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Do private coffee standards 'walk the talk' in improving socio-economic and environmental sustainability?

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ABSTRACT

Private sustainability standards cover an increasingly large production area and involve an increasing number of farmers worldwide. They raise expectations among consumers about the economic, ethical and environmental implications of food production and trade; and attract donor funding to certification schemes. The sustainability impact of standards remains unclear as research focuses on either economic or environmental implications. We analyze both the socio-economic and environmental impacts of coffee standards in Uganda and show that these are not in line with expectations created towards consumers. We find that standards improve either productivity and farm incomes or biodiversity and carbon storage but fail to eliminate trade-offs between socioeconomic and environmental outcomes, even when combined in multiple certification. Our analysis is based on a unique combination of economic survey data and ecological field inventory data from a sample of certified and non-certified coffee farms. Our findings are relevant for farmers, food companies, policy-makers, donors and consumers. They imply that combining different standards in multiple certification is counterproductive; that the design of standards could improve to mitigate observed trade-offs between economic and environmental outcomes; and that this requires increased productivity within ecological boundaries, rather than a price premium and added control mechanisms through multiple certification.

1. Introduction

Private sustainability standards (PSS) – each with their own promises on improving sustainability of food production and trade – are increasingly important in global agri-food sectors (Gereffi et al., 2005; Henson and Humphrey, 2010; Lee et al., 2012). PSS focus on social, economic and/or environmental aspects, and are most important in trade relations with developing countries (Henson and Humphrey, 2010; Lee et al., 2012; Beghin et al., 2015; Reardon et al., 2009). For example, organic certification is promoted as eco-friendly production without chemical inputs. Fairtrade claims to improve farmers' lives and to offer consumers a powerful way to reduce poverty through their everyday shopping. Rainforest Alliance claims to ensure the long-term economic health of communities through protecting ecosystems, safeguarding the well-being of local communities and improving productivity. UTZ assures that coffee, tea and cocoa suppliers follow expert guidance on better farming methods, working conditions and care for nature; which leads to better production, a better environment and a better life for everyone.

But do PSS effectively provide a way to improve socio-economic and environmental sustainability of global food production and trade? Answering this question is important for various stakeholders: first for developing countries, for whom agri-food exports are critical for growth and whose farmers are often poor and operate in environmentally sensitive areas; second for consumers to know if PSS deliver what they promise and to judge if a price premium is justified; third for companies and non-profit organizations initiating and adopting standards to know the impact of the standards they promote and justify the rents they extract from agri-food chains; and fourth for donors in order to ascertain the effectiveness of financial support to certification schemes in comparison with other development projects.

There is evidence on both socio-economic and environmental implications of specific PSS. Socio-economic evidence suggests that PSS can enhance the competitive position of developing countries and exporters in international markets but that the implications for smallholder producers are complex, case-specific and should be analyzed in a

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comparative way – as recently reviewed by (Beghin et al., 2015). Evidence on environmental issues suggests that certification of tropical commodities can support biodiversity conservation but that the causal impact is still questionable – as recently reviewed by (Tscharntke et al., 2015). There are no multidisciplinary studies that concurrently assess socio-economic and environmental impacts of PSS, which are needed to understand the full sustainability implications of PSS including potential trade-offs between socio-economic and environmental benefits.

In this paper, we analyze the on-farm socio-economic and environmental implications of a double Fairtrade – Organic (FT-Org) and a triple UTZ – Rainforest Alliance –4C (UTZ-RA-4C) smallholder coffee certification scheme in Uganda. We take a unique inter-disciplinary approach using survey and field data from certified and non-certified farms. We use household- and field-level socio-economic data from a quantitative survey among 595 farm-households producing coffee on 1183 fields. We combine these with geo-referenced data on agro-ecological conditions and a field-level inventory of environmental indicators from a sub-sample of 74 fields. We use instrumental variable regressions that pass weak- and over-identification restrictions to estimate the impact of PSS on agronomic practices, coffee yield, labor productivity, coffee income and poverty; and linear mixed models to reveal the implications of PSS for tree and invertebrate diversity and carbon stocks. We use a correlation analysis to detect trade-offs between socio-economic and environmental indicators.

Given that an estimated 25 million smallholders worldwide (11.7 million in Africa) depend on coffee production as their main income source, that the incidence of poverty among them is high (Eakin et al., 2009), and that coffee trade has been identified as a major cause of biodiversity threats in tropical countries (Chaudhary and Kastner, 2016; Lenzen et al., 2012), sustainable coffee cultivation remains a challenge. Understanding the contribution of PSS in addressing this challenge is pertinent, given that an estimated 40% of global coffee production is certified (Lernoud et al., 2016). This requires an interdisciplinary approach, and while studies on increased intensification of tropical commodity production analyze the trade-offs between economic and environmental outcomes (Bos et al., 2007; Philpott et al., 2008; Steffan-Dewenter et al., 2007; Teuscher et al., 2015), studies on coffee certification are mainly discipline specific and mostly from Latin-America. Socio-economic studies analyze the impact on productivity, income, poverty and food security (Bacon, 2005; Bacon et al., 2008, 2014; Barham and Weber, 2012; Beuchelt and Zeller, 2011; Méndez et al., 2010; Ruben and Fort, 2012; Ruben and Zuniga, 2011; Valkila, 2009; Valkila and Nygren, 2010; Wollni and Zeller, 2007 for studies from Latin-America; Bolwig et al., 2009; Chiputwa et al., 2015; Chiputwa and Qaim, 2016; Mitiku et al., 2017; Van Rijsbergen et al., 2016 for studies from Africa; Jena and Grote, 2017 for a study from India); agronomic studies focus on the adoption of agronomic and agri-environmental practices (Elder et al., 2013; Blackman and Naranjo, 2012; Ibanez and Blackman, 2016; Rueda and Lambin, 2013); and ecological and environmental studies analyze effects on tree cover and biodiversity (Haggar et al., 2015; Hardt et al., 2015; Perfecto et al., 2005; Philpott et al., 2007; Rueda et al., 2015) and on deforestation and forest degradation (Takahashi and Todo, 2013; 2014; 2017). Three studies concurrently analyze socio-economic and agronomic outcomes (Ruben and Fort, 2012; Ibanez and Blackman, 2016; Rueda and Lambin, 2013) and one ecological study includes a non-casual analysis of revenues and costs (Philpott et al., 2007). A meta-analysis on the social, economic and environmental effects of tropical commodity certification (DeFries et al., 2017) identifies 13 studies with a rigorous causal analysis of the impact of coffee certification and reveals that multidisciplinary studies addressing different components of sustainability or studies comparing different and multiple certification schemes are very rare. This inter-disciplinary and comparative study on the socio-economic and environmental implications of different coffee certification schemes adds insights on the sustainability trade-offs of PSS and results in findings with broad implications towards policy-makers, food companies, non-profit organizations, donors, farmers and consumers.

