nature communications

Article

https://doi.org/10.1038/s41467-026-71245-x

Voluntary sustainability standards and trading-up in tropical agrifood commodities

Received: 25 June 2025

Accepted: 16 March 2026

Published online: 02 April 2026

Check for updates

Janne Bemelmans[1,2], Charline Depoorter[1,3,4], Axel Marx[3] & Miet Maertens[1] ✉

Voluntary Sustainability Standards (VSS) are widespread market-based instruments promoting sustainability through trade. While their socio-economic and environmental outcomes vary, their trade effects remain poorly understood, raising concerns about trade distortion without sustainability gains. We analyze trade effects for ten VSS across seven tropical commodity sectors, using data on VSS coverage and design, and gravity models of bilateral trade flows. We find that VSS coverage is associated with increased trade volumes and, in most cases, lower export prices; price increases occur only for some VSS and commodities. VSS adoption tends to improve market access, particularly for less stringent standards and where governance distance between trade partners—a typical trade-inhibiting factor—is large. Only VSS with stringent environmental and ethical requirements and strong compliance control generate price premiums. Overall, VSS entail the potential for sustainability trading-up, but this potential is not fully realized across tropical commodity sectors.

Agrifood trade is key for food security and climate change adaptation but poses sustainability challenges, e.g., related to tropical deforestation, biodiversity loss, and labor or human rights violations[1–3]. Voluntary Sustainability Standards (VSS) are the most prevalent private market-based instruments to govern sustainability in global agrifood trade, operating alongside government regulations on trade and sustainability[4–6]. VSS define sustainability requirements that suppliers voluntarily comply with, rely on third-party certification to monitor and enforce compliance, and create labels to communicate the credence attributes they certify to consumers and food businesses[7]. The main goal of VSS is to promote sustainability by compensating (poorer) producers for adopting more sustainable and ethical practices through the premium prices that (richer) consumers are willing to pay for products that meet higher standards. Trade is a core mechanism for VSS to foster sustainability, reflecting the process of sustainability trading up—where the market share of certified products progressively increases relative to that of conventional ones, thereby shifting market practices toward higher value and higher sustainability standards and partially internalizing environmental and social externalities. Based on the premise that VSS effectively enable sustainability trading up, governments rely on VSS in (trans)national regulations (e.g., in free trade agreements, market access regulations, public procurement policies, and export promotion policies), companies integrate VSS in corporate sustainability and due diligence strategies, and donors invest in smallholder certification schemes[8–11]. VSS are widespread, particularly in tropical commodity sectors. Cocoa and coffee are the most intensively certified crops, with 31 to 44% and 15 to 31% of the global production area, respectively, certified to one or multiple VSS[12]. The actual sustainability and trade effects of VSS are hence critical matters.

Despite trade being the intrinsic mechanism by which VSS aim to promote sustainability, the trade effects of VSS remain poorly understood. The environmental and socio-economic benefits of VSS adoption are diverse and context-specific[4,13–18], raising concerns that VSS may distort trade without delivering sustainability gains. Theoretically, the trade and export price effects of VSS are equivocal. On the one

[1]Department of Earth and Environmental Sciences, KU Leuven, Leuven, Belgium. [2]Earth and Life Institute, UC Louvain—Louvain-la-Neuve, Louvain-la-Neuve, Belgium. [3]Leuven Centre for Global Governance Studies, KU Leuven, Leuven, Belgium. [4]Department of Social Sciences, University of Basel, Basel, Switzerland. ✉e-mail: miet.maertens@kuleuven.be

hand, VSS generally increase production costs, as producers must cover certification costs and comply with specific criteria related to production processes. These requirements might necessitate additional investments, higher-quality inputs, and improved practices, resulting in an inward supply shift. Demand gradually shifts outward as consumers are willing to pay for the credence attributes certified by VSS[19–21]. Consequently, VSS can be expected to increase prices. In the short run, the increase in production costs may outweigh the initial demand response, leading to reduced trade volumes. In the medium to long run, trade volumes may increase as the demand-side effect becomes more pronounced. On the other hand, VSS may reduce information asymmetries and transaction costs in supply chains and stimulate the adoption of Good Agricultural Practices (GAP), improving yields[20]. As more producers adopt VSS and accumulate experience, efficiency gains and economies of scale in certified production may reduce compliance costs. Such effects can partially or fully compensate for higher production costs and dampen or reverse the negative supply-side effect. An outward supply shift, combined with demand expansion, results in increased trade volumes and may reduce prices—especially when demand is rather price inelastic, as is the case for tropical commodities. While theoretical insights are ambiguous and empirical insights limited, a prevailing assumption in research and policy discussions is that VSS adoption leads to improved market access or expanded trade volumes as well as price premiums[22].

Empirical evidence is limited. A few country-level studies, focusing on a single VSS or crop, document a trade-enhancing effect, such as GlobalGAP certification in horticultural sectors and International Featured Standards (IFS) certification in processed food sectors increasing trade values[23–26]. Soybean certification has been associated with reduced trade values[19]. Only two studies examine multiple VSS across sectors, documenting heterogeneity in effects of certification across crops, with e.g., positive effects on trade values for banana and tea but not for cocoa, and across exporting regions[27,28]. Firm-level studies show mixed evidence: IFS and British Retail Consortium (BRC) certification improve exports and prices for French food processors[29], Fairtrade slightly improves prices for Costa Rican coffee traders[30], while no effects on export volumes or prices are found from a variety of VSS adopted by Peruvian horticultural exporters[31]. The absence of comprehensive and comparative evidence on VSS trade effects represents a gap in the current understanding of VSS as market-based tools for sustainability trading-up.

We present a comprehensive analysis of VSS trade outcomes, focusing on trade volumes and export prices, and integrating insights on VSS design to explain heterogeneity in estimated effects. The VSS design literature highlights diversity in requirements and procedures, and their relevance for understanding adoption and impact[9,32–36]. Building on conceptual insights[37], we construct VSS stringency scores for substantive and procedural stringency. The former refers to the sustainability requirements and criteria in VSS that adopters need to comply with, which we measure with an overall substantive stringency score and four sub-scores for stringency in environmental, social, ethical, managerial, and quality and safety dimensions of sustainability. Procedural stringency refers to the rules and procedures VSS use to ensure compliance with those substantive requirements, which we measure with an overall procedural stringency score and three sub-scores for the different mechanisms VSS use to enforce, reward or facilitate compliance: control, market-based incentives, and capacity-building. By incorporating these scores into a trade analysis, we show how VSS design moderates the trade effect of VSS adoption.

We additionally investigate the moderating effect of VSS coverage and VSS stringency on the trade-inhibiting effect of governance distance between trade partners. Governance distance refers to differences in governance institutions of countries, which we measure as the average difference in scores for the six dimensions of the World Governance Indicators—control of corruption, regulatory quality, government effectiveness, political stability, rule of law, and accountability—between an importing and an exporting country. Trade tends to decline if governance distance widens as institutional dissimilarities increase transaction and learning costs for traders and diminish trust[38], and evidence from a recent study shows that GlobalGAP adoption can be trade-enhancing, particularly when the governance distance between trading partners is large[24]. We elaborate on these insights by investigating how VSS stringency moderates this relationship, assuming that more stringent VSS provide stronger, more credible, and internationally recognized instruments that can substitute for domestic governance weaknesses and thereby mitigate the trade-inhibiting effect of governance distance more effectively than less stringent VSS.

We estimate gravity models, including bilateral trade flows and an augmented trade-cost term, to analyze overall, commodity-, and VSS-specific trade volume and export price effects of VSS adoption. We thereby improve the understanding of whether VSS lead to trading-up in comparison with previous studies that focus solely on trade value, and on a single VSS or crop[23–26]. We focus on seven commodities and ten VSS, which represent the most certified agrifood sectors and the lion's share of certified area in these sectors[12]. We use data obtained through direct communication with VSS standard-setting and umbrella organizations to compile a country-level database of VSS coverage, measured as the share of certified area over total production area, for the period 2012-2020 (Fig. 1; Supplementary Figs. S1–S10 and Table S1). The sample includes 83 producing countries of the seven commodities, spread over Latin America, Africa, and Asia—of which 62 adopt VSS for at least one commodity in one year—and 149 importing countries. This sample covers nearly the universe of bilateral trade flows for the most certified agrifood commodities, leading to more general findings than in most of the literature on VSS trade effects.

In summary, this study investigates how VSS coverage, VSS stringency, and governance distance interact and shape bilateral trade volumes and export prices, using gravity estimations across seven commodities, ten VSS, 83 exporting and 149 importing countries. It sheds light on the market- and trade-based mechanism behind VSS and provides empirical evidence to debates on their effectiveness and design. Findings are largely consistent with the theoretical expectation that VSS improve market access but challenge the common notion that VSS lead to price premiums for producing countries and to sustainability trading-up. We reflect on the significance of the findings in the VSS landscape.

Results

VSS are generally associated with increased trade volumes and reduced unit prices

Overall, certified acreage expanded from 8.71 million ha in 2012 to 17.50 million ha in 2020, with VSS coverage shares increasing across all commodities, except for coffee. Concurrently, commodity export volumes increased while total export value fluctuated slightly with a marked increase since 2020 (Supplementary Fig. S11). We estimate augmented gravity models on trade volumes and unit prices, derived from bilateral trade volume and value data, with unit prices calculated as values divided by volumes and reflecting average exporter prices. The augmented trade cost term includes VSS coverage variables—measured, across different model specifications, as the total, commodity-specific, or VSS-specific share of certified production area, as well as interactions with VSS stringency scores or with governance distance between trade partners. We use state-of-the-art estimation methods, including PPML (Poisson Pseudo-Maximum Likelihood), OLS (Ordinary Least Squares), IV-PPML (Instrumental Variable PPML), and 2SLS (two-stage least squares). We use a Lasso (Least Absolute Shrinkage and Selection Operator) approach for automated selection of the best-performing instrumental variables (IVSs) from a large set of possible IVs[39,40], as explained in "Methods." We estimate trade volume

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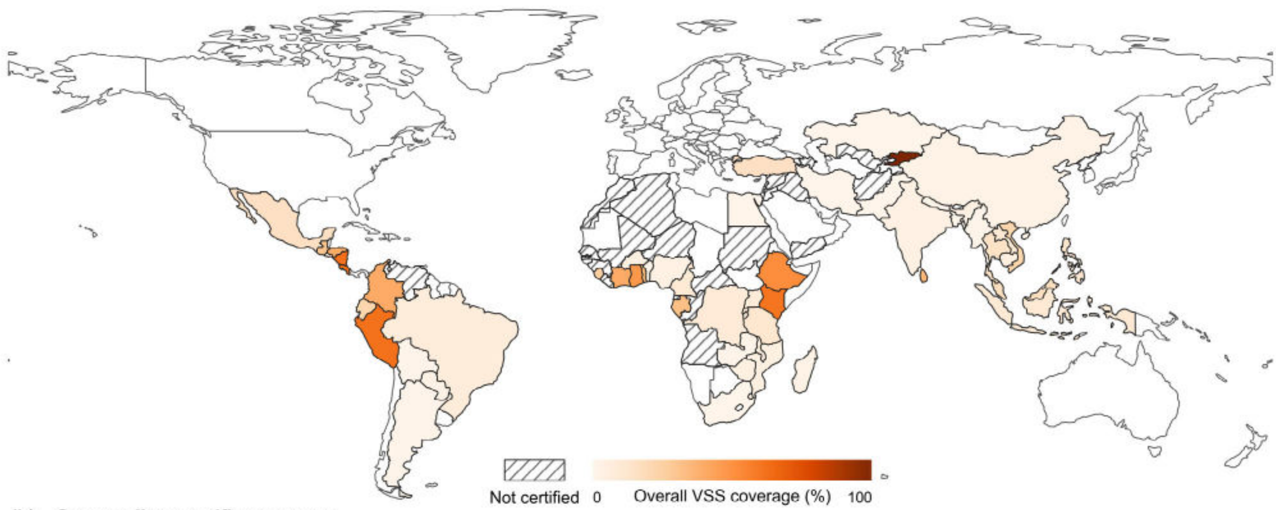
(a) VSS coverage - geographical spread



