The Economics and the Ecology of Shade-Grown Coffee

Abstract

Specialty coffee markets that recognize coffee-quality price premiums can improve business conditions for smallholders and promote agro-ecological practices. Specifically, better qualities are associated to the use of forest canopy or shade-grown coffee. This production system not only improves product quality but also contributes to climate change adaptation and offers habitat for coffee-borer predator birds. We studied the Relationship Coffee Model (RCM), a business model that supports long-term partnerships between coffee buyers and smallholders based on product quality. We examined how biophysical conditions and production practices affect smallholder's ability to participate in this model. Furthermore, we considered common unobservable variables driving grower's participation such as farm soil-quality and connection to social networks. In turn, we evaluated key environmental, socio-economic and technological outcomes, including tree and bird population diversity. Our estimations indicated that RCM participants employed more sustainable resource management practices, had better access to credit and were more informed and optimistic about the coffee business. However, we did not find significant farm-gate price differences. Increased adoption of organic farming and shade-grown systems to elevate coffee quality can stimulate sustainable business strategies

Keywords: Specialty coffee; shade-grown coffee; quality; sustainable agriculture; environment

1. Introduction

Coffees with remarkable attributes in aroma, flavor, and body are often referred to as specialty coffees. Specialty coffee is the most dynamic segment of the industry, with sales increasing from U$ 7.8 billion in 2000 to $25.3 billion in 2014 in the U.S. alone (SCAA, 2015; TransFair, 2008). Participation in this market can offer price premium opportunities for over 100 million people in developing countries, who account for 80% of global coffee production but face substantial price volatility in coffee commodity markets (Fairtrade, 2012). In addition to higher grower income, specialty coffee markets can help incentivize the adoption of agro-ecological practices associated with elevated product quality (e.g. shade-grown systems and manual harvest). Such practices provide various ecological services including preservation of bird habitats, pest control with less reliance on agrichemicals, and improved soil health, among others (Carvalho, 2006; Elder et al., 2014; Karp et al., 2013; Läderach et al., 2011; Méndez et al., 2009; Oberthür et al., 2011; Rappole and King, 2003; Wezel et al., 2014). Nevertheless, participation in specialty markets also implies additional costs for the growers. For instance, shade-grown, handpicked, or organic systems might reduce coffee yields, increase labor costs, and increase pest exposure in the short term (Atallah and Gómez, 2014; Valkila, 2009; Van der Vossen, 2005; Vellema et al., 2015). Furthermore, firms that currently certify product quality through various labels (e.g., Starbucks' C.A.F.E. and Nespresso's AAA) tend to be larger market players and raise concerns regarding arbitrage and market power (Elder et al., 2014). In sum, specialty coffee markets offer opportunities for smallholder growers but they require changes in production and business practices to participate in them.

Previous studies have focused primarily on evaluating the impact of certifications such as Fair Trade and Organic on enrolled smallholders (see, for example, Ibanez and Blackman 2016; Nelson and Pound 2009; Podhorsky 2013; Ruben and Fort 2012). However, the literature has largely ignored the farm- and community-level impacts of quality-based certifications and business models. One exception is Vellema et al. (2015), who show that the positive income effects of quality-certifications may be offset by the increased opportunity cost of smallholder household labor in alternative productive activities. To fill this gap in the literature, we examine socio-economic, environmental and technological impacts of smallholder participation in high-quality coffee markets through an emerging business model, namely the Relationship Coffee Model (RCM).

The RCM is a business model where coffee quality is at the core of the relationship between growers and global buyers. This business model is a specialty coffee value chain arrangement where smallholders work closely with roasters, buyers and importers to establish a direct, long-term trading partnership for coffees that have high-quality profiles. In addition to price premiums based on quality, RCM promotes transparency, traceability and active engagement of smallholders throughout the value chain (Raynolds, 2009). For instance, each year a group of RCM smallholders and coffee roasters meet for five days to analyze coffee market challenges and mutually agree on trading conditions and quality standards for the following cropping season (Sinclair, 2012). In addition, smallholders connect directly with social lenders who facilitate open-contracts with buyers as collateral for short-term, agricultural financing. This triangulation model for pre-harvest financing is crucial to the RCM model as it allows for longer time horizons for the producer organization to collect, store and evaluate coffee for entry into high-quality markets. Moreover, RCM exhibits characteristics typically observed in shared value creation business models such as collaboration in capacity building on farming practices and streamlining the logistics (Porter and Kramer, 2011). For instance, to ensure contract adherence and on-time delivery of coffee, the RCM importer works closely with cooperative leaders and farmers to train producers on best agricultural practices, risk management, quality assurance and business management.

Furthermore, the importer promotes the use of information systems that provide tracking of coffees as they make their way from origin to warehouses (Sustainable-Harvest, 2017). Finally, RCM contracts are often more complex than those for standard green coffee. They typically include specifications on physical and sensorial product quality (Ponte and Gibbon, 2005). Although under RCM there are not official compliance criteria in the way that there is for other standards (e.g., Fair Trade, Rainforest Alliance, Utz), disputes based on delivered product quality can be sent to an impartial third party, generally a licensed Q grader.