2. Methods

2.1. Research area

The research area covers five of the eight districts of the Mt. Elgon region in Eastern Uganda, a main coffee producing area in Uganda (Fig. SI1). The area ranges between 1200 and 2200 m above sea level, has a bi-modal rainfall pattern and volcanic soils, borders the Mt. Elgon National Park, is dominated by Bagisu and Sabiny ethnic groups, and faces increasing population pressure and land degradation problems.

Arabica coffee in Mt. Elgon is typically grown on small (1 ha) landholdings in a shade-garden system, intercropped with bananas and other food crops. Four major coffee export companies source from the region. Two companies source fresh, dried and washed coffee from independent farmers through spot-market transactions with traders and company agents. The other two companies source certified produce through contract-farming schemes. The first contract-farming scheme is a double Fairtrade – Organic certification scheme (FT-Org) existing since 2000, in which smallholder farmers organized in a network of cooperative societies supply fully-washed coffee. The FT-Org scheme promotes an organic production system and guarantees a minimum price and a social premium. The second scheme is a triple UTZ – Rainforest Alliance –4C certification scheme (UTZ-RA-4C) established in 2012, in which farmers located within a 12.5 km radius from a company washing station and organized in producer organizations supply fresh coffee cherries to one of the six washing stations across the region. The UTZ-RA-4C scheme promotes a shade-coffee system, good agricultural practices with responsible agro-chemical use, integrated crop management and stipulates requirements on forest and wildlife protection. For both schemes, the costs of certification and annual external audits are borne by the companies, who partially rely on donor funding. In the whole region 7479 farmers participate in the FT-Org scheme and 6048 in the UTZ-RA-4C scheme.

2.2. Data

Socio-economic survey data were collected in February-March 2014 from a stratified random sample of 600 coffee producing farm-households (clustered in 60 villages and 21 sub-counties), using a quantitative structured questionnaire. Strata of UTZ-RA-4C certified, FT-Org certified, and non-certified sub-counties, villages and households were constructed based on information from coffee companies. The sample includes 170 FT-Org and 130 UTZ-RA-4C certified producers, and 300 non-certified producers. Five observations were discarded due to missing information. The survey provides household-level data and field-level data for all 1183 coffee fields of the sampled households – with fields referring to coffee gardens and one farm-household often having multiple coffee gardens. Field-level data include GPS coordinates, which allowed to merge survey data with available GIS data on topography, soil and climate. Additional information was collected from semi-structured interviews with village leaders and coffee companies.

Environmental data were gathered through a field inventory on a subsample of 74 coffee fields in July-September 2014. This subsample included 18 FT-Org and 19 UTZ-RA-4C fields selected in a stratified random way with strata based on elevation and soil type. These 37 fields were pair-wise matched with 37 non-certified fields using propensity score matching (Rosenbaum and Rubin, 1983) using agro-ecological (elevation, rainfall, distance to the main road and to the national park) and socio-economic (household size and age, education, tribe and religion of the household head) information. After matching agro-ecological and socio-economic covariates are balanced between certified and non-certified fields with no remaining differences in means at the

5% significance level (Table SI1). Measurements were done in rectangular slope corrected 0.05 ha plots placed randomly within the field. Coordinates, slope and aspect were noted. We measured the Diameter at Breast Height (DBH) and height for all woody plant species, stumps, deadwood and coarse woody debris. Stem and/or plant counts were made for crop species. Litter was collected in two 1 m^2 quadrants per plot. Soil samples for bulk density and Soil Organic Carbon (SOC) determination were taken at 1 and 9 positions respectively, and from 3 soil layers up to 30 cm deep. Invertebrates were sampled according to the standard ALL-protocol using 16 pitfall traps (24 h.), 24 baits (1 cm^3 tuna, 45 min) spread over the plot soil and shrub layer (1 m height) and 2×1 m^2 litter sieving followed by Winkler extraction (Agosti et al., 2000). We identified 828 adult spiders (*Araneae*) and 44,690 ants (*Formicidae*) up to species/morphospecies (88 and 187 resp.) and counted 2732 rove beetles (*Staphylinidae*). Ant abundance and diversity were calculated leaving out *Dorylus*, *Pheidole* and *Myrmicaria* species. *Dorylus* species are not considered because of their nomadic life style and very variable numbers of foraging workers - they perform huge swarm raids along the ground and lower vegetation with hundreds of thousands of polymorphic workers (Gotwald, 1995). *Pheidole* and *Myrmicaria* species were hard to sort into morphospecies groups because of their extremely high abundance – present in resp. 85% and 99% of plots and over 1000 specimen per plot.

2.3. Socio-economic and environmental indicators

From survey data (1183 coffee fields) and in-depth interviews (74 coffee fields) we derive indicators for the use of agronomic practices. Binary field level variables are derived indicating the application of pesticides, copper fungicide, chemical fertilizer, cultural weed control, mulching, animal manure, green manure, shade trees, wind breaks, soil tillage, intercropping with legumes, slashing undergrowth, recommended spacing and pruning coffee shrubs during the past year.

From survey data we derive five socio-economic performance indicators: coffee yield, coffee labor productivity, net coffee income, total household income and poverty. Coffee yield is calculated at field level as the total quantity of coffee harvested over the 12-month period prior to the survey over the size of the field, and expressed in kg of fresh coffee cherries per ha. Labor productivity is calculated at the household level as the net income from coffee production per person-day of family labor in coffee production, processing and marketing, and expressed in UGX per person-day. Coffee income is net household income in UGX from coffee production and processing, and derived as total sales value of coffee minus the costs of variable inputs and hired labor. Total household income total is net household income in UGX from livestock rearing, coffee and other crop production, off-farm activities and private transfers, in the previous 12 months. Poverty is a binary variable for per capita household income falling below the international poverty line of $3.10/day (equivalent to 3473 UGX in 2014). Per capita income is calculated taking into account all labor and non-labor income sources and based on the modified OECD adult equivalence scale.