(b) Commodity-specific coverage

	Overall	Soy	Banana	Tea	Sugarcane	Coffee	Oil palm	Cocoa
# producing countries	83	63	68	36	67	52	63	67
# certified countries	62	25	19	29	28	36	19	27
Average VSS coverage (%)								
Producing countries	12.19 (25.37)	2.00 (10.86)	9.96 (25.75)	26.60 (34.64)	3.36 (11.44)	23.25 (29.84)	8.94 (20.36)	21.91 (30.34)
Certified countries	28.05 (32.20)	8.23 (20.88)	28.70 (37.10)	37.97 (35.79)	10.92 (18.55)	36.64 (30.21)	23.82 (27.42)	34.13 (31.90)

(c) VSS-specific coverage

	GlobalGAP	ProTerra	RA	4C	Bonsucro	Fairtrade	RSPO	IFOAM	UTZ	RTRS
# producing	68	73	74	52	67	77	37	83	58	63
# certified countries	21	13	37	26	15	29	16	57	36	6
Certifiable commodities										
Soy		×						×		×
Banana	×		×			×		×		
Tea			×			×		×	×	
Coffee			×	×		×		×	×	
Sugarcane		×			×	×		×		
Oil palm			×				×	×		
Cocoa			×			×		×	×	
Average VSS coverage (%)										
Producing countries	0.94 (6.92)	0.23 (3.56)	3.58 (16.68)	0.82 (4.67)	0.15 (1.66)	1.75 (7.40)	0.82 (6.52)	3.01 (11.51)	1.90 (8.90)	0.01 (0.14)
Certified countries	30.37 (25.55)	15.11 (25.23)	19.73 (26.73)	12.86 (13.78)	9.05 (9.17)	15.60 (16.55)	23.73 (26.30)	8.99 (18.51)	14.59 (20.60)	0.91 (0.77)

Fig. 1 | Geographical, commodity-specific, and VSS-specific VSS coverage. **a** Geographical spread of VSS coverage for seven agrifood commodities in 2020, presented as the share of certified production area averaged over the commodities produced in the country. **b** Overall and commodity-specific VSS coverage and **c** VSS-specific coverage for certifiable commodities, presented as average shares across countries and years (2012-2020) with standard deviations between brackets. Notes: Figures based on maximum certified production area, assuming no multiple certifications. Producing and certified countries include countries with non-zero production or non-zero certification, respectively, of a commodity (**b**) or group of certifiable commodities (**c**) in a given year. VSS voluntary sustainability standards, RA Rainforest Alliance, Fairtrade Fairtrade International, RSPO Roundtable on Sustainable Palm Oil, RTRS Round Table on Responsible Soy, IFOAM IFOAM Organics International (umbrella organization representing organic VSS).

effects using a full sample, including zero trade flows (N = 961,664) and reflecting total trade, and a non-zero sample, excluding zero trade flows (N = 120,800) and reflecting trade at the intensive margin (i.e., size of trade flows between trading countries). As unit values are only observed for non-zero trade flows, unit price effects are estimated only for the non-zero sample. The empirical strategy mitigates potential endogeneity bias—e.g., arising from countries' self-selection into certification based on unobservable variation that is correlated with trade outcomes—but does not allow for interpreting estimated effects as strictly causal. Results provide policy-relevant insights into the trade implications of VSS.

Estimates suggest that adoption of VSS, in general, enhances trade volumes while reducing export prices. Overall, a one percentage point (pp) increase in the share of certified production area in an exporting country is estimated to, on average, expand bilateral trade volumes by 1.17 to 2.24% (Fig. 2a) and reduce export unit prices by 0.11 to 0.52% (Fig. 2b). Estimates can be interpreted as elasticities and imply a rather strong and economic meaningful trade flow response to VSS adoption. For a large commodity-exporting country like Indonesia, e.g., this implies that a 10 pp increase in VSS coverage is associated with a 3.28 to 6.27 million tons of additional commodity exports, estimated based on 2021 aggregated export volumes of all product lines related to the seven commodities. Results are consistent across estimation methods, maintaining sign and significance, with only small differences in magnitude, indicating robust inference on positive trade volume and negative unit price effects of overall VSS coverage for the seven commodities. We observe no major differences in trade volume effects between full and non-zero samples, suggesting that VSS affect trade

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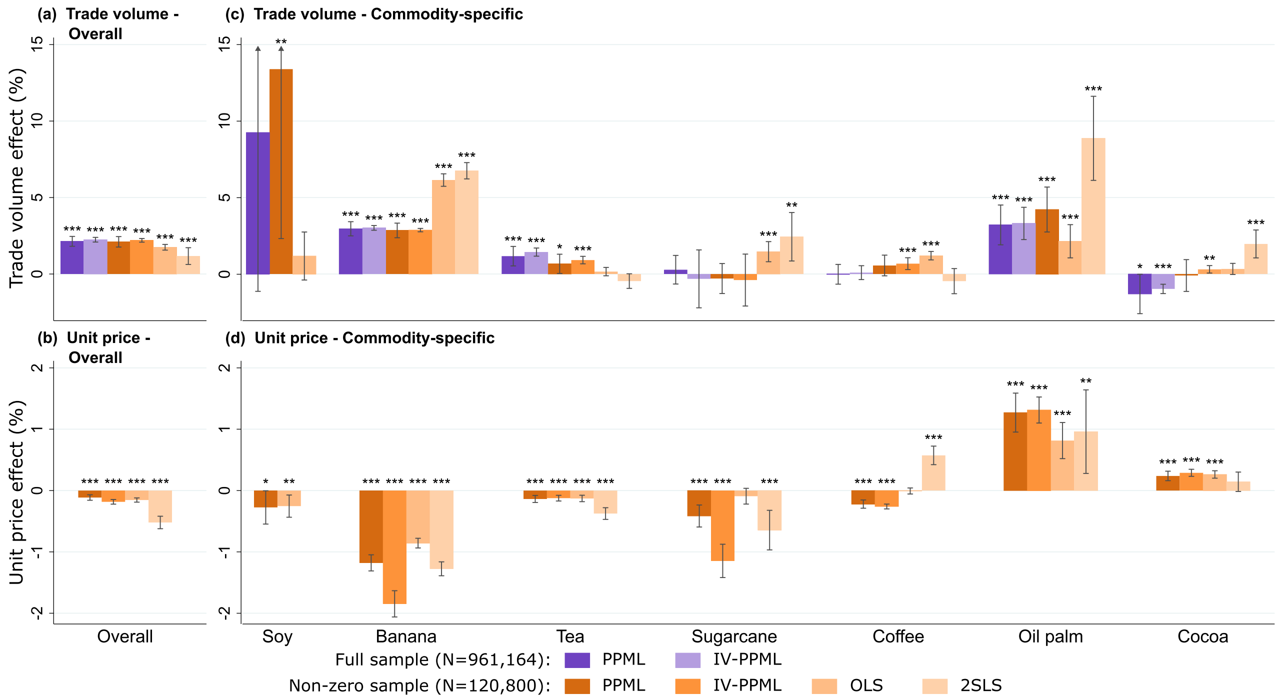

Fig. 2 | Estimated trade volume and unit price effects of overall and commodity-specific VSS coverage. a, b Estimated effects (%) of a one-percentage-point (pp) increase in overall certified production area on (**a**) trade volume and (**b**) unit price. **c, d** Estimated effects (%) of a one-pp increase in commodity-specific certified production area on (**c**) trade volume and (**d**) unit price. Notes: Bars indicate regression estimates derived from augmented gravity models at the exporter-importer-product-time level, and error bars present 90% confidence intervals. Trade volume effects (**a**, **c**) estimated for the full sample ($N = 961{,}664$ exporter-importer-product-time trade flow observations) using PPML and IV-PPML. Trade volume effects (**a**, **c**) and unit price effects (**b**, **d**) estimated for the non-zero sample ($N = 120{,}800$ exporter-importer-product-time trade flow observations) using PPML, IV-PMML, OLS, and 2SLS. Soy-specific IV-PPML and 2SLS and oil palm non-zero volume IV-PPML estimates could not be estimated. Significance is based on unadjusted two-sided *z*-tests (PPML, IV-PPML) or *t*-tests (OLS, 2SLS) and indicated as $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Regression results with exact *p*-values are reported in Supplementary Tables S2–S4. VSS voluntary sustainability standards, PPML Poisson pseudo-maximum likelihood, IV-PPML instrumental variable PPML, OLS ordinary least squares, 2SLS two-stage least squares.

primarily at the intensive margin, through intensifying existing bilateral trade flows.

Heterogeneous trade effects across VSS and commodities: two patterns

Estimated trade volume and unit price effects of VSS adoption are heterogeneous across commodities and VSS (Figs. 2 and 3). Volume effects are positive for most commodities and VSS, with IV-PPML estimates ranging from around +3% for banana and palm oil to between +0.91 and +1.41% for tea, coffee, and cocoa (Fig. 2c), and from around +3 to +4% for GlobalGAP, ProTerra; and RSPO to around +1.7% for RA and 4 C (Fig. 3a). Trade volume effects for specific commodities and VSS mainly manifest at the intensive margin—in some cases, estimates are zero or negative in the full sample but positive in the non-zero sample, as for coffee, cocoa and 4C. An exception is IFOAM, where volume effects are only significant in the full sample and not in the non-zero sample, suggesting effects at the extensive margin and the potential of organic certification to create new bilateral trade flows. Estimated volume effects are partially zero or negative and less consistent across estimation methods for sugarcane, Bonsucro, Fairtrade, and UTZ. Estimates for soy are large but partially insignificant. Slightly larger trade volume estimates under OLS compared to PPML in some cases (e.g., banana, sugarcane, and GlobalGAP) may reflect heteroskedasticity issues in OLS, reinforcing a preference for PPML estimation.