To estimate the outcomes associated with RCM participation, we developed a conceptual framework identifying inputs that influence smallholders' ability to produce high-quality coffee and thereby to participate in RCM. These include biophysical conditions, production factors and available technologies. Second, we collected farm-level data on crop elevation, soil quality, biodiversity of plants and birds, land-use, and household socio-economic characteristics in two coffee growing regions in Colombia. Third, we used a propensity score matching model (Imbens and Rubin, 2014) to identify specific inputs affecting smallholders' ability to participate in RCM and to assess outcome differences between comparable RCM participants and non-participants. In general, this study sheds light on the prospects for agricultural business models that target product quality while promoting sustainable environmental outcomes and a profitable integration of smallholders into high value chains.

2. Conceptual Framework

In our conceptual framework, we first identified input variables known to affect both coffee quality and RCM participation by smallholders (Fig. 1). Contracts under RCM generally require a minimum threshold in coffee quality (typically over 80 points on a scale from 0-100) for participation; otherwise, smallholders participate in the conventional coffee market. We then explicitly compared socio-economic, environmental and technological outcomes observed for RCM participants and non-participants. To classify variables as input or outcome variables, we used the notion of stock and flows proposed in studies linking ecological and economic systems (Häyhä and Franzese, 2014). Accordingly, input variables refer to long-term endowments or stocks of human, physical, social and natural capital and the types of technologies employed to combine these stocks to yield a target-product quality level. Outcome variables, for their part, refer to the short-term flow of environmental services, socio-economic effects and technological and management innovations derived from using those assets (Costanza and Daly, 1992; Odum, 1994). We hypothesize that these outcomes depend on smallholders' ability to participate in RCM.

[FIGURE 1 HERE]

2.1 Input Variables

Several types of inputs can impact coffee quality at different levels. At a regional scale, elevation influences coffee quality, while other biophysical characteristics such as terrain slope and soil properties are more relevant when analyzing a particular farm (Läderach et al., 2011; Oberthür et al., 2011). Furthermore, soil chemistry and nutrient retention capacity are important factors associated with coffee-cup quality (Castro-Tanzi et al., 2012). Consequently, in our framework, the first set of inputs comprises farm elevation as well as biological, chemical and physical soil health indicators at the farm level (Fig. 1).

In addition to biophysical conditions, the use of certain production practices as well as pre- and post- harvest technologies affects coffee quality. For instance, harvesting, fermenting, de-pulping and washing exclusively ripe coffee cherries improve product quality and prevent specific crop diseases (Dias et al., 2012; Guhl, 2008; Knopp et al., 2006; Mueller et al., 2013). Extension services, education programs and associations collectively disseminate and educate smallholders in these quality-enhancing practices.

Accordingly, we defined a second set of variables that characterize the technologies used by the smallholders and the available inputs that facilitate the implementation of specific practices related to higher quality. Indicators that reflect the type of technologies used by smallholders include identification of the production factors more intensively used (e.g. percentage of land allocated to coffee crops or remuneration to contracted workers), coffee-varieties grown (e.g. percentage of non-rust resistant and rust resistant), and any associated coffee certifications that validate specific-production practices (e.g. Fair Trade, Organic). In addition, factors that influence grower's ability to adopt specific harvest and post- harvest techniques include training in coffee production, ownership of machinery or other forms of physical capital, and participation in social networks that facilitate positive spillovers effects (Angelucci and Di Maro, 2016; Bebbington, 1999; Conley and Udry, 2010; Weber, 2012).

2.2 Outcome Variables

Outcomes derived from RCM participation are not limited to the quality price premium and additional income received by smallholders. For instance, to increase product quality many RCM participants grow coffee under a canopy of trees, indirectly stimulating sustainable land-use systems (Elder et al., 2014; Läderach et al., 2011; Vaast et al., 2006). Furthermore, RCM engages smallholders in commercialization and marketing processes that promote an active interaction between buyers and suppliers and positively affects smallholders' knowledge of the business model from farm to table.

We considered three broad outcome dimensions where RCM participation could have a potential impact: environmental, technological and socio-economical. The environmental and technological dimensions in coffee are closely related and typically involve issues related to water use and discharge (especially for washed *Arabica* coffee), tree cover conservation in coffee plots and surrounding areas, and use of pesticides and fertilizers to increase productivity. These practices have important impacts on several ecosystem services such as water quality and regulation, biodiversity, and nutrient cycles (Ibanez and Blackman, 2016; Jha et al., 2014; Siebert, 2002; Tscharntke et al., 2011). In addition, we consider technological changes not only limited to the use of specific harvest practices, but also to innovations in the smallholders' role in commercialization activities. This is important, because smallholders often have a poor understanding of market instruments such as price premiums and certifications (Ruben and Fort, 2012). Our framework includes metrics reflecting growers' knowledge and empowerment with respect to downstream value chain activities and functions (e.g. knowledge of the exporter and roaster who buy the coffee that they produce).