The environmental performance indicators relate to carbon storage and biodiversity. Total Carbon (C) stocks (Mg C ha^{-1}) are calculated based on above ground woody species-, crop- and root-biomass C, coarse woody debris and litter C, and SOC in the top 30 cm soil layer. Woody species biomass C (DBH > 5 cm) is assessed using the pantropical aboveground biomass equation with tree DBH, tree height, species specific oven dry wood density presented by (Chave et al., 2014) and a standard C/dry biomass ratio of 0.5 (Chave et al., 2014; Zanne et al., 2009; Eggleston et al., 2006). Crop C is estimated and time averaged based on stem and/or plant counts, oven dry crop weights, length of the crop growth cycles and annual cropping periods. Tree regeneration (DBH < 5 cm) biomass C is assessed using species specific dry wood densities and simplifying their shape to a cone. Coarse woody debris is simplified to cylinder shapes. Deadwood densities are corrected for decomposition (IFER, 2002). Root biomass C is assessed based on the above ground biomass C using a shoot-root ratio of 0.205 (Mokany et al., 2006). Coffee and banana biomass C is assessed using species specific allometric relations (Hairiah et al., 2011; Negash et al., 2013). Litter C is assessed from oven dry litter weights. SOC is measured by dry combustion at 1020 °C (Carlo Erba 1108 Elemental Analyzer). Bulk density is determined from undisturbed, Kopecky ring, soil sample weights dried 48 h at 105 °C.

As trees provide numerous ecosystem services besides carbon storage (Tscharntke et al., 2011; Jose, 2009; Harvey et al., 2008), we investigate tree density and diversity. Basal area per tree species is calculated based on the DBH of individual trees. Tree, ant and spider species/morphospecies data are used to calculate the Simpson diversity index: $D' = 1 - \sum_{i=1}^{s} {p_i}^2$ where p_i is the proportion of the *i*th species (*s*) in the population (Simpson, 1949). Plot heat load indices are calculated based on slope, latitude and folded aspect – with folding around the north-south line for rescaling of 0-360° to 0-180° such that folded aspect = 180 – |aspect – 180| (McCune and Keon, 2002). Plot coordinates and altitude are measured by GPS. Rainfall data are obtained from the CCLM model (Thiery et al., 2015).

2.4. Estimating effects

2.4.1. Instrumental variable (IV) models

We use limited-information maximum likelihood estimators and IVs to estimate the following models, respectively at the field level (Eq. (1) with subscripts referring to field *j* and household *i*) and household level (Eq. (2) with subscripts referring to household *i*):

$$Y_{ij} = \beta_0 + \beta_1 Utz-RA-4C_i + \beta_2 FT-Org_i + \beta_3 F_{ij} + \beta_4 X_i + \beta_5 V_i + \varepsilon_i + \theta_{ij} \quad (1)$$

$$Y_i = \beta_0' + \beta_1' Utz-RA-4C_i + \beta_2' FT-Org_i + \beta_3' F_i + \beta_4' X_i + \beta_5' V_i + \beta_6' D_i + \varepsilon'_i \quad (2)$$

Outcome variables Y_{ij} at field level include different agronomic practices and coffee yield. Outcome variables Y_i at household level include labor productivity in coffee production, net coffee income, total household income and poverty. For binary outcome variables (agronomic practices, poverty) the IV estimation is interpreted as a linear probability model. The binary certification variables *UTZ-RA-4C* and *FT-Org* are considered endogenous because a farmer's decision to become certified is likely correlated with unobservable characteristics, such as motivation and ability, that also influence the outcome indicators. The certification variables are instrumented for in order to reduce the bias that might arise from unobserved heterogeneity. The vector of control variables *F* includes field size, age of coffee shrubs, distance from the plot to the homestead, and agro-ecological characteristics (altitude, slope, heat load, topographic wetness, soil type) at the field level (F_{ij}) or field-size weighted averages at the household level (F_i). The latter are derived from geo-databases (Table SI2b). The vector *X* includes household level control variables measuring human capital (age, education and gender of the household head, number of adults and children in the household) and physical capital (livestock units, land, land-squared) – land is measured as total coffee area or total farm size. Variables in *X* are derived from survey data (Table SI2a). The vector *V* includes village level institutional and accessibility characteristics (distance to Mbale town and the nearest trading centre, access to an all-weather road, a market-day, a primary school and a health centre in the village) and *D* are district fixed effects (Table SI2a). The latter are not included in the field-level regressions on agronomic practices. From these models (Tables SI4 & 5) we obtain least-square means (LS-means), which are used in Figs. 1 and 2.

Three instruments are used: years of experience of the household in Bugisu Cooperative Union (BCU); distance between the homestead and the nearest washing station of the UTZ-RA-4C scheme; and the square of this distance. BCU was a state-controlled cooperative that collapsed in