Unit price effects are negative for most commodities, with IV-PPML estimates ranging from −1.8% for banana and −1.2% for sugarcane to −0.12% for tea, but consistently positive for oil palm (+ 1.3%) and cocoa (+ 0.29%) (Fig. 2d). Across VSS, we find negative unit price effects for GlobalGAP, ProTerra, RA, 4C, and Bonsucro, with IV-PPML estimates ranging from −4.0% to −0.18%, and positive effects ranging from +1.4% to +0.61% for RSPO, IFOAM, and UTZ (Fig. 3b). Estimated unit price effects are less consistent across estimation methods for coffee and Fairtrade. IV models yield more negative unit price estimates in several cases (e.g., banana, sugarcane, GlobalGAP, ProTerra, and RA)—this is consistent with Herzfeld and co-authors[41], who note that countries with stronger trade performance are more likely to select into certification. This indicates the presence of endogeneity bias and reinforces the credibility of the IV estimates, while the similarity between IV-PPML and other estimates suggests limited bias from incidental parameters in IV-PPML results.

These estimated elasticities imply economically meaningful trade responses to VSS coverage in specific sectors. For instance, estimated based on 2021 export volumes and prices: For Ecuador, the largest banana exporting country, a 10 pp increase in VSS coverage is associated with an additional 2.2 million tons of banana exports and a price decrease of 91.8 USD/tons. For Indonesia, the second largest palm oil exporter, a 10 pp increase in VSS coverage is estimated to lead to an additional 7.9 million tons of palm oil exports and a price increase of 140 USD/tons. For Sri Lanka, the second largest tea exporter, a 10 pp increase in VSS coverage is associated with an additional 25.6 to 39.7 thousand tons of tea exports and a price decrease of 57 USD/tons.

Taken together, two broad patterns emerge. First, VSS coverage is associated with positive price effects and mostly positive volume effects (oil palm, cocoa, RSPO, IFOAM, and UTZ). Second, price effects are negative while trade volume effects are mostly positive (banana, tea, GlobalGAP, ProTerra, RA, and 4C). These patterns suggest that VSS may either support sustainability trading-up through price premiums or facilitate trade expansion through lower export prices, depending on the commodity and the specific VSS. Fairtrade, a multi-commodity

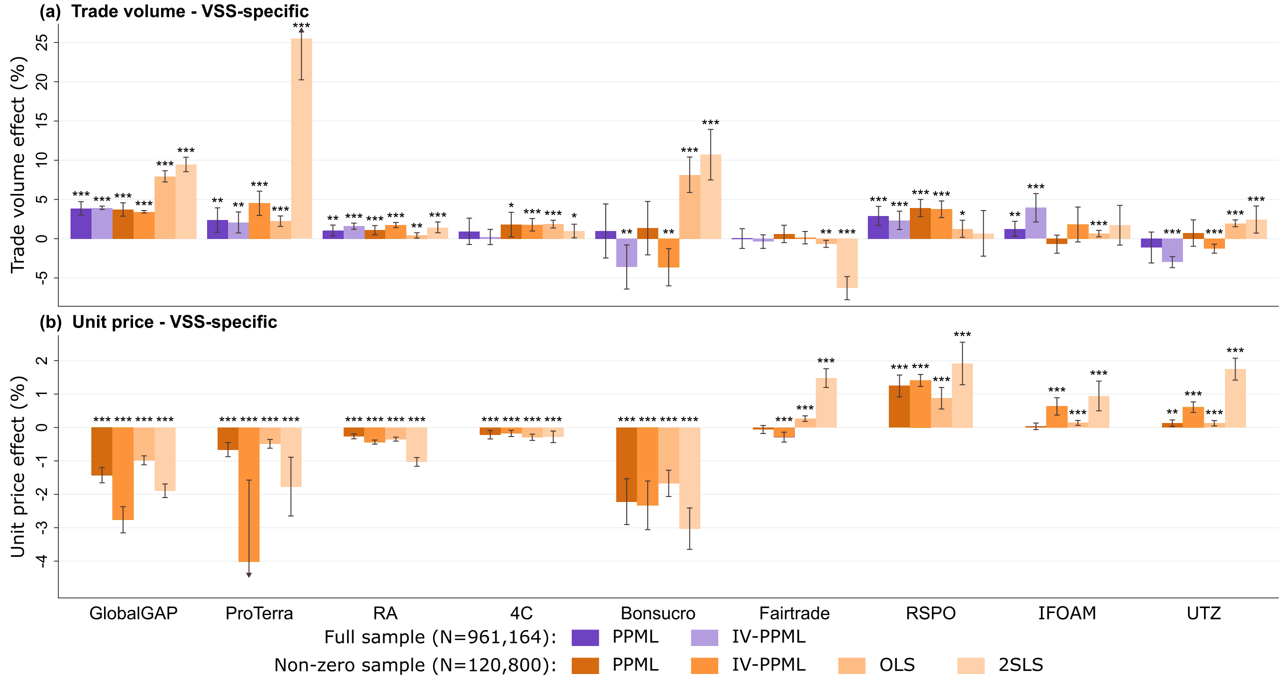

Fig. 3 | Estimated trade volume and unit price effects of VSS-specific coverage. **a**, **b** Estimated effects (%) of a one-percentage-point (pp) increase in VSS-specific certified production area on (**a**) trade volume and (**b**) unit price. Notes: Bars indicate regression estimates derived from augmented gravity models at the exporter-importer-product-time level, and error bars present 90% confidence interval. Trade volume effects (**a**) estimated for the full sample ($N = 961{,}664$ exporter-importer-product-time trade flow observations) using PPML and IV-PPML, and trade volume effects (**a**) and unit price effects (**b**) estimated for the non-zero sample ($N = 120{,}800$ exporter-importer-product-time trade flow observations) using PPML, IV-PMML, OLS, and 2SLS. ProTerra full-sample IV-PPML volume effects could not be estimated. Significance is based on unadjusted two-sided z-tests (PPML, IV-PPML) or t-tests (OLS, 2SLS) and indicated as $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Regression results with exact p-values are reported in Supplementary Tables S5–S7. VSS voluntary sustainability standards, RA Rainforest Alliance, Fairtrade Fairtrade International, RSPO Roundtable on Sustainable Palm Oil, IFOAM IFOAM Organics International, PPML Poisson pseudo-maximum likelihood, IV-PPML instrumental variable PPML, OLS ordinary least squares, 2SLS two-stage least squares.

VSS, does not clearly fit into one of these patterns due to inconsistent estimates of unit price effects. However, commodity-specific estimations for Fairtrade (Supplementary Tables S8 and S9) reveal results that corroborate the emergence of two distinct patterns: for banana, Fairtrade coverage is associated with positive volume and negative price effects, whereas for tea, sugarcane, coffee, and cocoa, it shows positive price effects and zero to negative volume effects.

Substantive and procedural design stringency moderates VSS trade effects

VSS vary in both substantive and procedural stringency. Substantive stringency relates to the content of VSS requirements along four sustainability dimensions (Fig. 4a; Supplementary Table S10 and Supplementary Data 1). Environmental sustainability requirements cover aspects such as soil quality, forest and biodiversity conservation, energy and water use, waste management, greenhouse gas emissions, and climate change. Social sustainability relates to human rights and labor conditions, e.g., child or forced labor, fair wages, discrimination, working hours, and training, as well as to engagement with local communities and vulnerable groups. Ethical and managerial requirements include criteria on, e.g., fair competition, living income, traceability, and recordkeeping. The last dimension relates to management, documentation, and testing of quality and safety aspects. Generally, VSS are more stringent on environmental sustainability requirements than on social and ethical and managerial requirements, and least stringent on quality and safety aspects (Fig. 4a). ProTerra is the most stringent VSS, especially on environmental and social requirements, followed by RSPO, which is particularly stringent on social and ethical and managerial dimensions, and UTZ, which is rather stringent across the four dimensions. GlobalGAP stands out for its stringency on product quality and safety and its relative neglect of social and ethical and managerial dimensions.

Procedural stringency relates to three mechanisms VSS use to ensure compliance with substantive requirements and their related rules and procedures (Fig. 4b; Supplementary Table S11 and Supplementary Data 1): through control (e.g., audits, sanctions, dispute settlement), market-based incentives (e.g., price premiums, minimum price), and capacity-building (e.g., training, technical and financial assistance). Capacity-building and control mechanisms are, in general, more used than market-based incentives (Fig. 4b). Fairtrade, RSPO, and RA are the most stringent VSS on procedural aspects. In Africa, it is less common for producing countries to adopt VSS, while those that do adopt less stringent VSS than in Latin America and Asia (Figs. 1a and 4c, d).

VSS design matters for trade and partially explains observed differences in VSS-specific trade effects. Some more stringent VSS, such as RSPO and Fairtrade, have positive unit price effects, while some less stringent VSS, such as GlobalGAP, have larger trade volume effects but negative unit price effects (Fig. 3a, b). Analyzing this more formally through interaction terms in the gravity models on overall VSS coverage, we find that overall substantive stringency does not moderate the observed trade volume-enhancing effect of VSS coverage (Fig. 5a) but weakens, or even reverses, the estimated price-reducing effect (Fig. 5b). Estimates suggest that a 10 pp increase in VSS coverage is associated with a 1.4% decrease in export price for VSS with an average substantive stringency, but with a 1.2% increase in export price for VSS which substantive stringency is one standard deviation above the average. These moderating effects vary over the four sustainability dimensions. The estimated trade volume-enhancing effects of VSS coverage are larger for VSS with more stringent quality and safety

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(a) Substantive stringency

	Overall	Sustainability dimensions: Environ-mental	Social	Ethical & managerial	Quality & safety
ProTerra	0.32	0.52	0.42	0.27	0.08
RSPO	0.29	0.32	0.41	0.37	0.07
UTZ	0.29	0.37	0.32	0.25	0.24
4C	0.24	0.34	0.36	0.24	0.02
IFOAM	0.24	0.48	0.22	0.18	0.08
Fairtrade	0.22	0.27	0.30	0.30	0.01
RTRS	0.22	0.35	0.32	0.19	0.03
RA	0.22	0.36	0.30	0.20	0.03
GlobalGAP	0.18	0.24	0.07	0.06	0.37
Bonsucro	0.16	0.19	0.21	0.16	0.04

(b) Procedural stringency

	Overall	Compliance mechanisms: Control	Market-based incentives	Capacity-building
Fairtrade	0.76	0.83	0.60	0.86
RSPO	0.71	0.93	0.20	1.00
RA	0.64	0.86	0.20	0.86
Bonsucro	0.61	0.86	0.40	0.57
RTRS	0.60	0.82	0.40	0.57
UTZ	0.55	0.86	0.30	0.50
GlobalGAP	0.55	0.82	0.40	0.43
4C	0.51	0.67	0.30	0.57
ProTerra	0.50	0.71	0.20	0.57
IFOAM	0.45	0.79	0.20	0.36

