management strategies (e.g., contract farming, diversification, hedging) compared to non-certified farms, and how these strategies interact with price and yield volatility. Furthermore, given the growing policy interest in stabilizing agricultural markets and the diverse policy interventions across countries, future research could investigate how national policies (e.g., minimum price guarantees, subsidies, or trade agreements) interact with VSS in influencing price and yield stability. Understanding whether these interactions are complementary or conflicting would provide valuable insights for designing more coherent market governance frameworks.

Acknowledgments

The authors acknowledge funding from the Flemish Fund for Scientific Research (FWO) (Grants 1S40222N and V466523N) and the KU Leuven Special Research Fund (Grant C24M/19/031). The funding institutions were not involved in the design, analysis and writing of the study. The authors would like to thank Diana Llacsahuanga Carrasco for support in facilitating the primary data collection in Peru.

Funding

This work was supported by the Flemish Fund for Scientific Research (FWO) (Grants 1S40222N and V466523N) and the KU Leuven Special Research Fund (Grant C24M/19/031).

Ethics Statement

This study complies with the ethical guidelines of the authors' affiliated institutions. The secondary data used, drawn from a nationally representative farm household survey, are publicly available in anonymized form. Primary data from stakeholder interviews were conducted with informed consent and anonymized to protect participant confidentiality. In line with the ethical review procedures of the authors' institutions, formal approval from an institutional or national ethics committee was not required for this study, as no identifiable personal or sensitive data were collected.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Endnotes

[1] In localized markets, however, price volatility might be a sign of market efficiency, as it reflects the market's ability to adapt to changes in yield volatility, potentially stabilizing farm incomes.

[2] We refer to Fairtrade as the umbrella of various fair trade organizations, including but not limited to Fairtrade International, Fair Trade USA, Small Producer's Symbol, and Fair For Life.

[3] Farms observed in multiple ENA waves are randomly selected for longitudinal follow-up from the 2012 agricultural census sampling frame, explicitly to enable farm-level tracking over time (INEI and DNCE 2025). We further assessed potential selection into the panel by comparing observable characteristics of panel farms with farms observed only cross-sectionally and found no systematic differences between the two groups.

[4] The ENA is also conducted in 2014, but does not include information on prices, in 2021, when no data on certification was collected, and in 2022 only for family farms which does not allow to calculate volatility over consecutive years. Family farms were also sampled in 2015, but these farms do not form a panel with subsequent years.

[5] A conglomerate is a georeferenced minimum unit of the 2012 Agricultural Census. In total, there are 19,264 conglomerates in Peru covering on average 66 km^2 and 120 producers (INEI and DNCE 2025).

[6] Producer prices refer to the prices received by farmers—that is, prices determined at the farm gate or at the first point of sale, when farmers act as sellers of their own products. In the ENA questionnaire, producers were asked to report prices alongside the type of buyer, which included a range of actors such as collectors, wholesalers, retailers, cooperatives, agro-industrial companies, and final consumers. For Fairtrade-certified producers, this does not capture effects operating through the Fairtrade Premium, an additional payment on top of the Fairtrade Minimum Price that is collectively managed by producer organizations and invested in social, economic, and environmental development. Part of this premium may be distributed to producers in cash; for example, in Peru this amounted to approximately 40% for coffee in 2019, 2%–3% for bananas in 2017–2019, and 6% for cocoa in 2019 (Fairtrade International 2025). Information on Fairtrade Premium receipts and use is not available in the ENA survey and is therefore not included in the price (and net farm revenue) measure.

[7] The ENA also includes data on annual production costs, allowing for the calculation of net farm revenues. While VSS might indirectly influence cost volatility—such as through shifts in input use (e.g., from synthetic to organic inputs)—this is not their primary objective. As such, we present results on the volatility of both production costs and net farm revenues in Supporting Information Appendix Tables A10 and A11. For net farm revenue, volatility is calculated using absolute means, given that revenues can take negative values.

[8] While the CV may become unstable when means approach zero, this concern is not relevant in this setting, as all outcome variables are positive and their means do not approach zero over the observation period.

[9] The CV is a relative volatility measure that accounts for differences in mean levels, making it more relevant in this context than absolute volatility. It captures uncertainty in proportion to expected price or yield levels, which is particularly relevant when certified and noncertified farms differ substantially in price or yield levels. Results based on absolute volatility (standard deviation) are reported in Supporting Information Appendix Table A14 for comparison.

[10] We use the International Livestock Research Institute's conversion factors (2011).

[11] Identical results are obtained using a between estimator, which is, however, less efficient.

[12] This can be especially the case with the recall of price data that varies by batch, time of sale, and especially quality.

[13] The reported prices and yields are similar to the FAOSTAT data for the 10 main certified crops, but omitted for brevity.