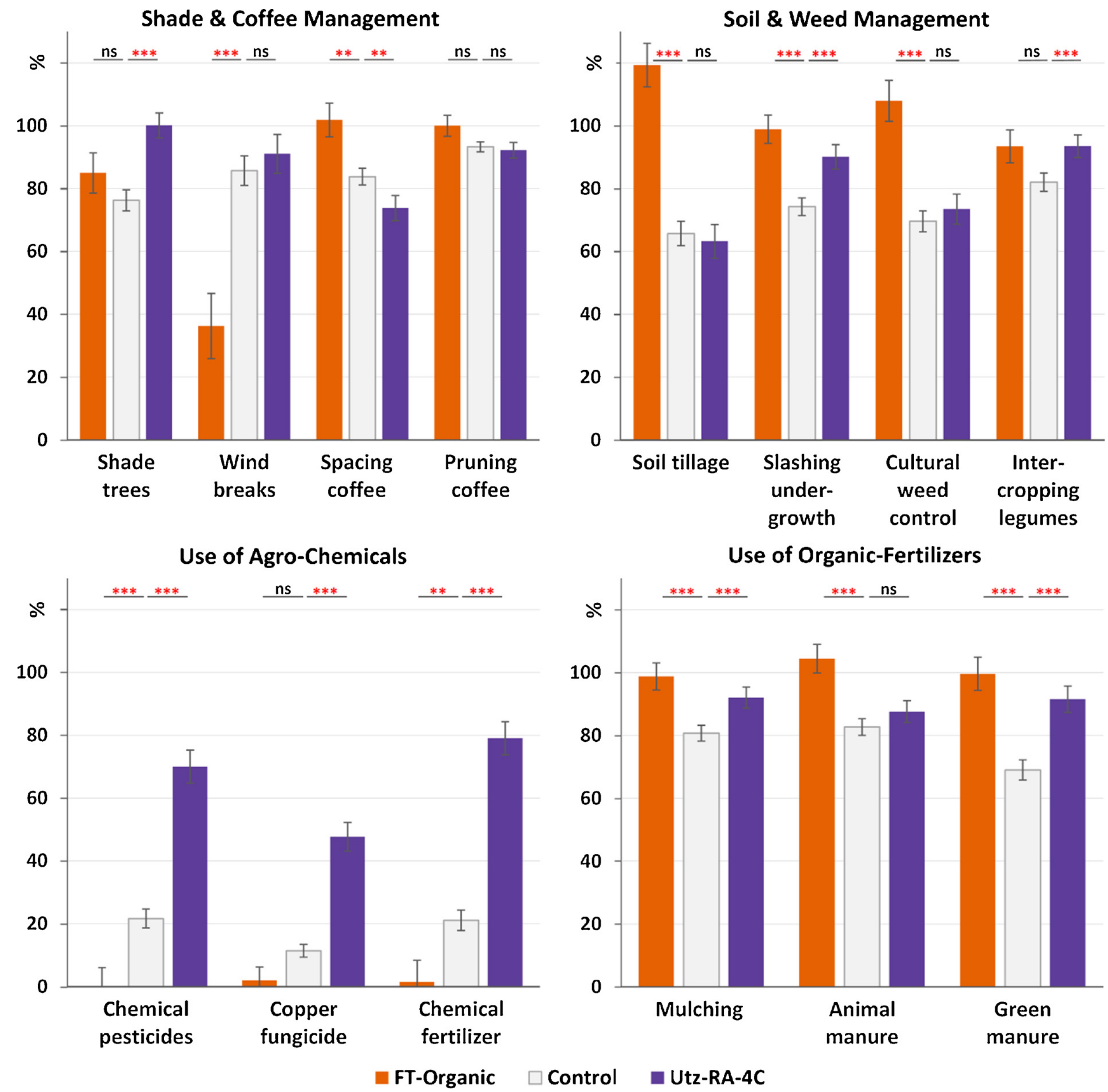

Fig. 1. Effect of certification on agronomic practices. Least-square means for certified (Fairtrade-Organic, UTZ-Rainforest Alliance-4C) and non-certified fields estimated from farm-household survey data (ns not significant,* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$). Estimated effects are obtained from maximum likelihood instrumental variable estimations at field level (n = 1183).

1997 and farmers with a bad experience in BCU are less likely to engage in coffee cooperatives and contracting schemes again. Instruments are relevant and plausibly exogenous. Joint exclusion of instruments is rejected with an F-statistic of 245.15 ($p < 0.001$) for UTZ-RA-4C and 40.12 ($p < 0.001$) for FT-Org for the household-level regressions (Table SI3a); and with an F-statistic of 212.5 ($p < 0.001$) for UTZ-RA-4C and 31.14 ($p < 0.001$) for FT-Org for the field-level regressions (Table SI3b). Instruments pass the Kleibergen-Paap test for under-identification with an LM test statistic of 59.34 ($p < 0.001$) and 54.60 ($p < 0.001$) for respectively the household- and field-level regressions; and the Kleibergen-Paap test for weak identification with a Wald F statistic of 34.67 and 27.69 for respectively the household- and field-level regressions (which are above the 10% Stock-Yogo critical value of 13.43) (Table SI3a&b). For all socio-economic indicators, regressions pass the Sargan-Hansen test for over-identification restrictions at the 1% significance level while the Anderson-Rubin test indicates both certification variables are endogenous (Table SI5a) - which justifies the use of the less efficient but consistent IV estimators. For some management variables, regressions do not pass the Sargan-Hansen test and weak correlation with the error term remains (Table SI4a).

2.4.2. Linear mixed models

Generalized linear interactive mixed models with log link function (glimmix) are used to analyze impact of certification on Poisson-distributed invertebrate abundance indicators. Linear mixed models (mixed) are used to analyze impact on carbon stocks, tree- and invertebrate diversity. In both sets of models, the variable *group* distinguishing certified and non-certified fields and the variable *match* distinguishing matched pairs of fields are specified as class variables; *match* is additionally specified as random effect; and *group* along with covariates for altitude, rainfall, heat load, number of years under coffee, and recent ploughing of the field – as this could affect the soil dwelling invertebrate abundance – are added as explanatory variables. Denominator degrees of freedom and p-values of the fixed effects are estimated using Satterthwaite's approximation. From these models (Table SI5) we obtain LS-means, which are used in Fig. 3.