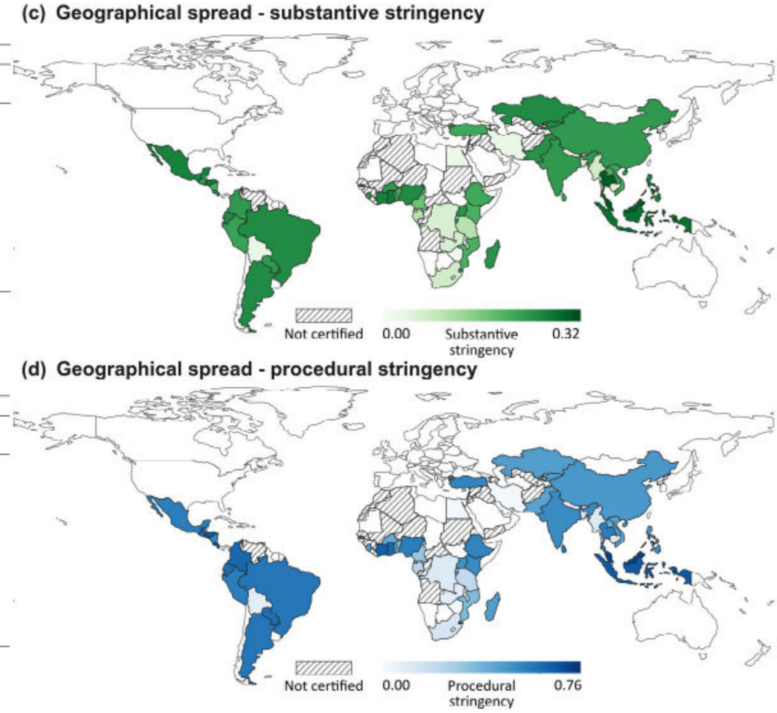

Fig. 4 | VSS stringency scores and geographical coverage of VSS by stringency. **a** Substantive VSS stringency, overall scores and specific scores for four sustainability dimensions. **b** Procedural VSS stringency, overall scores and specific scores for three compliance mechanisms. **c**, **d** Geographical spread of VSS adoption by (**c**) substantive stringency and (**d**) procedural stringency in 2020, averaged over VSS and commodities. Notes: Substantive stringency score is a weighted composite index of 598 sustainability requirements (166 environmental, 196 social, 78 ethical and managerial, 158 quality and safety), weighted by how explicit and critical the requirement is in a VSS. The procedural stringency score is a composite index of 26 compliance attributes (14 control, 5 market-based incentives, 7 capacity-building). Scores theoretically range from 0 to 1. VSS voluntary sustainability standards, RA Rainforest Alliance, Fairtrade Fairtrade International, RSPO Roundtable on Sustainable Palm Oil, RTRS Round Table on Responsible Soy, IFOAM IFOAM Organics International.

requirements and smaller for VSS with more stringent ethical and managerial requirements (Fig. 5c). The negative price effect of VSS coverage reverses for VSS with above-average stringency in environmental and ethical and managerial requirements (Fig. 5d): Estimates indicate that a 10 pp increase in VSS coverage is associated with a 1.5% and 3.6% increase in export price for VSS which environmental and ethical and managerial stringency, respectively, is one standard deviation above the average. Overall procedural stringency strongly reduces the observed positive trade volume effect of VSS coverage (Fig. 5a) but does not moderate the price effect (Fig. 5b). Procedural stringency through market-based incentives and through capacity-building reduces the trade volume-enhancing effect (Fig. 5e), while stringency through control mechanisms weakens, or even reverses, the price-reducing effect (Fig. 5f). Moderated price effects are less strong for procedural stringency than for substantive stringency.

The moderated trade volume effects reported in Fig. 5 are derived from the full sample and are largely consistent with estimates from the sample of non-zero trade flows (Supplementary Tables S12 and S13, columns 3 and 4), suggesting that observed effects mainly manifest at the intensive trade margin. Yet, when excluding zero trade flows, the moderating effect of stringency in the social dimension is significantly positive (Supplementary Table S12, column 4) and estimated moderation effects of procedural stringency and the three compliance mechanisms are somewhat smaller in magnitude (Supplementary Table S13, columns 3 and 4).

VSS tend to mitigate the impact of governance distance on trade

Trade partners vary with respect to governance strength or institutional quality, which constitutes a barrier for trade since trade between countries diminishes as governance distance increases[42]. We find that the estimated trade volume-enhancing effect of VSS coverage increases with the importer-exporter governance distance (Table 1, column 1), implying that VSS adoption is associated with the mitigation of the trade-inhibiting effect of governance distance between trade partners. However, this effect diminishes for VSS with above-average procedural stringency (Table1, column 2)—but does not change with substantive stringency (Table 1, column 3)—which suggests that only VSS with less stringent compliance procedures tend to mitigate the impact of governance distance as a trade barrier. We find that the negative price effect of VSS coverage dampens with the governance distance between trade partners (Table 1, column 4). Above-average substantive and procedural stringency of VSS diminishes their price-reducing effect, but this is less the case when the governance distance between trade partners is larger (Table 1, columns 5 and 6).

Discussion

This study documents and explains the heterogeneity in the trade effects of VSS. While findings confirm the trade-enhancing effect of GlobalGAP and other VSS estimated in previous studies[23–25,27], they show that this cannot be generalized and is mostly driven by trade volume increases rather than price increases. In general, and across most commodities and VSS, trade volumes increase with VSS coverage, which is mostly driven by expansion at the intensive margin—except for IFOAM, which appears to promote bilateral trade expansion at the extensive margin. In general, VSS adoption in tropical commodity sectors is associated with lower export prices, although price effects vary in direction and magnitude across commodities and VSS. The findings challenge the prevailing assumptions to some extent: While VSS adoption most often improves market access and expands trade volumes—yet not consistently for all commodities and VSS—it

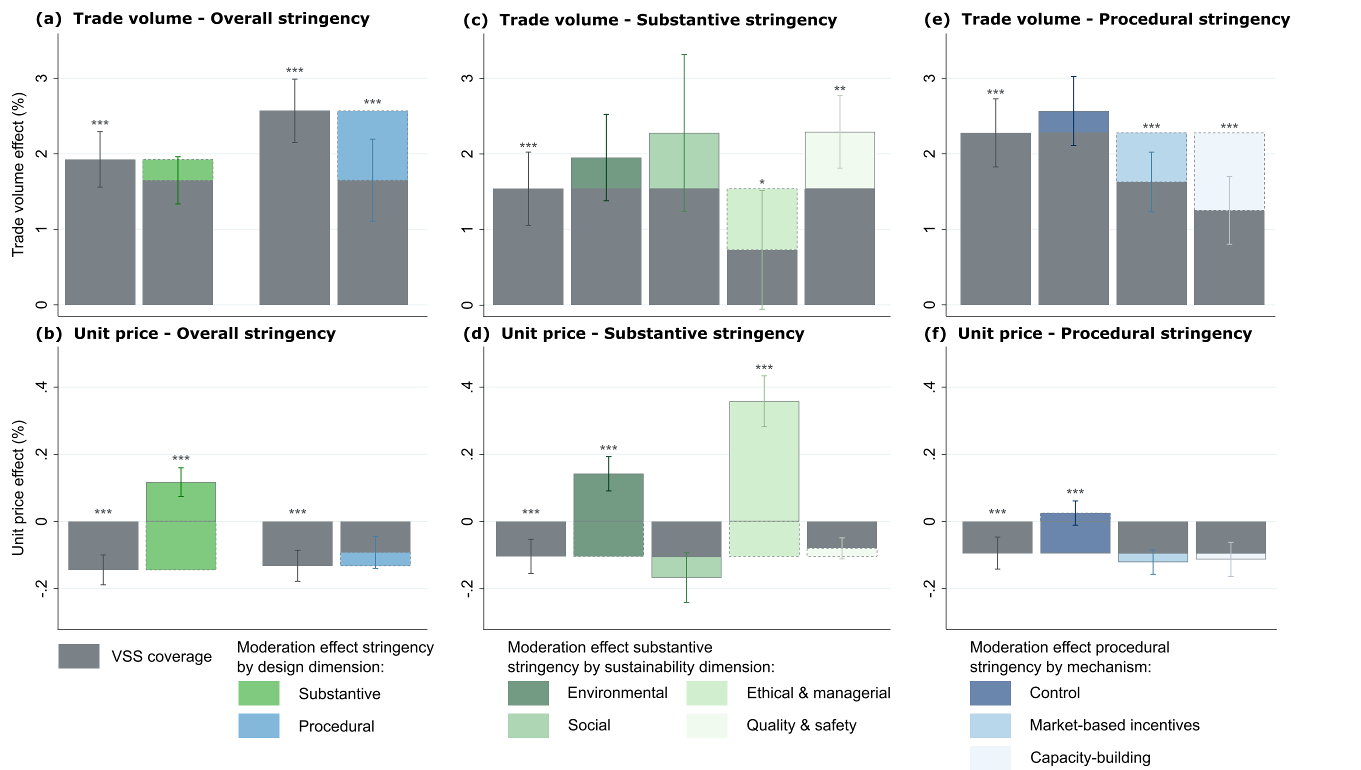

Fig. 5 | Estimated moderation effects from VSS stringency on trade volume and unit price effects of VSS coverage. **a**, **c**, **e** Estimated trade volume effects (%) of a one-percentage-point (pp) increase in certified production area moderated by (**a**) overall substantive and procedural VSS stringency, (**c**) substantive stringency dimensions, and (**e**) procedural stringency mechanisms. **b**, **d**, **f** Estimated unit price effects (%) of a one-pp increase in certified production area moderated by (**b**) overall substantive and procedural VSS stringency, (**d**) substantive stringency dimensions, and (**f**) procedural stringency mechanisms. Notes: Bars indicate regression estimates derived from augmented gravity models at the exporter-importer-product-time level, and error bars present 90% confidence interval. Trade volume effects estimated using PPML for the full sample ($N = 961{,}664$ exporter-importer-product-time trade flow observations) (**a**, **c**, **e**). Unit price effect estimated using PPML for the non-zero sample ($N = 120{,}800$ exporter-importer-product-time trade flow observations) (**b**, **d**, **f**). Main effect VSS coverage: trade volume or unit price effect of a one-pp increase in certified production area with commodity- and VSS-average VSS stringency. Moderation effect stringency: change in main effect from a one-standard-deviation change in stringency scores. Significance is based on unadjusted two-sided z-tests and indicated as ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Regression results with exact p-values are reported in Supplementary Tables S12 and S13. VSS voluntary sustainability standards, PPML Poisson pseudo-maximum likelihood.

does not necessarily result in price premiums, implying that VSS do not always lead to sustainability trading-up.

Trade effects exhibit two broad patterns across commodities and VSS (Table 2). A first pattern appears in the oil palm and cocoa sectors, and for RSPO, IFOAM, and UTZ, where positive price effects occur in combination with mostly positive but sometimes zero-to-negative volume effects. Similar effects are observed for Fairtrade in the tea, coffee, cocoa, and sugarcane sectors. These results are broadly consistent with prevailing theoretical expectations, suggesting an inward supply shift due to increased production costs associated with VSS compliance, alongside an outward demand shift driven by consumer willingness to pay for certified produce. In the oil palm sector, and for RSPO and IFOAM, demand-side effects appear to dominate, resulting in both higher prices and increased trade volumes. In the cocoa sector and for UTZ and Fairtrade, weaker or negative volume effects suggest that increased production costs and inward supply shifts may partially offset demand-driven trade expansion. This pattern aligns with VSS that have above-average stringency in environmental, ethical, and managerial requirements and in control of compliance—factors likely contributing to sustainability outcomes. Overall, these findings indicate that certification coverage for these VSS, and in these sectors, is associated with price premiums and sustainability trading-up.