We analyzed socio-economic outcomes through a broader lens than just income or prices, as these variables are very volatile and only capture part of the outcomes of participation in agricultural commodity chains (Rueda and Lambin, 2013a). For instance, we considered outcomes likely to affect smallholders´ health such as use of protective gear during agro-chemical application and the availability and access to alternative food sources. In addition, we considered credit access that can affect smallholder possibilities to accumulate assets (Bacon et al., 2008; Raynolds, 2009). We also measured price premiums using farm gate prices received by each grower. Lastly, we evaluated how RCM participation affects grower's expectations about coffee market, measuring the desire that their children would continue in coffee business in the future.

Finally, our conceptual framework (Fig. 1) illustrates that initial inputs, technology, and biophysical conditions can be affected by RCM participation and the outcomes can lead changes in the long run. For instance, the adoption of shade-grown coffee and tree diversity to potentially improve product quality also provide habitat to many resident and migratory birds, which in turn, can halve coffee berry borer infestations. This service can save a medium-sized coffee farm up to US$9,400 annually (Karp et al., 2013; Newell et al., 2014) and modify the cost structure and technologies used on the farm. Another example is related to land-use decisions. Rueda and Lambin (2013b) showed that regions selling to high-quality and sustainable coffee markets experienced the greatest increase in area planted. We acknowledge these potential long-term outcomes when considering indicators such as bird population.

3. Data

To evaluate the outcomes of RCM participation, we considered an organization where all their members have been involved with this business model for six years at the time of data collection. This group of RCM participants included 78 smallholders from a cooperative located in the Cauca department (state), Colombia. The control group included 186 smallholders who did not participate in RCM. Of these, 66 smallholders were located in the same department than RCM participants. The other 120 smallholders in the control group were located in the Antioquia department and represented smallholders across a range of coffee quality cup profiles and affiliations with coffee grower associations. We assembled a farm-level database of input and outcome variables and collected information for a variety of indicators, as described below.

3.1 Socio-economic variables

We conducted a voluntary survey eliciting detailed socio-economic information of the household during the period 2013 and 2014. For each farm in our sample, we interviewed the head of the household and collected information on family composition, health status, educational level, number of family members working in the farm, among other household characteristics. In addition, the survey incorporated questions about production factors and endowments such as availability and use of machinery and equipment, farm size and farm ownership, among others. The survey also included questions related to production, harvest and post-harvest practices, common crop diseases and risks, use of paid labor, and farm gate prices. Finally, the survey considered information on community characteristics, including participation in civil organizations, security conditions in the region and smallholder's expectations about the future of the coffee business.

3.2 Soil-quality variables

During the same period, we collected soil samples from fertile and less fertile areas on each farm, which were identified by the smallholders following the protocols and transportation requirements for their posterior analysis (Gugino et al., 2009). These analyses included long-term soil health indicators such as aggregate stability and water capacity; biological soil indicators, including organic matter, active carbon and potentially mineralizable nitrogen; and a protein analysis to determine storage of organic nitrogen for later use by the soil system and plants. In addition, we performed a standard soil chemical composition soil test that reflect soil management practices such as the intensive use of inorganic fertilizers that can lead soil degradation in conventional coffee agriculture (Castro-Tanzi et al., 2012)

3.3 Biophysical characteristics of coffee plantations and landscape

We documented differences between land use practices in RCM and non-participant smallholders by collecting spatially explicit biophysical data along delimited quadrants at each farm. We used a random sampling design to measure coffee-tree density, as well as non-coffee tree species richness and composition, canopy strata and soil cover. On each farm, we established a 20 x 50m quadrant, and at the northwest and southeast corners of the plot were additionally demarcated 10 x10m quadrants. Within each of the $10m^2$ quadrants, we measured the diameter at breast height (*dbh*) and identified species of each non-sapling tree (i.e., >2m tall at bifurcation). In addition, within the larger 20 x 50m quadrant, we assessed tree species richness by counting the number of different tree species within the entire transect area and estimated complexity of forest structure using a modified Relevé method (Mueller-Dombois, 2001). We used this information to estimate above-ground biomass

(Alvarez et al., 2012). All quadrants were geo-referenced in their southwestern-most point, where also we recorded the elevation.