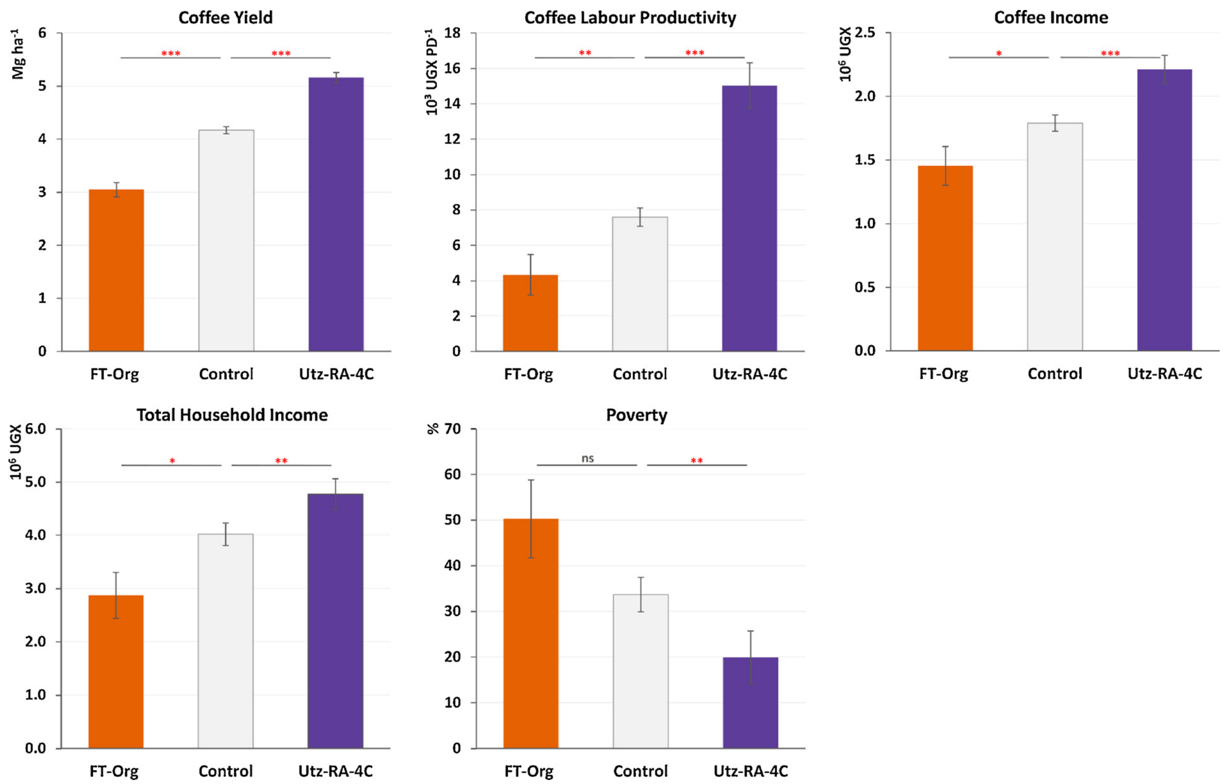

Fig. 2. Effect of certification on the socio-economic indicators coffee yield, coffee labor productivity, coffee income and the likelihood of poverty. Least-square means for certified (Fairtrade-Organic, UTZ-Rainforest Alliance-4C) and non-certified fields and households estimated from farm-household survey data (ns not significant,* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$). Estimated effects are obtained from maximum likelihood instrumental variable estimations at field level (yield) (n = 1183) and farm-household level (labor productivity, coffee income and poverty) (n = 595). UGX = Ugandan Shilling; PD = person-day.

2.4.3. Relationships and trade-offs

The sensitivity of invertebrate abundance and diversity to agronomic practices, tree diversity and carbon stocks, and other environmental variables is tested using mixed and glimmix models (Table SI7). Correlation between agronomic practices and economic indicators is analyzed using point biserial correlations (Table SI8), and between environmental indicators and coffee yield using Kendall's rank correlation (Table 1).

3. Results

3.1. Agronomic practices

Instrumental variable estimations reveal that certification has a clear impact on the agronomic practices applied on coffee fields (Fig. 1). UTZ-RA-4C certification increases the likelihood of using agrochemicals – for pesticides with 48 percentage points (pp) ($p < 0.001$), fungicide with 36 pp ($p < 0.001$), and inorganic fertilizer with 58 pp ($p < 0.001$). It also increases the use of mulching (11 pp, $p = 0.003$) and green manure (22 pp, $p < 0.001$) but less strongly. FT-Org certification reduces but does not completely eliminate the use of agrochemical inputs[i] – for pesticides with 21 pp ($p = 0.009$) and for fertilizer with 20 pp ($p = 0.041$) – and strongly increases the use of organic practices such as cultural weed control (38 pp, $p < 0.001$), mulching (18 pp, $p = 0.004$), animal manure (22 pp, $p = 0.001$) and green manure application (31 pp, $p < 0.001$).

UTZ-RA-4C certification increases the likelihood of using shade trees (24 pp, $p < 0.001$), intercropping with legumes (11 pp, $p = 0.008$), slashing the undergrowth (16 pp, $p = 0.001$), and planting more coffee shrubs than the recommended spacing (10 pp, $p = 0.010$). FT-Org certification reduces the likelihood of using wind breaks (49 pp, $p = 0.001$) and increases the likelihood of tilling the soil (54 pp, $p < 0.001$), slashing the undergrowth (25 pp, $p < 0.001$), and using recommended spacing (18 pp, $p = 0.017$).

3.2. Socio-economic effects

Survey data reveal that the price FT-Org farmers received for fully washed coffee in the 2013–2014 season was 10% higher than the price non-certified farmers received (4364 UGX/kg on average versus 3947 UGX/kg), while UTZ-RA-4C farmers received a similar price for fresh coffee than non-certified farmers (857 UGX/kg on average versus 821 UGX/kg).

Instrumental variable estimations show that the two certification schemes have opposite effects on the socio-economic performance of coffee farms (Fig. 2). UTZ-RA-4C certification increases coffee yield at field level with 990 kg/ha ($p < 0.001$) and coffee labor productivity at household level with 7430 UGX/person-day ($p < 0.001$). These effects on land and labor productivity result in a positive income effect: UTZ-RA-4C certification is estimated to increase coffee income with 421,002 UGX ($p < 0.001$), which comes down to an increase in coffee income of 24% in comparison with non-certified households. Effects are opposite for FT-Org certification. Estimates show that FT-Org certification reduces coffee yield with 1121 kg/ha ($p < 0.001$), labor productivity with 3263 UGX/person-day ($p = 0.029$), and coffee income with 336,203 UGX ($p = 0.079$) or 19%. These effects on coffee productivity and income translate into more general household welfare effects. By increasing coffee yields, labor productivity and net incomes from coffee production, UTZ-RA-4C certification creates a positive effect of 754,000 UGX ($p = 0.015$) on total household income and a poverty reducing effect of 13.8 pp ($p = 0.022$). Given lower yields, labor productivity

[i] During in-depth interviews 40% of farmers admits to occasionally use chemical pesticides in FT-Org fields.