A second pattern emerges in the soy, banana, tea, sugarcane, and coffee sectors, and for GlobalGAP, ProTerra, RA, 4C, and Bonsucro, where negative price effects coincide with positive trade volume effects – although for sugarcane and Bonsucro, estimated volume effects are less consistent, and for coffee, both unit price and volume effects are less consistent. Fairtrade in the banana sector exhibits a similar pattern. These findings do not align with the prevailing assumption of price premiums in certified markets. Possible explanations relate to efficiency gains, yield improvements, and reduced transaction costs. On the supply side, efficiency gains may lower the cost of supplying certified produce. As VSS coverage expands in a country or region, economies of scale may reduce certification and compliance costs, e.g., through shared infrastructure for auditing, bulk sourcing of higher-quality inputs or learning effects between certified producers. Moreover, VSS emphasizing GAP (e.g., GlobalGAP) may contribute to yield improvements. When the cost implications of VSS adoption are minimal—e.g., due to lenient requirements, requirements already met pre-certification, weak enforcement of compliance, donor-funded certification schemes, or long-term learning effects—yield gains could expand supply, resulting in increased trade volumes and lower prices. VSS adoption may also be associated with vertical coordination and lower transaction costs along supply chains. Producer-level impact studies confirm yield improvements and cost reductions from VSS adoption, though with variation across commodities and VSS[43–45]. Review studies validate potential cost-reduction effects but caution against generalization[13,15].

Alternatively, this second pattern may be explained by price competition and over-certification. Expanding VSS coverage may

Table 1 | Trade volume and unit price effects of VSS coverage, moderated by exporter-importer governance distance and VSS substantive and procedural stringency

	Trade volume effect			Unit price effect		
	(1)	(2)	(3)	(4)	(5)	(6)
VSS_{ikt-1}	0.0141*** (0.0025)	0.0167*** (0.0033)	0.0127*** (0.0030)	−0.0020*** (0.0004)	−0.0031*** (0.0004)	−0.0027*** (0.0004)
VSS_{ikt-1} ×						
Governance $distance_{ijt}$	0.0078*** (0.0019)	0.0111*** (0.0024)	0.0062*** (0.0023)	0.0009*** (0.0003)	0.0017*** (0.0003)	0.0011*** (0.0003)
Procedural $stringency_{ikt-1}$		-0.0057 (0.0037)			0.0017*** (0.0004)	
Substantive $stringency_{ikt-1}$			−0.0013 (0.0023)			0.0036*** (0.0003)
VSS_{ikt-1} × Governance $distance_{ijt}$ ×						
Procedural $stringency_{ikt-1}$		−0.0073*** (0.0025)			−0.0013*** (0.0002)	
Substantive $stringency_{ikt-1}$			−0.0021 (0.0016)			−0.0015*** (0.0002)
Observations	955,861	955,861	955,861	120,382	120,382	120,382

Notes: Estimated trade volume effect (columns 1 to 3) and unit price effect (columns 4 to 6) moderated by governance distance and by overall substantive and procedural VSS stringency. Estimates derived from augmented gravity models at the exporter(i)-importer(j)-product(k)-time(t) level, estimated using PPML on the full sample (N = 955,861 exporter-importer-product-time trade flow observations) for trade volume effects and the non-zero sample (N = 120,382 exporter-importer-product-time trade flow observations) for unit price effects. All estimations include bilateral, importer-time, exporter-time, and product-time fixed effects. Robust exporter-importer-product standard errors in parentheses. Significance tested with unadjusted two-sided z-test and indicated as ***$p < 0.01$. Regression results with exact p-values are reported in Supplementary Table S14.
VSS voluntary sustainability standards, *PPML* Poisson pseudo-maximum likelihood.

Table 2 | Summary of results with two emerging patterns of VSS trade effects

	Sustainability trading-up	Market access and price competition
Estimated trade effects of VSS coverage	↑ trade volumes ↑ export price	↑ trade volumes ↓ export price
Heterogeneity across commodities and VSS		
Commodities	oil palm, cocoa[a]	banana, tea, soy, sugarcane[a]
VSS	RSPO, IFOAM, UTZ[a]	GlobalGAP, ProTerra, RA, 4C, Bonsucro[a]
VSS – commodities	Fairtrade tea, sugarcane, coffee, cocoa	Fairtrade banana
VSS design matters		
VSS stringency	More stringent VSS	less stringent VSS
Substantive stringency (requirements)	More stringent environmental, ethical and managerial requirements	
Procedural stringency (compliance procedures)	More stringent control and enforcement	

VSS Voluntary Sustainability Standards, *RA* Rainforest Alliance, *Fairtrade* Fairtrade International, *RSPO* Roundtable on Sustainable Palm Oil, *IFOAM* IFOAM Organics International (umbrella organization representing organic VSS).
[a]For cocoa, sugarcane, UTZ, and Bonsucro, estimated export volume effects are less consistent.

intensify competition within certified markets. Larger producers may be able to absorb certification and compliance costs and spread them over larger (certified and non-certified) production volumes, enhancing price competitiveness. By offering certified produce at lower prices, they can protect or expand market shares. In addition, large processors or retailers may leverage increasing VSS coverage to push suppliers toward lower prices and demand certification as a baseline rather than a premium. This may erode price premiums for producers and producing countries and shift value capture more downstream and towards importing countries. On the demand side, growth in demand for certified agrifood products may lag behind growth in supply[12,14], such that price premiums from consumer willingness to pay for certified produce may be eroded through over-certification – this is empirically observed in some cases[30,46].

This second pattern, with price-reducing and volume-increasing effects, occurs under VSS that have an average or below-average stringency in both substantive requirements and compliance procedures. When efficiency drives lower prices, sustainability trading up would not necessarily be undermined, as lower costs and prices would further increase producer adoption of VSS as well as consumer demand for certified produce. Yet, because these effects occur for less stringent VSS, lower costs and prices are more likely associated with easier-to-adopt requirements and more limited sustainability gains. Notably, this second pattern is most evident in sectors where export production is dominated by large-scale commercial production (e.g., banana) or by mixed systems (e.g., tea, soy, and sugarcane) rather than by smallholders, and for business-to-business (B2B) VSS (e.g., GlobalGAP, ProTerra, 4 C, Bonsucro) as opposed to consumer-facing VSS, which increases the likelihood of price-based competition in certification. Overall, the observed pattern of trade effects for these VSS and in these sectors points to increased competition in tropical commodity trade, rather than to a process of sustainability trading-up.

Estimation results reveal that heterogeneity in trade effects can be partially explained by differences in VSS stringency. VSS with an average or below-average stringency in requirements and compliance procedures lead to increased trade volumes and improved market access, but they result in lower unit prices and appear to increase competition in tropical commodity sectors. Only VSS that are more stringent in environmental or ethical and managerial requirements or with more stringent control of compliance result in positive price effects. Such VSS are for producers more difficult and more costly to comply with, but create larger demand effects. Stringency in the social dimension does not moderate trade effects, which may relate to social sustainability being valued less in international markets. Piracci and coauthors[47] confirm that consumers are less willing to pay for social sustainability than for environmental sustainability. A higher stringency in quality and safety requirements leads to larger trade volumes but is not rewarded through premium prices. VSS that strongly enforce compliance through market-based incentives and capacity-building create smaller trade gains – yet, such VSS are more easily adopted[33,37]. Positive enforcement through market incentives and capacity-building versus negative enforcement through control entails a trade-off between ease of adoption and trade facilitation[48,49]. Results also confirm that VSS adoption might mitigate the trade-inhibiting effect of governance distance between trade partners[25,27] and show that especially VSS with less stringent compliance procedures can facilitate exports from producing countries with a weaker governance capacity to importing countries with a stronger capacity.

Results show that VSS coverage is generally associated with higher trade volumes and exporter prices that may increase or decrease, suggesting that exporting countries share in the benefits of certification through improved market access but not necessarily through price premiums. These price effects estimated at the exporter level do not necessarily entail implications for the further distributional consequences of VSS along supply chains or towards farmers. Positive export price effects estimated for RSPO, IFOAM, UTZ, and Fairtrade would not necessarily translate into positive effects on producer prices, as the value distribution in commodity value chains may be skewed and rents from certification may be extracted in post-farm stages of the value chain[50,51]. Our results are to some extent in line with heterogeneous findings from farm-level case-studies, documenting that VSS adoption in some cases relates to higher farm-gate prices for certified produce—e.g., for Fairtrade certification in the coffee sector in Costa Rica[30] and Uganda[45] and for IFAOM and GlobalGAP certification in Peru[43]—and in other cases to zero or even negative effects on farm-gate prices—e.g., UTZ certification in the coffee sector in Uganda[45] and Fairtrade certification in Peru[43]. Review studies and meta-analyses point to general positive effects of VSS adoption on farm-gate prices[13,15] but included case-studies are biased towards Fairtrade and IFOAM, while our results suggest that producer price effects may critically depend on the design stringency of VSS.

In summary, VSS do entail the potential for sustainability trading-up, but this is not fully realized for all main VSS in tropical commodity sectors. Adoption of VSS in these sectors largely improves market access and enhances bilateral trade at the intensive margin, but only the most environmentally, ethically and managerially strict VSS for which compliance is enforced through strong control mechanisms lead to price premiums and sustainability trading-up. There is no general empirical validity for the common assumption in much of the literature that adoption of VSS leads to premium prices for producing countries. Only some VSS—RSPO, IFOAM, UTZ, and Fairtrade—present evidence for creating higher-value markets and leading to sustainability trading-up, whereas other VSS appear to exacerbate price competition in global agrifood markets. Less stringent VSS may benefit consumers and importing countries more than producers and exporting countries, and may yield fewer sustainability impacts. Yet, stimulating the adoption of such VSS in countries with weak governance capacity (e.g., in Africa) through continued donor investments, corporate efforts, and integration of VSS in government export promotion and private sector development policies might expand trade with these countries. This study reveals varying trade effects among VSS and confirms the importance of VSS institutional design, triggering reflection on the objectives and theory of change of VSS. Realizing the potential for sustainability trading-up through VSS requires prioritizing strict requirements, strong enforcement, and stimulating demand for sustainability-certified produce—rather than relaxing requirements or weakly enforcing them to expand the market share of VSS.