[14] While the share of certified farms is relatively small, this reflects the empirical distribution of certification in the population and is common in observational studies. As discussed by Alvarez et al. (2025), unequal treatment shares do not invalidate inference when the treated sample is sufficiently large and treated and control units exhibit adequate overlap. We address these conditions by applying matching and inverse-probability-weighted regression adjustment, which reweight the control group and limit estimation to common support, ensuring that results are not driven by sample imbalance.

References

Abadie, A., S. Athey, G. W. Imbens, and J. M. Wooldridge. 2023. "When Should You Adjust Standard Errors for Clustering?" *Quarterly Journal of Economics* 138, no. 1: 1–35. https://doi.org/10.1093/qje/qjac038.

Adjemian, M. K., and S. H. Irwin. 2018. "USDA Announcement Effects in Real-Time." *American Journal of Agricultural Economics* 100, no. 4: 1151–1171. https://doi.org/10.1093/AJAE/AAY018.

Akoyi, K. T., and M. Maertens. 2018. "Walk the Talk: Private Sustainability Standards in the Ugandan Coffee Sector." *Journal of Development Studies* 54, no. 10: 1792–1818. https://doi.org/10.1080/00220388.2017.1327663.

Albers, H., C. Gornott, and S. Hüttel. 2017. "How Do Inputs and Weather Drive Wheat Yield Volatility? The Example of Germany." *Food Policy* 70: 50–61. https://doi.org/10.1016/J.FOODPOL.2017.05.001.

Alvarez, L., B. Ferman, and K. Wüthrich. 2025. "Inference With Few Treated Units." *ArXiv* preprint: 2504.19841v2.

Barrett, C. B., J. Fanzo, M. Herrero, et al. 2021. "COVID-19 Pandemic Lessons for Agri-Food Systems Innovation." *Environmental Research Letters* 16, no. 10: 101001. https://doi.org/10.1088/1748-9326/AC25B9.

Bazzi, S., and C. Blattman. 2014. "Economic Shocks and Conflict: Evidence From Commodity Prices." *American Economic Journal: Macroeconomics* 6, no. 4: 1–38. https://doi.org/10.1257/MAC.6.4.1.

Bissinger, K., and D. Leufkens. 2020. "(Fairtrade) Certification: Consequences of Being a Niche Market." *Agrekon* 59, no. 2: 188–201. https://doi.org/10.1080/03031853.2019.1699840.

Boonaert, E., and M. Maertens. 2023. "Voluntary Sustainability Standards and Farmer Welfare: The Pathways to Success?" *Food Policy* 121, no. 102543: 102543. https://doi.org/10.1016/j.foodpol.2023.102543.

Bray, J. G., and J. Neilson. 2017. "Reviewing the Impacts of Coffee Certification Programmes on Smallholder Livelihoods." *International Journal of Biodiversity Science, Ecosystem Services & Management* 13, no. 1: 216–232. https://doi.org/10.1080/21513732.2017.1316520.

Brümmer, B., O. Korn, K. Schlüßler, T. J. Jaghdani, and A. Saucedo. 2013. "Volatility in the After Crisis Period—A Literature Review of Recent Empirical Research." 1. ULYSSES Project, EU 7th Framework Programme, Project 312182 KBBE.2012.1.4-05.

Brümmer, B., O. Korn, K. Schlüßler, and T. J. Jaghdani. 2016. "Volatility in Oilseeds and Vegetable Oils Markets: Drivers and Spillovers." *Journal of Agricultural Economics* 67, no. 3: 685–705. https://doi.org/10.1111/1477-9552.12141.

Carranza, G., and M. J. Gallo Gold. 2019. *The Vizcarra Era: Political Instability and Business Uncertainty in Peru*. Lima. https://ideas.llorenteycuenca.com/wp-content/uploads/sites/5/2019/08/The_Vizcarra_era_political_instability_and_business_uncertainty_in_peru_EN.pdf.

Chiputwa, B., D. J. Spielman, and M. Qaim. 2015. "Food Standards, Certification, and Poverty Among Coffee Farmers in Uganda." *World Development* 66: 400–412. https://doi.org/10.1016/j.worlddev.2014.09.006.

Dalheimer, B., and M. F. Bellemare. 2025. "Global Agricultural Value Chains and Food Prices." *American Journal of Agricultural Economics*: 1–8. https://doi.org/10.1111/ajae.70030.

d'Hôtel, E. M., and T. Le Cotty. 2018. "Why Does On-Farm Storage Fail to Mitigate Price Volatility?" *Agricultural Economics* 49, no. 1: 71–82. https://doi.org/10.1111/AGEC.12396.

Diaz-Bonilla, E., B. Mcnamara, J. Swinnen, and R. Vos. 2023. "Financial Imperatives to Food System Transformation." *Nature Food* 4: 531–533. https://doi.org/10.1038/s43016-023-00785-y.