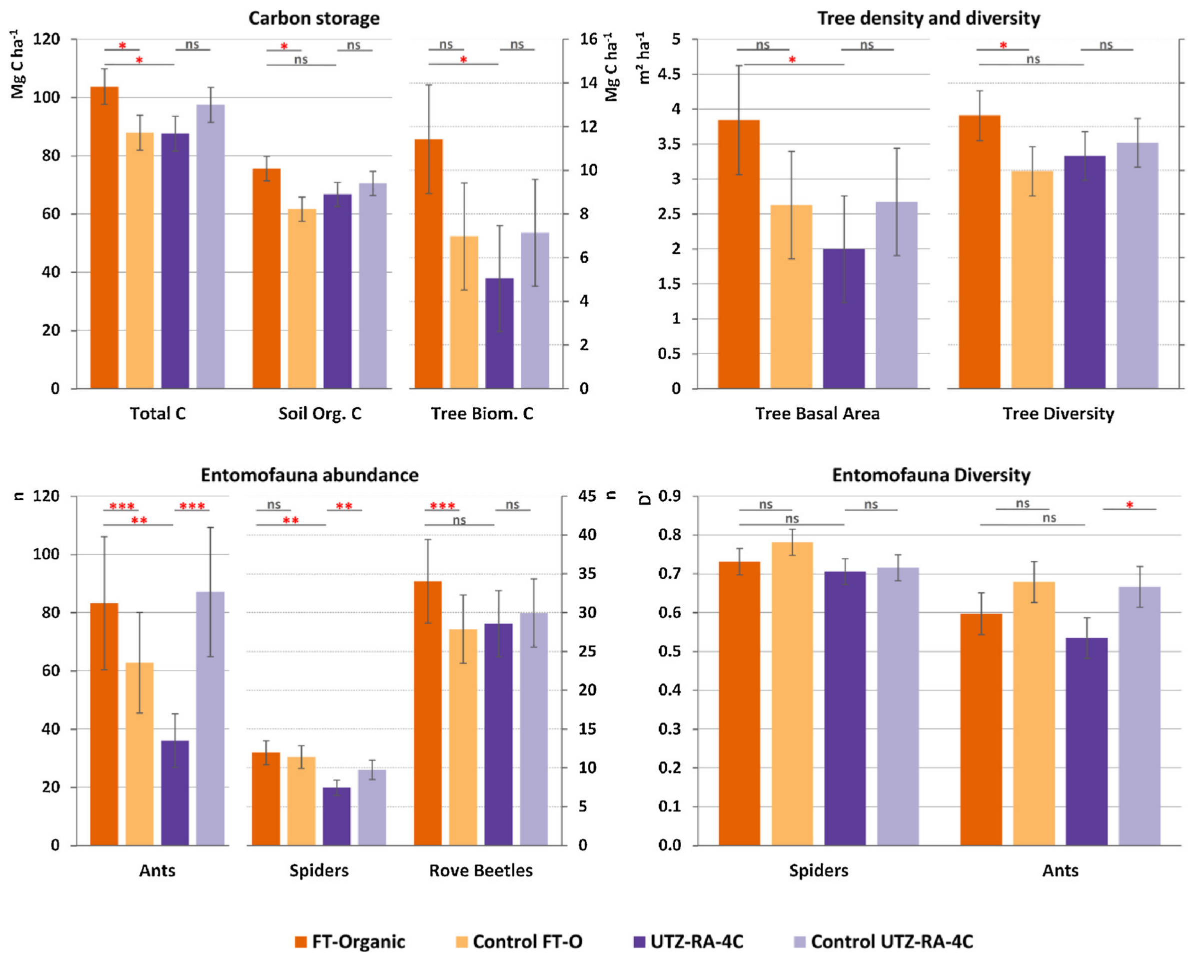

Fig. 3. Effect of certification on the environmental indicators carbon storage, tree density and diversity, and entomofauna abundance and diversity. Least-square means for certified (Fairtrade-Organic, UTZ-Rainforest Alliance-4C) and non-certified fields estimated from field inventory data (ns not significant, * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$). Estimated effects are obtained from linear mixed models (n = 74). Total C = Total organic carbon stock; Soil Org. C = Soil Organic Carbon stock in top 30 cm; Tree Biom. C = Carbon stock in above and below ground tree biomass.

and coffee incomes, FT-Org certification reduces total household income with 1,149,000 UGX (p = 0.055) and fails to reduce poverty. Estimates indicate a much higher poverty incidence for FT-Org households (50.2%) than for control households (33.6%) but the effect is statistically not significant (p = 0.142).

3.3. Environmental effects

Results of linear mixed models reveal that certification has an effect onfarm ecosystem services and biodiversity (Fig. 3). FT-Org fields store 15.8 ton more carbon per ha than their matched controls (+18%, p = 0.072). This difference is attributable to significantly higher soil organic carbon stocks (+13.9 Mg ha^{-1}, p = 0.023) and tree biomass carbon stocks (+4.5 Mg ha^{-1}, p = 0.212). For UTZ-RA-4C fields, differences with matched control fields in total carbon stocks (−9.9 Mg ha^{-1}), soil organic carbon stocks (−3.8 Mg ha^{-1}) and tree biomass carbon stocks (−2.1 Mg ha^{-1}) are not significant but when compared to FT-Org fields, significant differences in total carbon stocks (−16.1 Mg ha^{-1}, p = 0.062) and tree biomass carbon stocks (−6.4 Mg ha^{-1}, p = 0.069) are observed.

Table 1
Kendall's rank correlation between environmental indicators and coffee yield (kg/ha). Tau b reported; Significance indicated * $p < 0.10$, ** $p < 0.05$. *Source:* Authors' calculation from survey and field inventory data.