3.4 Bird assessment

Bird communities were surveyed using a point-count methodology (Bibby et al., 2000). Using the same protocol to establish habitat-sampling points in the coffee landscape, we randomly established a survey point within each coffee quadrant and another at the nearest edge between the coffee and an adjacent habitat. For each point count, a trained observer recorded all birds seen or heard within a 10-minute period between 05:45am and 11:00am, which corresponds to the period with the greatest bird activity. Distance to each bird, its relative location within the coffee plot (i.e., being inside, outside, or on the edge of each coffee plot), and participation in mixed-species foraging flocks was recorded for each individual detected within 100 meters of the point count center. We recorded 205 bird species in surveys. Species diversity (i.e., total number of species detected on a farm) and total bird abundance were used as two broad descriptors of the bird community. Because we were interested in potential pest control services provided by birds, we considered species within three genera identified in feeding trials by Karp et al. (2013) to be predators of the coffee borer beetle: *Setophaga (S. petechial, S. cinerea, S. fusca, S. pitiayumi, S. ruticilla*), *Basileuterus (B. culicivorus, B. luteoviridis)* and *Pheugopedius (P. mystacalis).*

3.5 Quality Scores

A certified coffee cupper in our team (Q grader) verified the coffee quality and quality evaluation protocols followed by the cooperative under RCM participants and non-participants. These quality assessments are actually performed by the roasters when deciding to buy or not specific coffee lots, and follow the Specialty Coffee Association of America standards (SCAA, 2013). Although it was not possible to collect and analyze individual coffee samples for each grower, it was verified that the coffee gathered and exported by the cooperative under RCM fulfilled the required standards. In addition, in the control group, we found smallholders with quality scores that potentially would allow them to participate in the RCM.

4. Empirical model

Due to the absence of a baseline data, one possible way to assess outcome differences between participants and non-participants is to establish comparable groups of growers on each market (Blackman and Naranjo, 2012; Ibanez and Blackman, 2016; Ruben and Zuniga, 2011). We followed Imbens and Rubin's (2014) algorithm and propensity score matching to restrict our analysis to a subset of comparable RCM participants and non-participants. First, we selected the relevant input variables (Fig. 1) to predict RCM participation based on a large set of candidate variables. Subsequently, we verified that selected input variables were similar among RCM participants and non-participants (i.e. balancing and overlapping properties). Finally, we estimated differences in outcomes between equivalent participants and non-participants.

To predict the probability of participate in the RCM (or *p-scores)* we specified a logistic regression where the dependent binary variable W – one if the grower participated in RCM, zero if not - was a function of all possible input variables. A critical assumption of this methodology is referenced by the literature as *unconfoundedness* (Imbens and Rubin, 2014). This assumption implies that, given the potential outcomes and the observed inputs, the probability (*Pr*) of RCM participation equals the probability of participation given only the observed inputs. In mathematical terms:

$$\Pr(W_i = 1 |\, Y_i(0), Y_i(1), X_i) = \Pr(W_i = 1 | X_i) = e(X_i) \qquad (1)$$

In equation (1), $Y_i(0)$ and $Y_i(1)$ represent the outcome variables for grower i if not enrolled and enrolled in the RCM respectively, X is a vector of inputs or observed variables used to predict participation, and *e* is the probability of participation in the RCM, or the propensity score (*p-score*). The *unconfoundedness* assumption is not testable because we lack counterfactuals; in other words, we cannot know the outcomes had a grower made a different choice in terms of RCM participation (RCM $(Y_i(0), Y_i(1))$. In that case, our strategy was to collect as much information as possible from each grower (about 950 variables), assuming that even unobservable characteristics could be properly accounted for through the use of observable input variables.

Furthermore, we verified that RCM participants and non-participants shared a *common support*, which refers to an initial block of comparable *p-scores* among participants and non-participants (Heckman et al., 1997). This procedure, called trimming, ensures the existence of comparable probabilities between groups, and improves the consistency of the estimated parameters, but at the cost of reducing the original sample. Finally, we matched participants and non-participants according to the estimated propensity scores. We estimated outcome differences between the two groups based on six matching criteria. (See supplementary material for more details).

5. Results

Table 1 shows the input variables that were selected by Imbens and Rubin's (2014) algorithm to predict RCM participation (see Appendix for model specification and estimation). These include biophysical and environmental variables associated to geographical location (e.g. altitude); soil characteristics (e.g., respiration, protein score); production factors related to human capital (e.g. skills, health), physical capital (e.g. ownership of productive assets, infrastructure) and social capital (e.g. social interactions) and production, harvest and postharvest practices (e.g. coffee varieties, share of coffee in total production area, environmental/social certifications).

[TABLE 1 HERE]

A comparison of means of input variables between RCM participants and non-participants in the full sample shows that RCM participants enjoy some input advantages compared with non-participants (left columns, Table 2). In particular, higher indicators of protein and soil respiration among RCM participants are associated to soils' ability to make nitrogen available by mineralization, soil aggregation and water movement (Gugino et al., 2009). In addition, greater levels of human, social, and physical capital also give RCM participants an advantage compared to non-participants. In terms of human capital, most RCM participants received training in agricultural production from twice as many organizations (1.88 institutions for RCM participants versus 0.85 for non-participants). Social capital was also higher among RCM participants, as they participated more in formal and informal networks with other coffee smallholders than non-participants. The relatively greater levels of physical capital of RCM participants are reflected in higher rates of ownership of coffee production assets and more informal saving stocks compared to non-participants. However, the greatest difference between the groups was the enrollment in certification programs such as Fair Trade. Almost all RCM participants (97%) but only 30% of the non-participants were certified. Collectively, these differences suggest the possibility of selection bias in our sample since smallholders could perform better regardless of their participation in RCM.