Fairtrade International. 2025. "Fairtrade Product Platform." Accessed May 2025. https://www.fairtrade.net/en/products/Fairtrade_products.html.

FAO, IFAD, IMF, OECD, UNCTAD, WFP, the World Bank, the WTO, IFPRI, and the UN HLTF. 2011. *Price Volatility in Food and Agricultural Markets: Policy Responses*.

García-Machado, J. J., J. Greblikaitė, and C. E. Iranzo Llopis. 2024. "Risk Management Tools in the Agriculture Sector: An Updated Bibliometric Mapping Analysis." *Studies in Risk and Sustainable Development* 398, no. 398: 1–26. https://doi.org/10.22367/SRSD.2024.398.3.

Gilbert, C. L., and C. W. Morgan. 2010. "Food Price Volatility." *Philosophical Transactions of the Royal Society, B: Biological Sciences* 365, no. 1554: 3023–3034. https://doi.org/10.1098/RSTB.2010.0139.

Goyal, R., E. Mensah, and S. Steinbach. 2024. "The Interplay of Geopolitics and Agricultural Commodity Prices." *Applied Economic Perspectives and Policy* 46, no. 4: 1533–1562. https://doi.org/10.1002/AEPP.13481.

HLPE. 2011. *Price Volatility and Food Security. A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*.

INEI and DNCE. 2025. "Base de Microdatos." Accessed May 2025. https://proyectos.inei.gob.pe/microdatos/.

International Livestock Research Institute. 2011. *Gender, Livestock and Livelihood Indicators*. Nairobi. https://gender.cgiar.org/publications/gender-livestock-and-livelihood-indicators-0.

Kemper, L., G. Sampson, S. Bermúdez, et al. 2025. *The State of Sustainable Markets 2024: Statistics and Emerging Trends*. ITC.

Knapp, S., and M. G. A. van der Heijden. 2018. "A Global Meta-Analysis of Yield Stability in Organic and Conservation Agriculture." *Nature Communications* 9, no. 1: 1–9. https://doi.org/10.1038/s41467-018-05956-1.

Kukal, M. S., and S. Irmak. 2018. "Climate-Driven Crop Yield and Yield Variability and Climate Change Impacts on the U.S. Great Plains Agricultural Production." *Scientific Reports* 8, no. 1: 1–18. https://doi.org/10.1038/S41598-018-21848-2.

Lee, J., G. Gereffi, and J. Beauvais. 2012. "Global Value Chains and Agrifood Standards: Challenges and Possibilities for Smallholders in Developing Countries." *Proceedings of the National Academy of Sciences of the United States of America* 109, no. 31: 12326–12331. https://doi.org/10.1073/pnas.0913714108.

Legrand, N. 2023. "War in Ukraine: The Rational 'Wait-and-See' Mode of Global Food Markets." *Applied Economic Perspectives and Policy* 45, no. 2: 626–644. https://doi.org/10.1002/AEPP.13335.

Lewbel, A. 2012. "Using Heteroscedasticity to Identify and Estimate Mismeasured and Endogenous Regressor Models." *Journal of Business & Economic Statistics* 30, no. 1: 67–80. https://doi.org/10.1080/07350015.2012.643126.

Marx, A., C. Depoorter, and R. Vanhaecht. 2022. "Voluntary Sustainability Standards: State of the Art and Future Research." *Standards* 2, no. 1: 14–31. https://doi.org/10.3390/STANDARDS2010002.

Meemken, E. M. 2020. "Do Smallholder Farmers Benefit From Sustainability Standards? A Systematic Review and Meta-Analysis." *Global Food Security* 26, no. 100373. https://doi.org/10.1016/j.gfs.2020.100373.

Meemken, E. M. 2021. "Large Farms, Large Benefits? Sustainability Certification Among Family Farms and Agro-Industrial Producers in Peru." *World Development* 145, no. 105520. https://doi.org/10.1016/j.worlddev.2021.105520.

Oxford Business Group. 2019. "Increased Agricultural Exports and Production Drive GDP Growth in Peru." Accessed May 2025. https://oxfordbusinessgroup.com/reports/peru/2019-report/economy/global-competitor-increases-in-production-and-exports-have-seen-agriculture-become-a-driving-force-behind-economic-growth.

Oya, C., F. Schaefer, and D. Skalidou. 2018. "The Effectiveness of Agricultural Certification in Developing Countries: A Systematic Review." *World Development* 112: 282–312. https://doi.org/10.1016/j.worlddev.2018.08.001.

Patel, P. C., and P. Dahlin. 2022. "The Impact of B Corp Certification on Financial Stability: Evidence From a Multi-Country Sample." *Business Ethics, the Environment & Responsibility* 31, no. 1: 177–191. https://doi.org/10.1111/BEER.12403.