	Total sample		Non-certified		UTZ- RA-4C	FT-Org	UTZ-RA-4C & FT-Org
Sample size	74		38		19	17	36
Total Carbon (Mg ha^{-1})	−0.100		−0.190	*	0.235	0.081	−0.025
Soil Organic Carbon (Mg ha^{-1})	−0.068		−0.104		0.211	0.081	−0.041
Tree Biomass Carbon (Mg ha^{-1})	−0.141	*	−0.240	**	−0.164	−0.111	−0.111
Tree Basal Area (m^2 ha^{-1})	−0.141	*	−0.226	**	−0.164	−0.140	−0.108
Tree Diversity (D')	−0.064		−0.095		0.188	−0.170	−0.033
Ant Abundance	−0.221	**	−0.322	**	0.065	−0.015	−0.155
Spider Abundance	−0.096		−0.296	**	0.153	0.105	0.032
Rove Beetle Abundance	−0.111		−0.223	*	0.214	−0.186	-0.050
Spider Diversity (D')	0.031		0.022		0.177	0.082	0.088
Beetle Diversity (D')	0.045		0.056		0.106	0.199	0.045

Tree Basal Area (BA) – a good measure for the density of the tree cover – increases 30% or 1.2 $m^2 ha^{-1}$ with FT-Org certification but decreases 0.7 $m^2 ha^{-1}$ with UTZ-RA-4C certification. Due to the high variability in tree BA among coffee fields, the statistical significance of these differences is low. The difference in tree BA between FT-Org and UTZ-RA-4C is 1.9 $m^2 ha^{-1}$ ($p = 0.093$). Tree diversity increases 13% with FT-Org certification ($p = 0.059$) while UTZ-RA-4C certification has no impact on tree diversity. For invertebrate biodiversity – which are used because they are fast and sensitive indicators of environmental change (Andersen and Majer, 2004; Uehara-Prado et al., 2009; Brown, 1997; Armbrecht et al., 2005) – results indicate that FT-Org certification leads to higher abundance of ants (+33%, $p < 0.001$) and rove beetles (+22%, $p = 0.004$) while UTZ-RA-4C certification has a negative impact on abundance of spiders (-24%, $p = 0.027$) and ants (-59%, $p < 0.001$). When comparing FT-Org fields with UTZ-RA-4C fields, the same trends are confirmed with significant differences for spiders ($p = 0.013$) and ants ($p = 0.032$). UTZ-RA-4C certification also lowers ant diversity (−20%, $p = 0.057$).

3.4. Trade-offs

Correlation analyses reveal a link between agronomic practices and socio-economic and environmental outcomes (Tables SI7&8), and point to trade-offs between socio-economic and environmental effects (Table 1). The agronomic practice of using agrochemical inputs is positively correlated with yield, labor productivity and income, and mostly negatively correlated with invertebrate abundance and diversity. Organic practices such as tillage, legume intercropping, slashing undergrowth, manure application, mulching and cultural weed control are negatively correlated with yield, labor productivity and/or income, and mostly positively correlated with invertebrate abundance. The abundance and diversity of trees on coffee fields is positively correlated with invertebrate abundance and diversity, while the use of shade trees is also positively correlated with land and labor productivity. Rank correlations between coffee yield on the one hand and carbon storage and invertebrate abundance on the other hand are significantly negative in the sub-sample of non-certified fields – pointing to strong trade-offs between yields and ecosystem services (Table 1). These negative correlations are substantially lower and not significantly different from zero in the sub-sample of certified fields (and in both sub-samples of FT-Org and UTZ-RA-4C fields) – pointing to reduced trade-offs in certified coffee systems.

4. Discussion and conclusion

Private standards affect coffee yields, labor intensity and cost of coffee production, and on-farm carbon storage and biodiversity through the agronomic practices they promote, and farm-gate coffee prices through the price premium they entail. Standards affect farm incomes and poverty levels through their impact on yields, costs of production, and prices. Private standards are found to generate impacts that are not in line with the expectations they create towards consumers, and fail to create a win-win outcome between socio-economic and environmental sustainability. UTZ-RA-4C increases coffee yields, labor productivity and incomes, and decreases the incidence of poverty but reduces on-farm ecosystem services. FT-Org results in higher ant and rove beetle abundance, larger tree diversity and larger carbon storage on coffee fields but reduces yield, labor productivity and incomes - despite higher farm-gate prices. The latter relates to lower yields not being off-set by the FT-Org price premium: on average only 40% of the income loss from yield reduction is compensated by the price premium of 10%[ii]. Findings do not uphold the claims PSS make about their impact. FT focuses most on improving smallholder wellbeing and reducing poverty but is found to actually reduce productivity and smallholders' income while RA focuses more on nature conservation but is found to create adverse environmental impacts.

Results can be put in perspective to previous studies on the socio-economic and environmental impact of coffee standards, although evidence from Africa is scarce. First, we find that UTZ-RA-4C certification increases fertilizer, pesticide and fungicide use while other studies find no effect of RA certification on the use of agro-chemicals and organic fertilizers (Rueda and Lambin, 2013). The finding that UTZ-RA-4C certification increases the use of shade trees, mulch and intercropping with legumes is in line with results on RA certification from Colombia (Rueda and Lambin, 2013; Rueda et al., 2015) but does not corroborate findings from Brazil where no impact is found on soil conservation measures (Hardt et al., 2015). Org certification is mostly found to reduce agro-chemical use and to increase the use of organic fertilizer, shade trees and soil conservation measures (Blackman and Naranjo, 2012; Ibanez and Blackman, 2016). Our estimated 21 pp reduction in pesticide use, 20 pp reduction in inorganic fertilizer use, 22 pp increase in animal manure and 31 pp increase in green manure are smaller than other estimates of 40 to 70 pp reduction in agro-chemical use and 60 pp increase in organic fertilizer use (Blackman and Naranjo, 2012). Diverging results are likely related to the overall lower rate of agro-chemical use and more wide-spread use of organic fertilizer on Mt. Elgon. Agronomic studies on FT certification hardly exist, except for a study on Rwanda (Elder et al., 2013) reporting no impact on the use of pesticides, mulch and chemical fertilizer.

Second, the finding that FT-Org certification adversely affects productivity and does not improve the wellbeing of smallholder coffee farmers in spite of a price premium, corroborates earlier results on FT and double FT-Org certification not contributing to yield improvements, farm incomes and profits, poverty reduction and/or improved living conditions (Bacon et al., 2008; Jena and Grote, 2017; Mitiku et al., 2017; Ruben and Fort, 2012; Ruben and Zuniga, 2011; Valkila, 2009; Ibanez and Blackman, 2016). Our results on the socio-economic impact of UTZ-RA-4C are in line with previous findings on RA certification outperforming FT because of a strong positive yield effect (Ruben and Zuniga, 2011). A study from Central Uganda (Chiputwa et al., 2015) indicates a strong poverty-reducing impact of double UTZ-FT certification and finds no impact of double UTZ-Org and single UTZ certification. Although caution is needed in comparing results – because of different years of observation and different coffee systems – findings might imply that from a producer point of view it is more effective to combine FT with UTZ as their respective focus on fair prices and on good agricultural practices and yield improvements results in reinforcing effects, than it is to combine FT with Org certification.