[TABLE 2 HERE]

We apply trimming procedures suggested by Imbens and Ruben (2014) to obtain a comparable subsample of RCM participants and non-participants (right columns, Table 2). The final subsample of comparable participants and non-participants includes 25 percent of the observations in the full sample. As expected, after refining the sample, we found no significant differences in input variables between participants and non-participants. The only exception was the index that aggregates labor-related certifications (in particular Fair Trade), which exhibited a statistically significant association with RCM-participation. Moreover, additional statistics confirmed that inputs were balanced and overlapped (Tables A2-A3), with the exemption of labor-related certifications. This issue will be considered at the end of this section. Finally, additional input variables we controlled for were not selected by Imbens and Rubin (2014) algorithm to predict RCM participation and were not statistically different between comparable participants and non-participants. In particular, for both groups the area of planted coffee and the farm size did not exceed 2 to 3 hectares respectively (Table 2).

Outcome variables are described in Table 3 and were classified as environmental, technological and socio-economic outcomes according to the conceptual framework (Fig. 1). As mentioned earlier, outcome variables refer to management decisions (e.g. resources management) or flow variables (e.g. access to credit) that influence the stocks and endowments required for coffee production. Table 4 summarizes the differences in outcome variables between comparable RCM participants and non-participants. The results showed that some outcome variables exhibit statistically significant differences in all the six matching criteria (e.g. preparation of own organic fertilizers or grower's knowledge of final buyer/exporter of their coffee). However, in other cases, outcome variables where not significantly different in all criteria but at least two out of six matching criteria exhibited statistically significant differences (e.g. crop tree diversity). The lack of consistently significant differences across the six matching criteria may be partly due to the fact that our sample was limited to a relatively small number of RCM farms. Our difference in means tests may have less power as a result (Blackman and Naranjo, 2012).

[TABLE 3 HERE]

Our findings suggest that RCM participation is associated with sustainable environmental and technological outcomes (Table 4). Specifically, RCM participants used on average at least one additional water saving technique compared with similar non-participants. In addition, RCM participants affirmed that they used biological control methods more frequently than other smallholders in the area (between 18 and 56 percentage points more). Furthermore, a greater proportion of RCM smallholders prepared their own organic fertilizers compared to non-RCM participants (between 27 and 42 percentage points more), used organic fertilizers during the last cropping season (between 43 and 59 percentage points more), and adopted more organic fumigation alternatives for coffee rust (between 28 and 65 percentage points more). Our results indicate that RCM farms had greater tree diversity than their non-participant counterparts (one to two more trees species per plot in average). In addition, the RCM participant' quadrants had on average seven more *Inga-edulis* trees than non-participants. We also found that RCM participant' farms had 8.5 more tones of biomass per hectare but this difference was not statistically significant (p-value was 0.18 according to third matching criteria).

[TABLE 4 HERE]

In relation to socio-economic outcomes, we found no significant differences in farm-gate prices received by RCM participants and non-participants (Table 4). However, RCM participants had 30 to 60 percentage points more access to credit for, than non-participants. We also identified outcomes that affect livelihood resilience. Specifically, for nearly 50 percentage points more of the comparable RCM participants, over half of the food that they consume daily was produced in their own farms. These food sources were not only for self-consumption or subsistence. RCM participants sold in local markets and consumed a greater number of food staples produced on their farms compared to non-participants. Regarding factors describing smallholders' link to the value chain, our results suggest that RCM participants had better knowledge of the value chain (e.g. retail and wholesale market situation and outlook) than non-participants. In addition, a higher proportion of participants (at least 35 percent points more) expressed their expectation and desire that future family generations continue in the coffee business (Table 4).

Moreover, to expand our long-term outcome indicators, we estimated differences between participants and non-participants in the bird survey, for the full and refined samples (Table 5). We found similar abundance and richness of bird species in participant and non-participant farms for the refined sample. Because a bird-friendly habitat can take years to develop fully, biodiversity benefits are best examined over longer time scales. Interestingly, the most common genus of documented borer predators, *Setophaga*, was nearly 60% more abundant on participant farms on average (1.92 and 1.19 for participants and non-participants, respectively). Though this difference was not statistically significant, it hints that pest control services provided by birds may be more common on RCM farms.