Pimm, S. L., and A. Redfearn. 1988. "The Variability of Population Densities." *Nature* 334, no. 6183: 613–614. https://doi.org/10.1038/334613a0.

Plavcan, J. M., and D. A. Cope. 2001. "Metric Variation and Species Recognition in the Fossil Record." *Evolutionary Anthropology* 10, no. 6: 204–222. https://doi.org/10.1002/EVAN.20001.

Ray, D. K., J. S. Gerber, G. K. Macdonald, and P. C. West. 2015. "Climate Variation Explains a Third of Global Crop Yield Variability." *Nature Communications* 6, no. 1: 1–9. https://doi.org/10.1038/NCOMMS6989.

Reckling, M., H. Ahrends, T.-W. Chen, et al. 2021. "Methods of Yield Stability Analysis in Long-Term Field Experiments. A Review." *Agronomy for Sustainable Development* 41, no. 27: 1–28. https://doi.org/10.1007/s13593-021-00681-4.

Ruben, R. 2017. "Impact Assessment of Commodity Standards: Towards Inclusive Value Chains." *Enterprise Development & Microfinance* 28: 82–97. https://doi.org/10.3362/1755-1986.16-00020.

Ruben, R., and G. Zuniga. 2011. "How Standards Compete: Comparative Impact of Coffee Certification Schemes in Northern Nicaragua." *Supply Chain Management* 16, no. 2: 98–109. https://doi.org/10.1108/13598541111115356.

Rueda, X., and E. F. Lambin. 2013. "Linking Globalization to Local Land Uses: How Eco-Consumers and Gourmands Are Changing the Colombian Coffee Landscapes." *World Development* 41, no. 1: 286–301. https://doi.org/10.1016/J.WORLDDEV.2012.05.018.

Schuster, M., and M. Maertens. 2013. "Do Private Standards Create Exclusive Supply Chains? New Evidence From the Peruvian Asparagus Export Sector." *Food Policy* 43: 291–305. https://doi.org/10.1016/J.FOODPOL.2013.10.004.

Seufert, V., and N. Ramankutty. 2017. "Many Shades of Gray—The Context-Dependent Performance of Organic Agriculture." *Science Advances* 3, no. 3: 1–14. https://doi.org/10.1126/SCIADV.1602638.

Swinnen, J. 2016. "Economics and Politics of Food Standards, Trade, and Development." *Agricultural Economics* 47, no. S1: 7–19. https://doi.org/10.1111/AGEC.12316.

The World Bank. 2025. "Data the World Bank." Accessed May 2025. https://data.worldbank.org/indicator/.

Traldi, R. 2021. "Progress and Pitfalls: A Systematic Review of the Evidence for Agricultural Sustainability Standards." *Ecological Indicators* 125, no. 107490. https://doi.org/10.1016/J.ECOLIND.2021.107490.

UNFSS. 2022. "Voluntary Sustainability Standards - Sustainability Agenda and Developing Countries: Opportunities and Challenges: 5th Flagship Report." Geneva.

United Nations General Assembly. 2015. "Transforming Our World: The 2030 Agenda for Sustainable Development." Accessed May 2025. https://undocs.org/en/A/RES/70/1.

Vanderhaegen, K., K. T. Akoyi, W. Dekoninck, et al. 2018. "Do Private Coffee Standards 'Walk the Talk' in Improving Socio-Economic and Environmental Sustainability?" *Global Environmental Change* 51: 1–9. https://doi.org/10.1016/j.gloenvcha.2018.04.014.

Vellema, W., A. Buritica Casanova, C. Gonzalez, and M. D'Haese. 2015. "The Effect of Specialty Coffee Certification on Household Livelihood Strategies and Specialisation." *Food Policy* 57: 13–25. https://doi.org/10.1016/J.FOODPOL.2015.07.003.

Wang, Y., S. Hug, J. Irek, and R. Finger. 2024. "Product Differentiation, Quality, and Milk Price Stability: The Case of the Swiss Cheese Market." *Applied Economic Perspectives and Policy* 47, no. 1: 416–420. https://doi.org/10.1002/AEPP.13467.

Wooldridge, J. M. 2010. *Econometric Analysis of Cross Section and Panel Data*. Vol. 1. 1st ed. MIT Press.

World Food Programme. 2025. "Annual Country Reports 2015–2019." Accessed May 2025. https://www.wfp.org/operations/annual-country-report?operation_id=PE02&year=2023#/27068.

Wright, B. D. 2011. "The Economics of Grain Price Volatility." *Applied Economic Perspectives and Policy* 33, no. 1: 32–58. https://doi.org/10.1093/AEPP/PPQ033.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** aepp70079-sup-0001-Supinfo.pdf.