While this study, based on an extended sample covering ten VSS for seven agrifood commodities and all bilateral trade flows for these commodities, is unique in the literature, it is not without data and methodological limitations. Multiple certifications of the same area can be substantial for some VSS combinations in some sectors and might be used strategically by companies to flexibly adapt to market demand[14,52]. A lack of complete data on multiple certifications prompted us to rely on maximum and minimum VSS coverage, assuming either full or no overlap in certification. While results are robust to these specifications, the relation between VSS coverage and trade may not be monotonic, and trade effects estimated with true VSS coverage data could deviate. Systematic data on VSS coverage could only be compiled for the period 2012-2020, covering a period of important growth in VSS acreage, but not the early VSS expansion in the early 2000s. Data on certified trade volumes (and values) is lacking, implying that we cannot disentangle compositional changes of certified and non-certified volumes in bilateral trade flows from overall trade volume growth. Potential endogeneity bias limits causal inference, and the estimated trade effects of VSS coverage cannot be interpreted as strictly causal. While the empirical strategy—incorporating lagged VSS coverage variables, high-dimensional fixed effects, and a Lasso-based IV selection approach—mitigates endogeneity bias to a large extent, it cannot be ruled out completely. Remaining bias in the IV-based models may, e.g., stem from regional shocks that simultaneously affect a country's exports and VSS adoption in neighboring countries or from direct spillovers of VSS adoption in neighboring countries on a country's exports (e.g., reputational effects at the regional level). Given that tropical commodity trade is predominantly intercontinental, such biases may be relatively small.

Future research on VSS could build on the methods and findings in this study. Studies at national level could consider trade displacement effects—analyzing explicitly whether increased trade volumes associated with VSS are derived from expanded or newly created trade opportunities or from redirected export flows from uncertified to certified countries—and potential trade-offs between export growth and other sustainability outcomes for which national-level data are available, such as deforestation. To deepen understanding of supply-chain and distributional consequences of VSS, studies could apply similar methods and consider farm-gate as well as exporter prices. Such work could be complemented with subnational analyses conducted at a nationwide scale, building on recent evidence on the farm- and village-level development outcomes of RSPO certification in Indonesia[16,53–55] and commodity certification in Peru[43,56,57]. This requires disaggregated data on VSS coverage, either from nationally representative farm surveys or from geo-referenced sources, which are not yet systematically available for multiple VSS and countries. This study performs an innovative analysis of how VSS substantive and procedural stringency moderate trade effects. Further research in this direction could elaborate on how VSS design determines adoption and sustainability impacts, and how VSS interact with other regulatory factors and trade policies. We advocate for the continued integration of economic and governance studies to comprehend trade- and market-based sustainability tools.

Methods

VSS coverage data

We selected the most certified commodities based on 2023 statistics[58], excluding cotton as a non-food commodity. For the resulting seven commodities (soy, banana, tea, sugarcane, coffee, oil palm, and cocoa), active VSS were identified from the online Ecolabel Index and ITC Standards Map directories and all producing and exporting countries from FAOstat[59]. Company-owned or in-house VSS were excluded. A database on country-level VSS acreage coverage for the ten most relevant VSS for the period 2012-2020 was constructed based on information compiled through direct communication with identified VSS standard-setting and umbrella organizations. This data was combined with FAOstat production data[59] to calculate shares of VSS-specific certified production area at country-commodity-time and country-time levels. Shares above 100% (1.6% of data points) were adjusted to 100%. Shares of overall certified production area at country-commodity-time and country-time levels were calculated based on a simple aggregation of VSS-specific coverage shares, thereby representing maximum certified area coverage assuming no multiple certification.

VSS design and stringency scores

Based on a review of the literature[33–35,37,49], we identified two VSS institutional design aspects that are potentially relevant to trade performance. First, substantive design refers to the content and stringency of the requirements in VSS. VSS prescribe a range of criteria along different sustainability dimensions, including environmental sustainability criteria, social sustainability criteria, economic and managerial criteria, and product quality and safety criteria[33]. Second, procedural design refers to the rules and procedures VSS put in place to ensure compliance with the substantive requirements. VSS ensure compliance through three main mechanisms: by controlling compliance with requirements, by giving market-based incentives to comply, and by building capacity to comply[37]. Substantive and procedural design can affect trade.

We constructed substantive stringency scores for the ten selected VSS as a weighted composite index of individual sustainability criteria, including an overall score (SS) and a score for each of the four sustainability dimensions (SS_x), as follows:

$$SS = 1/4\left(SS_{EV} + SS_{SO} + SS_{EM} + SS_{QS}\right) \tag{1}$$

$$SS_x = \frac{\sum_{i=1}^{n_x} w_{xi} C_{xi}}{n_x} \text{ for } x \in \{EV, SO, EM, QS\} \tag{2}$$

in which EV stands for environmental, SO for social, EM for economic and managerial and QS for quality and safety. We derived all (598) individual sustainability criteria (C_i) applicable to the ten selected VSS and seven commodities from the ITC Standards Map and categorized them along the four sustainability dimensions with $n_{EV} = 166$, $n_{SO} = 196$, $n_{EM} = 78$, $n_{QS} = 158$. A simplified overview of the sustainability criteria per dimension is given in Supplementary Table S10, and the full list of criteria is provided in Supplementary Data 1. Criteria weights (w_i) were constructed to reflect the extent to which criteria are covered in a VSS, based on ITC Standards Map data on how critical and how explicit criteria are, with criticality being streamlined based on VSS compliance policies, retrieved from their respective policy documents. Weights range from $w_i = 0$ to $w_i = 1$ and are given in Supplementary Table S15 as well as in Supplementary Data 1. The overall substantive stringency score was calculated as the arithmetic mean of the scores for the four sustainability dimensions. All scores theoretically range from 0 to 1 with higher scores implying stricter sustainability requirements (Fig. 4a). Details of all VSS scores on substantive stringency (overall and for the four sustainability dimensions) can be found in Supplementary Data 1.

We derived procedural stringency scores for the ten selected VSS from Depoorter and Marx[37], who developed an analytic framework to score VSS along three procedural mechanisms for compliance. The derived scores are a composite index of procedural design attributes, including an overall score (*PS*) and a score for each of the three compliance mechanisms (PS_y), as follows:

$$PS = 1/3\left(PS_C + PS_{MI} + PS_{CB}\right) \tag{3}$$

$$PS_y = \frac{\sum_{i=1}^{n_y} A_{yi}}{n_y} \text{ for } y \in \{CM, MI, CB\} \tag{4}$$

in which CM stands for control mechanism, MI for market-based incentives, and CB for capacity-building. The scoring included 26 procedural attributes (A_i), distributed over the three mechanisms for compliance with $n_C = 14$, $n_{MI} = 5$, $n_{CB} = 7$. The original framework by Depoorter and Marx[37] includes six instead of five attributes for PS_{MI}. We dropped one attribute related to marketing, i.e., whether the VSS includes a product label to communicate to consumers (B2C) or not (B2B), as both cases can lead to enhanced compliance, yet through different mechanisms[60]. Data on procedural attributes were retrieved from VSS policy documents. Some procedural attributes were identified by two attribute levels, reflecting the absence or presence of the specific procedural attribute and scored $A_i = 0$ and $A_i = 1$, respectively. Most procedural attributes were identified by three attribute levels based on empirical cutoff values, reflecting absence, weaker presence, and stronger presence of the specific procedural attribute and scored $A_i = 0$, $A_i = 0.5$, and $A_i = 1$, respectively. One attribute, audit frequency, was identified as continuous and scored $A_i = a/c$, with a being the number of mandatory audits within a certification cycle and c being the length (in years) of the certification cycle. Supplementary Table S11 provides an overview of the compliance mechanisms and their attributes, and the full list of attributes and scoring guidance is provided in Supplementary Data 1. The overall procedural stringency score was calculated as the arithmetic mean of the scores for the three compliance mechanisms. All scores theoretically range from 0 to 1, with higher scores implying stronger procedures to foster compliance (Fig. 4b). Details of all VSS scores on procedural stringency (overall and for the three compliance mechanisms) can be found in Supplementary Data 1

All stringency scores were constructed based on the most recent VSS design (Supplementary Table S1)—except for RA and UTZ, which merged in 2020 and for which versions prior to merging were used—and are time-constant in the analysis.

Bilateral trade data

Bilateral trade data at the six-digit product level (Harmonized System Code HS6) for all product lines that correspond to raw or minimally processed food products derived from the seven commodities (Supplementary Table S16) and for the years 2013 to 2021 were compiled from the Base pour l'Analyze du Commerce International (BACI) database[61]. We included disaggregated trade data to avoid confounding trade effects with product composition effects, and raw or minimally processed food products to avoid capturing re-exports of products processed outside the producing country. Waste products were excluded because of their irrelevance to VSS. The sample of exporting countries for each commodity was restricted to non-European middle- and low-income producing countries to exclude non-informative zero flows and re-exports. Small Island Developing States (SIDS) were excluded as exporters and importers. All other countries are included as importers, although some were dropped due to a lack of data or due to the prevalence of singletons or fixed-effect separation amongst all observations. A full list of the 83 exporting and 149 importing countries in the sample can be found in Supplementary Table S17.

Export unit prices were calculated by dividing bilateral HS6 trade values by volumes and are only observed for non-zero trade flows. Working with disaggregated product-level data, these unit prices approximate the average Free-On-Board (FOB) prices received by exporters. Since such unit value calculations are susceptible to measurement errors in both export volumes and values, we excluded observations with unit values or unit value growth rates outside the 5th and 95th percentiles at the HS6 level. Resulting trade data include 961,664 trade flow observations (including zero trade flows, referred to as the full sample) and 120,800 unit price observations (excluding zero trade flows, referred to as the non-zero sample).

Gravity variables

Six-digit applied tariff data were derived from the United Nations Conference on Trade and Development (UNCTAD) Trade Analysis Information System (TRAINS). We followed Fernandes and co-authors[62] to impute missing tariff observations by first interpolating missing years and then replacing missing observations with importer-product-year Most Favored Nation (MFN) tariffs or bilateral-product-year preferential tariffs if available, or with average applied tariffs at the HS4- or HS2-level. We extended the imputation procedure by completing zero tariffs for cases when importer-product-year MFN or bilateral-product-year preferential tariffs at the HS4- or HS2-level are zero, followed by completing observed importer-product-year MFN or bilateral-product-year preferential tariffs when HS4- or HS2-level lines are invariable, and using nearest neighbor interpolation. Production volume data were derived from FAOstat, and information on trade agreements from Mario Larch's Regional Trade Agreements Database[63].

Governance distance

An indicator for governance distance between trading partners was constructed as the absolute difference in institutional capacity between the importing and exporting countries. Institutional capacity was calculated using the World Bank's Worldwide Governance Indicators (WGI), which assesses countries' institutional capacity in six dimensions (control of corruption, government effectiveness, political stability and absence of violence, rule of law, regulatory quality, and voice and accountability) on a −2.5 to +2.5 grading scale[64]. Since the six indicators are strongly correlated and sometimes argued to reflect broader institutional quality rather than distinct governance capacity dimensions[65], we calculated country-year-level governance capacity as the arithmetic mean of the WGI scores over the six dimensions. For ease of interpretation, institutional capacity scores were rescaled to a zero-to-five range before subtracting the exporter's score from the importer's score. The resulting bilateral governance distance indicator theoretically ranges from −5 to +5, with negative values indicating the exporter's institutional quality outperforms that of the importer and vice versa. WGI scores are unavailable for one country in our sample (Palestine). As a result, the sample size for model estimations, including governance distance, slightly reduces (Full sample: $N = 955{,}861$; Non-zero sample: $N = 120{,}382$).