[TABLE 5 HERE]

Finally, to attribute any of the previous outcome differences to RCM participation, we considered if in general growers who are already using certifications, in particular Fair Trade, are the same who enter the high-quality market. We did this because in the cooperative analyzed Fair Trade preceded RCM enrollment. In addition, the Imbens and Rubens procedures above indicated problems of balancing and overlapping in this input variable. First, Fair Trade certification does not recognize product quality premiums *per se*. Although some Fair Trade certified contracts require specific quality standards, Fair Trade criteria are mostly socio-economic and generally targets an economically disadvantaged producers that can receive price premiums without concerns about product quality (Raluca et al., 2014). In this scenario, the certification may not by sustainable by itself because consumers can eventually reduce their demand Fair Trade certified coffee if the quality is low (De Janvry et al., 2010; Hainmueller et al., 2014; Hertel et al., 2009; Van Loo et al., 2015; Verteramo et al., 2014).

Second, in our sample, the environmental outcomes associated to RCM participation were not explained by certifications. In fact, only 12.8% of RCM participants were Organic certified or in process of certification. Moreover, the index that aggregates environmental certifications was not selected by Imbens and Rubin algorithm to predict RCM participation and was not statistically different between participants and non-participants (Table 2). In addition, considering that uncertified growers could learn and adopt practices from certified growers, we considered potential spillover effects by controlling for smallholders' participation in formal and informal networks (Ibanez and Blackman, 2016). Furthermore, we ran the Imbens and Rubin (2014) algorithm for Fair Trade certified (treatment) and non-certified (control) smallholders and we did not find significant differences in outcomes associated with RCM participation. The only exception was the use of protective equipment during fumigation, which is not surprising given that Fair Trade certification aims to verify safe-working conditions (see Supplementary material for estimation details). Taking together, previous literature and our analysis suggested that Fair Trade or other certifications do not guarantee participation in high-quality coffee markets. Therefore, our estimated differences in outcomes can be attributed to RCM-participation.

6. Discussion

Our results provide evidence that smallholder participation in quality-oriented coffee markets is associated with desired environmental, technological and socio-economic outcomes. In particular, the results showed that RCM participation is related with sustainable landscape management decisions such as keeping high tree diversity in coffee farms. Previous studies suggest that tree diversity and canopy improve coffee quality, contribute to soil health and reduce production costs in the long run. In fact, the relationship between coffee quality and shade-grown handpicked coffee has been promoted by coffee companies, which realized that substitution of shade plantations for densely planted full-sun plantations significantly reduces coffee quality (Elder et al., 2014; Rappole and King, 2003). In addition, tree diversity also contributes to nitrogen-fixation, conserves soil health, diminishes nutrient leaching and forest fragmentation, and reduces dependence on chemical inputs due to pest adaption (Carvalho, 2006; Méndez et al., 2009; Rhoades et al., 1998; Wezel et al., 2014). In fact, we provide evidence of less intensive use of chemicals in RCM farms (reflected in 52.9 *ppm* less potassium compared to non-RCM soil samples). Additionally, our results suggest that the increased diversity of trees and products observed in RCM farms can expand the set of foods that smallholders consume and represent an additional source of income. Furthermore, among the higher tree diversity at the RCM crops, we found that there were a higher number of *Inga-edulis* trees. These tropical tree species provide the preferred habitat for insectivorous birds that offer pest control services

Regarding sustainable resource management practices, we found that RCM growers used more water saving techniques and biological control methods. Water saving is particularly important considering that converting harvested ripe berries into dry green coffee requires large volumes of water at depulping, fermentation and washing processes (Van der Vossen, 2005). In addition, among practices that promote environmental sustainability, we showed that a greater proportion of RCM participants prepared and used organic fertilizers and organic fumigation alternatives against coffee rust. Overall, these results suggest that economic incentives and environmental goals are aligned when smallholders consider organic farming alternatives and the inclusion of diverse trees in coffee-shade composition to improve coffee quality. These environmental outcomes are particularly relevant when evaluating agricultural sustainability (Whitehead, 2016).

A primary benefit of RCM participation is thought to be higher prices. Surprisingly, we found no significant differences in farm-gate prices received by RCM growers and non-participants. Further inquiry with the smallholders suggested that RCM participants received these benefits indirectly, in the form of enhanced access to credit and other financial and social services from the cooperative. In general, cooperatives facilitate the negotiation process, gather the volumes and qualities required by clients, sign the contracts and manage and allocate the price premiums paid by coffee buyers. Furthermore, cooperatives are crucial to link smallholders with high-value markets. However, the ownership and governance of these cooperatives ultimately may determine who benefits from quality differentiation (Neilson, 2007; Wollni and Brümmer, 2012). Through our interviews, and from other similar studies, we found that smallholders who enrolled in cooperatives often complain about the lack of communication with cooperative leaders in decision making processes (Prevezer, 2013). The allocation of price premiums remains a critical challenge for specialty coffee business models. It is therefore critical to examine the consequences of alternative grower payment schemes.