Third, findings contradict earlier results that show no impact of FT-Org and Org certification on ant and bird species richness (Philpott et al., 2007). We find that FT-Org certification creates substantial environmental benefits, which is in line with previous findings on Org certification increasing soil organic carbon (Elder et al., 2013); tree diversity, basal area and biomass (Blackman and Naranjo, 2012; Haggar et al., 2015; Philpott et al., 2007); and leaf litter ant species richness (Armbrecht et al., 2005). We find adverse environmental effects of UTZ-RA-4C certification while previous studies do point to larger tree diversity but no effect on species abundance and diversity or soil organic carbon in RA certified systems (Haggar et al., 2015). These previous studies focus on Latin-America and it is not straightforward to compare results from Eastern Uganda where poverty is high, coffee fields small

[ii] This is derived as follows: for the average farmer the negative income effect of yield reduction is 627,021 UGX (i.e. 1,112 kg/ha yield reduction * 0.6 ha coffee on average * 3,947 UGX / kg for non-certified coffee * 0.2381 conversion from fresh to fully washed coffee); only 40% of this negative income effect or 248,180 UGX (i.e. a positive price effect of 417 UGX/kg * 4,166 kg / ha for non-certified coffee * 0.6 ha coffee on average * 0.2381 conversion from fresh to fully washed coffee) is compensated by the price premium of 10% or 417 UGX / kg in the season 2013-2014.

and agro-chemical application low with findings from middle-income countries in Latin-America where farms are larger, farmers less poor and agro-chemical application more common. Yet, the lack of on-site environmental benefits in our study likely relates to the combination of RA certification with UTZ that promotes agro-chemical use as good agricultural practice and stipulates training on agro-chemical application.

Results imply that adoption of improved agronomic practices and productivity effects are more important than value-adding and price effects in creating welfare gains from PSS. The income-enhancing and poverty-reducing effect of UTZ-RA-4C certification is linked to substantial positive effects on land and labor productivity while there is hardly a price premium for UTZ-RA-4C certified coffee and no home-processing. The negative income effect and the insignificant poverty effect of FT-Org certification result from adverse effects on productivity that are not off-set by the current price premium or by home-processing to fully washed coffee. Results support the view that improved agronomic practices are key for increasing coffee productivity (Bongers et al., 2015; van Asten et al., 2011); that yields are more important than prices in increasing returns for smallholder coffee farmers (Barham and Weber, 2012; Perfecto et al., 2005); and that low intensity agriculture promoted by PSS can trap farmers into poverty (Valkila, 2009).

Results suggest that PSS do not create a win-win outcome for socio-economic and environmental sustainability. UTZ-RA-4C certification creates substantial economic benefits but ecological impacts are adverse. FT-Org certification leads to higher carbon stock and biodiversity conservation but reduces productivity and economic returns. Despite resulting in win-lose outcomes PSS do contribute to reducing trade-offs between socio-economic and environmental goals. The production practices promoted by PSS do allow to increase productivity at a lower cost in terms of ecosystem services loss, which implies that improving the sustainability of smallholder coffee production is possible. Our results do not support the rationale of multiple certification to exploit the complementarities between PSS with a socio-economic focus (such as FT) and PSS with an environmental focus (such as Org and RA). This over-certification – which is likely to raise transaction costs – is mainly demand-driven and used as a marketing strategy and product differentiation tool by larger players in the chain. PSS should rather be designed to compensate for existing trade-offs between socio-economic and environmental benefits. On the one hand, this might entail harmonization of PSS into a set of requirements that minimizes trade-offs between socio-economic and environmental outcomes and leads to win-win outcomes. On the other hand, this might entail differentiation of PSS to adapt requirements to local agro-ecological and socio-economic conditions.[iii]

An adverse socio-economic or environmental impact of PSS could result either from a lack of effectiveness of PSS to improve sustainability or from a lack of compliance to PSS – or both. We find that PSS are not strictly complied to but do affect agronomic practices on coffee fields and that these practices are correlated with productivity, carbon stock and biodiversity. Improving the sustainability impact of PSS likely entails a focus on both more effective requirements in PSS, and better control and enforcement mechanisms. Yet without the former, the latter is meaningless and merely extracts rents from supply chains.

The inter-disciplinary approach in this study results in unique integrated insights on the socio-economic and environmental benefits and trade-offs of certification, and is based on methodological advancements. The socio-economic analysis on productivity, income and poverty effects is based on econometric analysis of survey data, taking into account a large set of geo-referenced agro-ecological field characteristics. The environmental analysis on carbon stocks and tree and invertebrate diversity is based on field measurements in certified and matched non-certified coffee fields. A drawback is that only on-farm impacts are considered – which is nevertheless in line with the on-field and on-farm sustainability focus of PSS. Requirements on environmental protection in PSS may create environmental impacts off-site – especially on forest conservation (Takahashi and Todo, 2014; 2017) – which requires the integration of landscape ecological indicators in impact studies (Rueda et al., 2015; DeFries et al., 2017). Also socio-economic benefits from PSS may include broader village or cooperative level effects, as suggested particularly for FT (Raynolds, 2012). While we show that the agricultural practices promoted by PSS are correlated with ecological and socio-economics outcomes, we cannot entirely disentangle the overall estimated on-farm impacts into price effects, effects through cooperative strengthening and through changing agricultural practices. Our results are case specific but do imply that there is room for improvement in the design of PSS. The sustainability implications of PSS may differ in other regions where coffee is produced under different agro-ecological, socio-economic and institutional circumstances, or in other periods when climate and market conditions are more conducive. Nevertheless, we conclude that PSS in the coffee sector do not always walk the talk.

[iii] For Uganda this likely implies taking into account the reality of a coffee-banana intercropping system (cf. van Asten et al., 2011; Jassogne et al., 2013).

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Appendix A. Supplementary data

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