Modeling framework

Consistent with the trade gravity framework, we specified a set of models at the product-exporter-importer-time level and augmented a traditional trade-cost term with vector Z_{ijlt-1}:

$$\ln\left(X_{ijkt}\right) = \delta + \alpha\, \mathrm{Z}_{\mathrm{ijlt-1}} + \beta_1\, \mathrm{RTA}_{\mathrm{ijt}} + \beta_2 \ln\left(1 + \mathrm{tariff}_{\mathrm{ijkt}}\right) + \beta_3 \ln\left(\mathrm{production}_{\mathrm{ilt}}\right) + \gamma_{ij} + \eta_{it} + \mu_{jt} + \nu_{tk} + \varepsilon_{ijkt} \tag{5}$$

The dependent variable X_{ijkt} is the volume or unit price of trade flows of product k from exporting country i to importing country j in year t. Independent variables include standard gravity variables: production volume of exporting country i for commodity l at four-digit level (or two-digit for cocoa) at time t ($\mathrm{production}_{\mathrm{ilt}}$); ad valorem tariffs for product k at time t ($\mathrm{tariff}_{\mathrm{ijkt}}$); and a binary variable indicating the existence of regional or bilateral trade agreements at time t ($\mathrm{RTA}_{\mathrm{ijt}}$). We included country-pair (γ_{ij}), exporter-time (η_{it}), importer-time (μ_{jt}), and product-time (ν_{kt}) fixed effects, which jointly control for time-invariant bilateral trade costs, multilateral resistance terms, and other exporter-, importer- and product-specific time-variant effects. ε_{ijkt} is the error-term. The trade-cost augmentation was specified in different ways in various models, either at exporter-commodity-time level $\mathrm{Z}_{\mathrm{ilt-1}}$ or at exporter-importer-commodity-time level $\mathrm{Z}_{\mathrm{ijlt-1}}$.

We estimated the overall, commodity-, and VSS-specific export volume and price effects of VSS coverage by defining $\mathrm{Z}_{\mathrm{ilt-1}}$ as specified in Eqs. (6) to (8), respectively.

$$\alpha Z_{ilt-1} = \alpha \mathrm{VSS}_{\mathrm{ilt-1}} \tag{6}$$

$$\alpha \mathrm{Z}_{\mathrm{ilt-1}} = \sum\nolimits_{l=1}^{7} \alpha_l \mathrm{VSS}_{\mathrm{ilt-1}} \times \mathrm{commodity}_{\mathrm{l}} \tag{7}$$

$$\alpha \mathrm{Z}_{\mathrm{ilt-1}} = \sum\nolimits_{n=1}^{10} \alpha_n \mathrm{VSS}_{\mathrm{ilt-1n}} \tag{8}$$

In Eq. (6), $\mathrm{VSS}_{\mathrm{ilt-1}}$ represents the one-year lagged annual share of commodity-specific certified production area in the exporter country and is calculated as the sum of the certified area for the ten VSS over the total production area of the respective commodity. The one-year lag was used to reduce endogeneity bias resulting mainly from reverse causality[41], which rests on the rationale that VSS coverage is strongly correlated over time and current export performance cannot influence past VSS adoption[66,67]. The estimated coefficient α can be interpreted as the percentage change in trade volume or unit price associated with a one percentage point (pp) increase in the share of certified production area in the exporting country. In Eq. (7), the VSS coverage variable $\mathrm{VSS}_{\mathrm{ilt-1}}$ is interacted with a categorical variable $\mathrm{commodity}_{\mathrm{l}}$, indicating commodity sector l. Hence, a vector of seven coefficients $\sum_{l=1}^{7}\alpha_l$ captures commodity-specific trade volume and unit price effects. In Eq. (8), $\mathrm{Z}_{\mathrm{ilt-1}}$ represents a vector of ten variables, measuring the share of commodity-specific certified production area for the ten VSS at exporter-time level. As fixed effects capture variation in country-level certification over time, commodity variation in certification coverage was exploited to estimate the vector of ten coefficients $\sum_{n=1}^{10}\alpha_n$, representing VSS-specific trade volume and unit price effects. Results for Eqs. (6) and (7) are summarized in Eq. 2, and for eq. (8) in Fig. 3. Full regression results are reported in Supplementary Tables S2–S7, respectively. RTRS certification, covering only six out of 63 soy-producing countries in the sample with a maximum coverage of three percent, was considered too small to yield meaningful results, and estimated coefficients for RTRS-coverage are therefore not reported in Fig. 3.

To assess how trade effects vary with the design of VSS, we estimated four different models in which $\mathrm{Z}_{\mathrm{ilt-1}}$ is defined as specified in Eqs. (9) to (12), respectively.

$$\alpha \mathrm{Z}_{\mathrm{ilt-1}} = \alpha \mathrm{VSS}_{\mathrm{ilt-1}} + \alpha' \mathrm{VSS}_{\mathrm{ilt-1}} \times \mathrm{SS}_{\mathrm{ilt-1}} \tag{9}$$

$$\alpha \mathrm{Z}_{\mathrm{ilt-1}} = \alpha \mathrm{VSS}_{\mathrm{ilt-1}} + \sum\nolimits_{x=1}^{4} \alpha'_x \mathrm{VSS}_{\mathrm{ilt-1}} \times \mathrm{SS}_{\mathrm{ilt-1x}} \tag{10}$$

$$\alpha \mathrm{Z}_{\mathrm{ilt-1}} = \alpha \mathrm{VSS}_{\mathrm{ilt-1}} + \alpha'' \mathrm{VSS}_{\mathrm{ilt-1}} \times \mathrm{PS}_{ilt-1} \tag{11}$$

$$\alpha \mathrm{Z}_{\mathrm{ilt-1}} = \alpha \mathrm{VSS}_{\mathrm{ilt-1}} + \sum\nolimits_{y=1}^{3} \alpha''_y \mathrm{VSS}_{\mathrm{ilt-1}} \times \mathrm{PS}_{\mathrm{ilt-1y}} \tag{12}$$

These models include two-way interaction terms between the VSS coverage variable $\mathrm{VSS}_{\mathrm{ilt-1}}$ and overall substantive stringency (SS), substantive stringency in four sustainability dimensions ($\mathrm{SS_x}$), overall procedural stringency (PS), or procedural stringency in three compliance mechanisms ($\mathrm{PS_y}$)—as specified above in Eqs. (1) to (4).

Stringency scores are specified at the country-commodity-time level and were derived by averaging VSS-specific stringency scores over VSS, weighted by VSS acreage coverage for a commodity in a given year. Scores were standardized to allow comparison of estimated coefficients and decrease collinearity between interaction terms. α can be interpreted as the percentage change in trade volume or unit price associated with a one pp increase in coverage for VSS with average stringency, while the α' and α'' represent how this trade effect changes with a one standard deviation change in the substantive and procedural stringency of VSS, respectively. Results are summarized in Fig. 5, and full regression results are reported in Supplementary Tables S12 and S13.

We examined the moderating effect of governance distance between trade partners by estimating three different models in which Z_{ijlt-1} is defined as specified in Eqs. (13) to (15), respectively.

$$\alpha Z_{ijlt-1} = \alpha VSS_{ilt-1} + \alpha^{*} WGI_{ijt} + \alpha^{\circ}\left(VSS_{ilt-1} \times WGI_{ilt}\right) \tag{13}$$

$$\begin{aligned}\alpha\, Z_{ijlt-1} &= \alpha\, VSS_{ilt-1} + \alpha^{*} WGI_{ijt} + \alpha^{\circ}\left(VSS_{ilt-1} \times WGI_{ijt}\right)\\ &+ \alpha'\left(VSS_{ilt-1} \times SS_{ilt-1}\right) + \alpha^{\circ\prime}\left(VSS_{ilt-1} \times WGI_{ijt} \times SS_{ilt-1}\right)\end{aligned} \tag{14}$$

$$\begin{aligned}\alpha\, Z_{ijlt-1} &= \alpha\, VSS_{ilt-1} + \alpha^{*} WGI_{ijt} + \alpha^{\circ}\left(VSS_{ilt-1} \times WGI_{ijt}\right)\\ &+ \alpha''\left(VSS_{ilt-1} \times PS_{ilt-1}\right) + \alpha^{\circ\prime\prime}\left(VSS_{ilt-1} \times WGI_{ijt} \times PS_{ilt-1}\right)\end{aligned} \tag{15}$$

The variable WGI_{ijt} measures the governance distance between exporter i and importer j at time t and was calculated as specified above. These models include two- and three-way interaction terms between VSS coverage (VSS_{ilt-1}), governance distance (WGI_{ijt}), and overall substantive (SS_{ilt-1}) or procedural stringency (PS_{ilt-1}). The coefficient α^{*} represents the trade effect of governance distance, but was not estimated as most of the variance in WGI_{ijt} was captured by the combination of the bilateral and product-time fixed effects. The estimated coefficient α° measures how VSS moderates the trade effect of governance distance, while the coefficients $\alpha^{\circ\prime}$ and $\alpha^{\circ\prime\prime}$ measure how this moderating effect varies with the substantive and procedural stringency of VSS, respectively. Results are summarized in Table 1 and full regression results reported in Supplementary Table S14. Summary statistics were calculated for all variables used in the analysis and reported in Supplementary Table S18.

Estimation approaches

All models were estimated using the Poisson Pseudo-Maximum Likelihood (PPML) estimator. As unit prices can only be observed for non-zero trade flows, models with unit price as the dependent variable were only estimated on the non-zero sample, excluding zero trade flows. Models with trade volume as the dependent variable were estimated on both the full sample, including zero trade flows, and the non-zero sample. For comparability reasons, we additionally report OLS estimates. Since OLS estimates gravity models in log-linear form, they are restricted to the estimation of the non-zero trade volume and unit price effects. In all models, standard errors were clustered at the exporter-importer-product level to deal with heteroskedasticity. Since model specifications include a one-year lagged VSS coverage variable, models were estimated for a sample of bilateral trade flows between 2013 and 2021. Significance of coefficient estimates was tested with unadjusted two-sided z-tests for PPML estimations and with unadjusted two-sided t-tests for OLS estimations.

The models include a set of fixed effects that control for time-invariant characteristics of bilateral trade relations and time-varying factors specific to exporters, importers, and products. Remaining unobserved heterogeneity bias is likely limited but may stem from unobserved bilateral shocks (e.g., trade disputes) or unobserved time-varying factors at the exporter-product or importer-product level that are correlated with VSS coverage (e.g., change in preferences in importing countries). To further address potential bias, we additionally estimated trade volume (full sample and non-zero sample) and unit price effects of overall, commodity-, and VSS-specific certification using the instrumental variable IV-PPML estimation approach. We expand upon previous studies[24,26,27], which have used VSS coverage in neighboring countries to construct instruments, arguing that it can enhance a country's VSS adoption, e.g., through information or cost-sharing mechanisms. We integrated this IV approach with a Lasso (Least Absolute Shrinkage and Selection Operator) method for automated instrument selection, thereby reducing the risk of weak instruments[39]. However, given concerns about potential bias in coefficient estimates due to the incidental parameter problem, which arises under IV-PPML estimation in the presence of many fixed effects[68], we also employed the two-stage least squares (2SLS) estimator as a robustness check. Although the 2SLS estimations provide a useful benchmark, it inherits limitations of the ordinary least squares (OLS) estimation of log-linearized gravity models, more specifically, potentially inconsistent estimates under heteroskedasticity due to Jensen's Inequality[69]. While these IV approaches reduce endogeneity bias, they do not guarantee causal identification of trade effects.