Given the increasing relevance of specialty coffee markets, it is important to identify mechanisms that allow smallholders to participate in them. We found that business models such as RCM positively impact the way in which smallholders perceive the coffee industry and their expectations. At the same time, private companies such as Starbucks and Nestle's Nespresso have contributed substantially to increase the consumer awareness of the link between product quality and sustainability. These initiatives help smallholders to participate in global markets based on product quality. However, it is unclear the extent to which large corporations share the benefits of differentiated, high-quality coffees with smallholder growers (Elder et al., 2014). Moreover, the poorest smallholder growers may not have the ability to participate in specialty coffee markets (Gómez et al., 2011). In this context, stimulating the demand for specialty coffee among consumers in exporting countries (e.g. Brazil, Colombia) could facilitate the participation of smallholder growers and reduce their dependence on international markets. Finally, although traditional certification schemes do not focus on quality standards, they communicate relevant information to consumers who value social and environmental consequences of their food purchases. Furthermore, Fair

Trade certification empowers smallholders to organize into democratically run cooperatives to compete on a global scale, increasing smallholder's organizations access and exposure to diverse partnerships, including clients that push for quality improvements as a necessary condition to participate in alternative business models such as RCM (Ruben and Zuniga, 2011).

In summary, this study shows how consumer preferences for product quality can influence desired environmental outcomes, and that the relationship between economics and the environment is not necessary limited to ecosystem degradation due to economic activities. Instead, as the RCM case suggests, the economic dynamics of food value chains can encourage the adoption of practices that promote environmental sustainability (Ring et al., 2010). Overall, the integration of efficient agricultural production with biodiversity conservation is a global challenge that requires linking sustainable agriculture production with sustainable livelihoods (Jha et al., 2014; Railsback and Johnson, 2014). Our results show that sustainability for smallholder coffee growers and their communities means more than just adopting fair trade practices and production methods that foster environmental protection. It is also about creating market opportunities that promote sustainable participation of smallholders in high-quality value chains. Our study should motivate future research to support this hypothesis and include other potential outcomes related to gender empowerment, behavioral effects, bargaining power and land use, among others (Ruben and Zuniga, 2011; Rueda and Lambin, 2013a).

7. Conclusions

Specialty coffees are a growing segment of the coffee market, and afford opportunities for production systems involving mostly smallholder growers in low and middle-income countries. This study contributes to evaluations of the socio-economic, technological and environmental outcomes for smallholder growers participating in high-quality coffee markets.

Specifically, we established differences between comparable smallholder growers based on their participation in a quality-oriented business model, namely the Relationship Coffee Model (RCM). In order to ensure the internal validity of our comparison, we collected extensive farm-level data that included over 950 farm-level variables on socio-economic, bird population and plant biodiversity indicators. In addition, we controlled for characteristics that can potentially drive participation decisions such as soil characteristics and involvement in social networks, among others. Overall, our study tests the hypothesis that supply chain arrangements directly linking roasters and growers, based on elevated product quality, can be drivers of sustainable coffee production.

We found evidence that RCM participation was associated with sustainable coffee production practices such as higher tree diversity, implementation of water saving practices, and higher use of biological and organic agronomic techniques. Our results suggest that these outcomes simultaneously affect other critical variables such as high soil quality, reduced dependency on agrichemicals and increased availability of food for smallholder consumption and sale. Adopting these practices is not the direct goal of RCM, but is the consequence of employing shade-grown and organic production systems to improve product quality. In addition, the results show that RCM participation helped empower smallholder growers, increasing their knowledge and information about downstream segments of the value chain, and positively affected their expectations about the future of the coffee business. Although we did not find differences in farm-gate price premiums, our results suggest that RCM growers had a higher access to credit through their cooperatives, which administer the price premiums received from buyers. Finally, our results indicate that participating in high-quality coffee markets may have advantages over traditional certification schemes, because they encompass consumer preferences for product quality. However, such certifications are likely to continue playing a key role in facilitating additional information of coffee attributes to consumers and producers, and encouraging smallholders to strength their organizations capacity.

This study provides valuable insights to public and private stakeholders interested in understanding the role of business models connecting smallholder growers with buyers based on elevated product quality. However, this work has limitations, which should be addressed by future research. First, we did not consider smallholder grower costs and benefits from RCM participation. Future research should address key characteristics of this business model such as the costs, risks and trade-offs of specific management practices associated with product quality as well as the implications of alternative allocation of price premiums. For example, dynamic modeling approaches could systematically describe these relationships, taking into account to growers' risk profiles and inter-temporal discount rates. In addition, future studies can improve understanding of the returns to investing premiums in collective goods that support growers' organizations and their programs or, alternatively, the consequences of price premiums directly transferred to the growers to promote individual efforts to improve quality. Finally, future research should address RCM-like business models in additional crops (e.g., cocoa) to shed light on how consumer demand for product quality can positively impact social, economic and environmental outcomes in agriculture.

Acknowledgements

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Appendix

[Appendix. Table A1 Here]

[Appendix. Table A2 Here]

[Appendix. Table A3 Here]

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Figure 1. Conceptual Framework - RCM participation.