We constructed the following set of potential IVs at exporter-commodity-time level: (1) simple and population-weighted average of overall VSS coverage, measured as maximum share of certified production area and additionally as total certified production area, across direct neighboring countries and across all other countries in the same region (= continent) (# IVs = 8); (2) simple and population-weighted average of each VSS-specific VSS coverage, measured as share of certified production area and additionally as total certified production area, across neighboring countries and across countries in the same region (# IVs = 80); (3) sum of total and VSS-specific certified production area, across neighboring countries and across countries in the region, divided by the sum of total production area across neighboring countries or countries in the region, respectively (# IVs = 22); (4) simple and population-weighted average of relative importance of each VSS in the overall VSS coverage, across neighboring countries and across countries in the region (# IVs = 40). Supplementary Table S19 provides an overview of the 150 constructed IVs. A Lasso approach[39,40] was used to select IVs that significantly predict certification at the exporter-commodity-time level. We applied the rlasso command in Stata[70] to perform Lasso with theory-driven penalization and select IVs for VSS coverage overall, for each commodity and each VSS. The approach resulted in the successful selection of a set of IVs for each of the potentially endogenous VSS coverage variables (reported in Supplementary Table S20), except for soy-specific certification.

Selected IVs were used in the first stage of the IV-PPML and 2SLS estimations. For overall VSS coverage, the IV estimations included first-stage prediction of overall VSS coverage based on Lasso-selected IVs, gravity variables, and fixed effects, and second-stage estimation of trade effects as specified in Eq. 5. For commodity-specific VSS coverage, the IV-PPML and 2SLS estimations were done separately for each commodity, instrumenting for VSS coverage of that specific commodity using Lasso-selected IVs. This approach was chosen because jointly instrumenting for seven endogenous VSS coverage variables would lead to an unwieldy large number of IVs. Since no appropriate IVs could be selected for soy-specific VSS coverage, we did not perform IV-PPML nor 2SLS estimations for soy-specific trade effects. IV-PPML, OLS, and 2SLS results for overall and commodity-specific VSS coverage are summarized in Fig. 2 and second-stage regression results documented in Supplementary Tables S2–S4.

We used a similar approach for VSS-specific coverage, where there are ten endogenous variables. For the IV-PPML and 2SLS estimations of

VSS-specific trade effects, we specified Z_{ilt-1} as:

$$\alpha Z_{ilt-1} = \alpha VSS_{ilt-1} + \alpha' O9\_VSS_{ilt-1} \tag{16}$$

Here, VSS_{ilt-1} represents VSS coverage for a specific VSS, while $O9\_VSS_{ilt}$ represents combined VSS coverage for the remaining nine VSS (measured as the maximum share of certified production area). A Lasso IV selection was done for each of the ten $O9\_VSS_{ilt-1}$ variables, reported in Supplementary Table S20. We then performed an IV-PPML and 2SLS estimations separately for each VSS, instrumenting for VSS coverage of that specific VSS, VSS_{ilt}, as well as for combined coverage by the remaining VSS, $O9\_VSS_{ilt}$, using Lasso-selected IVs. Significance of coefficient estimates was tested with unadjusted two-sided *z*-tests for IV-PPML estimations and with unadjusted two-sided *t*-tests for 2SLS estimations. Results are summarized in Fig. 3 and second-stage regression results are documented in Supplementary Tables S6 and S7. Since IV-PPML estimations in Stata do not permit verifying the identification assumption of instruments, *F*-statistics of two-stage least-squares (2SLS) estimations in the non-zero sample are reported in Supplementary Table S20 and confirm strong identification by IVs in all cases.

Supplementary analyses and robustness checks

We additionally estimated commodity-specific trade volume and unit price effects for Fairtrade in a VSS-specific model specification by defining Z_{ilt-1} as specified in Eq. (17):

$$\alpha Z_{ilt-1} = \sum\nolimits_{l=1}^{5} \alpha_l FT_{ilt-1} \times commodity_l + \sum\nolimits_{n=1}^{9} \alpha'_n VSS_{ilt-1n} \tag{17}$$

The variable FT_{ilt} represents Fairtrade area coverage at exporter-commodity-time level and is interacted with a categorical variable $commodity_l$ indicating commodity sector *l* in which Fairtrade is active (banana, tea, sugarcane, coffee, cocoa). Hence, a vector of five coefficients $\sum_{l=1}^{5} \alpha_l$ captures commodity-specific trade volume and unit price effects of Fairtrade. VSS_{iltn} represents a vector of nine variables, each measuring area coverage for one of the remaining nine VSS. We estimated this model using the PPML and OLS estimators. To perform IV-PPML and 2SLS estimations of commodity-specific trade volume and unit price effects of Fairtrade, we defined Z_{ilt-1}—in line with IV model specifications for VSS- and commodity-specific effects—as specified in Eq. (18):

$$\alpha Z_{ilt-1} = \sum\nolimits_{l=1}^{5} \alpha_l FT_{ilt-1} \times commodity_l + \alpha' O9\_VSS_{ilt-1} \tag{18}$$

Here, the variable $O9\_VSS_{ilt-1}$ measures combined VSS coverage for the nine VSS other than Fairtrade (measured as the maximum share of certified production area). A Lasso IV selection was done for Fairtrade certification in each of the five commodity sectors and for $O9\_VSS_{ilt-1}$. Selected IVs are reported in Supplementary Table S20. We then performed IV-PPML and 2SLS estimations separately for each commodity, only instrumenting for Fairtrade coverage of that specific commodity and for $O9\_VSS_{ilt-1}$, using Lasso-selected IVs. Second stage regression results are reported in Supplementary Tables S8 and S9, and first stage F-statistics in Supplementary Table S20.

Additionally, we performed six robustness checks related to sampling, variable definition, and model specification. First, the main analysis includes all importing countries (except SIDS). Because demand for certified produce is mainly in high-income countries, we estimated effects for overall VSS coverage on bilateral trade flows imported by OECD countries only. Results are reported in Supplementary Table S21 and prove robustness to using an OECD-importer sample. Second, VSS coverage shares above 100% were adjusted to 100% (1.6% of data points for the variable VSS_{ilt-1}), and to corroborate results, models were re-estimated excluding these adjusted observations. Results are reported in Supplementary Tables S22–S26 and prove robustness to these adjustments. Third, the possibility of multiple certification of the same area exists, and the variable VSS_{ilt-1} represents the maximum certified area coverage. Models including overall VSS coverage were re-estimated using the more conservative measure, minimum share of certified production area, $VSS\,min_{ilt-1}$, calculated as the acreage coverage of the largest VSS at exporter-commodity-time level. Results are provided in Supplementary Tables S27–S30 and prove robustness to this alternative variable specification. Fourth, we assumed that export of sugar beet derivatives is limited in the sample, but two sugarcane-related HS6-lines (170191, 170199) might, by definition, include sucrose derived from sugar beet. We re-ran the analysis without trade flows, potentially including sugar beet derivatives originating from exporters producing sugar beet. Results are given in Supplementary Tables S31–S35 and prove robustness to this exclusion. Fifth, we tested the sensitivity of the results to an alternative specification of the variable WGI_{ijt}. Models were re-estimated using the Kogut and Singh composite index[71] to measure governance distance, thereby following Fiankor and co-authors[25]. Results are provided in Supplementary Table S36 and prove robustness to the choice of governance distance measure. Sixth, to fully account for multilateral resistance terms, the gravity equation ideally includes exporter-product-time and importer-product-time fixed effects. While the former cannot be included in our analysis as it would absorb variables of interest defined at exporter-commodity-time level, we replace the importer-time fixed effects with importer-product-time fixed effects for the main, VSS-specific and commodity-specific model specifications. Results are presented in Supplementary Tables S37-S38 and prove relatively robust. These estimates show stronger trade-enhancing effects in the soy sector and for Bonsucro and IFOAM, and stronger negative volume and positive price effects for Fairtrade, compared to the main analysis.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The raw country-commodity-year level VSS coverage data are subject to confidentiality restrictions due to Data Non-Disclosure Agreements signed with Voluntary Sustainability Standards (VSS) organizations and are not publicly available. Replicated country-commodity-year level VSS coverage data have been deposited in a replication dataset on Zenodo under accession code https://doi.org/10.5281/zenodo.17935696. In the replication dataset, the VSS coverage variable was simulated to mirror the distributional properties of the original data. All derived variables that depend on VSS coverage were recalculated to align with the simulated values, while other variables, not depending on the VSS coverage data, are as in the original dataset. The VSS procedural and substantive stringency scores data generated in this study are provided in Fig. 4 in the Main Text and in Supplementary Data 1. The bilateral trade data used in this study are available in the Base pour l'Analyze du Commerce International (BACI) database under accession code http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37. The tariff data used in this study are available in the UNCTAD Trade Analysis Information System (TRAINS) database under accession code https://wits.worldbank.org/. The crop production data used in this study are available in the FAOstat database under accession code https://www.fao.org/faostat/en/#data/QCL. The regional trade agreement data used in this study are available in Mario Larch's Regional Trade Agreements Database from Egger and Larch (2008) under accession code https://www.ewf.uni-bayreuth.de/en/research/RTA-data/index.html. The country-level institutional capacity data used in this study are available in the World Governance Indicator database from the World Bank under accession code https://www.worldbank.org/en/publication/worldwide-governance-indicators.

Code availability

The custom Stata do-file for the analysis is available via Zenodo at https://doi.org/10.5281/zenodo.17935696. Data analyses were performed using StataMP, version 17, using the following commands and packages: ppmlhdfe, reghdfe, ivpoisson gmm, ivreghdfe, rlasso.

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Acknowledgements

The authors acknowledge project funding from the KU Leuven Special Research Fund (grant C24M/19/031, M.M., A.M.) and support from the Research Foundation-Flanders (FWO) through the Strategic Basic Research program (grant S010126N, M.M., A.M.) and the PhD Fellowship Strategic Basic Research program (grant 11J6123N, J.B.).

Author contributions

Conceptualization and design of the study, J.B., C.D., A.M., M.M.; Methodology development, J.B., C.D., A.M., M.M.; Acquisition, curation and analysis of data, J.B., C.D.; Interpretation of data and results, J.B., C.D., A.M., M.M.; Visualization, J.B.; Writing – Original draft, J.B., C.D., M.M; Writing – revisions and editing, J.B., C.D., A.M., M.M.; Funding acquisition, A.M., M.M.; Supervision, M.M.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41467-026-71245-x.

Correspondence and requests for materials should be addressed to Miet Maertens.

Peer review information *Nature Communications* thanks Rodrigo Cezar, who co-reviewed with Johnny KallaySantiago Fernandez de Cordoba, who co-reviewed with Paulo Mortara Batistic; and Cosimo Beverelli for their contribution to the peer review of this work. A peer review file is available.

https://doi.org/10.1038/s41467-026-71245-x