Note: This Figure 1 is attached as a separate File .TIFF 800 dpi

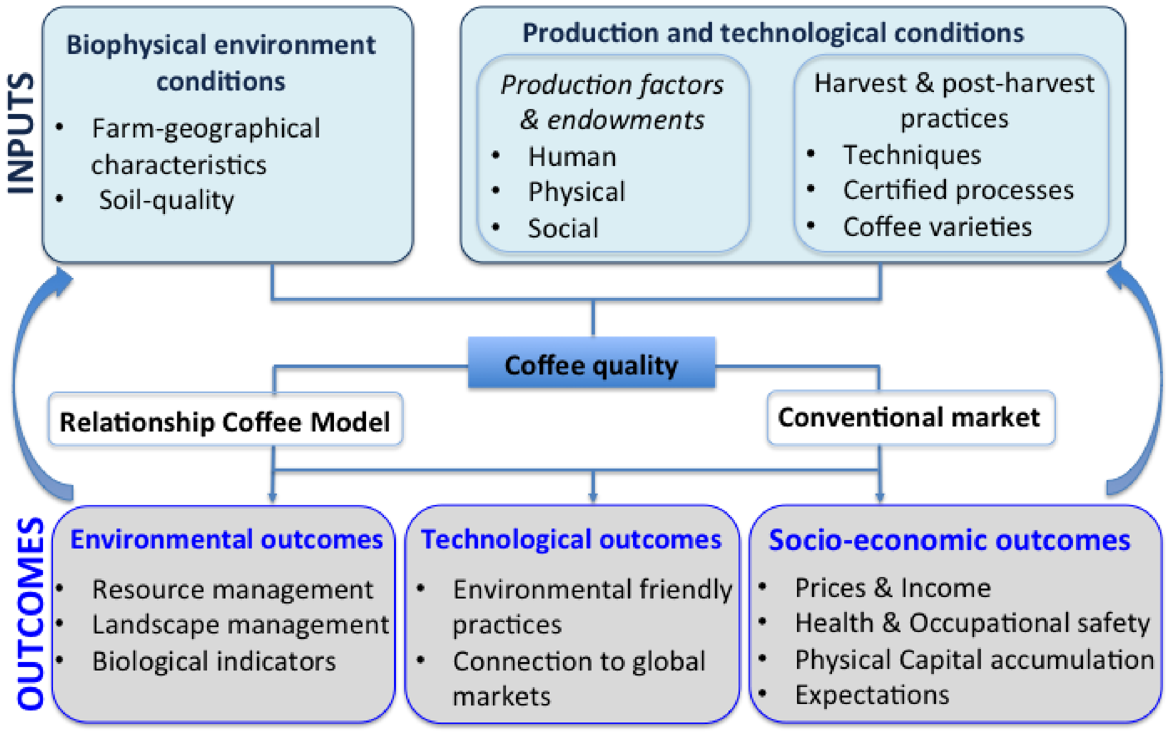

Table 1. Input variables selected according to Imbens and Rubin (2014) algorithm.

Category			Variable	Description
Biophysical environment conditions		Farm-geographical characteristics	Crop elevation	Crop elevation from sea level measured in each farms. Unit: Meters
		Soil-quality assessment	Soil-iron content	Quantification of particles per million of iron calculated after chemical evaluation of soil
			Soil respiration	Measure of metabolic activity from microbial community of the soil
			Soil-protein score	Quantification of protein content
Production & technological conditions	Production factors & endowments	Human capital	Health status	Index that aggregates: diabetes, heart diseases, dental diseases, eyes diseases, pressure and circulation problems, respiratory sicknesses and gastric illnesses.
			Training in agricultural production	Number of institutions from which the smallholder has received training at any point of his/her life.
		Physical capital	Housing infrastructure and access to facilities	Index that aggregates: electricity, gas pipes, natural gas, telephone, cell phone, water and sewage, garbage collection, internet, cable TV and or national TV.
			Ownership of coffee production machinery	Index that aggregates: coffee cherry depulping machine, mucilage-taker, dryer (3 types), fumigation equipment, lawn trimmer, power saw, grass-sting, silo
			Informal savings	Maintain savings by his/her own, family or friends or with not regulated groups (1 if true)
			Application to credit in	Requested a credit at the informal sector during last 12 months.

		the informal sector	Includes not regulated borrowers, family and friends (1 if true)
	Social Capital	Social interactions	Index that measures participation in civic organizations. Includes: coffee smallholders formal and informal organizations, religious, recreational and/or educational groups.
Harvest and post-harvest practices	Factor shares	Percentage of coffee-crop area/farm	Percentage of coffee hectares in relation to the total farm size.
		Remunerations to contracted workers	Includes: payments during the last crop to workers contracted to coffee beans collection plus payments to daily workers (Thousands of COL pesos)
	Coffee varieties	Percentage of non-rust resistant Arabica	Percentage of non-rust resistant Arabica trees in a representative quadrant.
	Certified processes and standards◆	Certifications related to labor conditions and some environmental aspects.	Index that aggregates: Fair Trade, Utz and 4C Common.
** Not selected by the algorithm*		* Environment and sustainability focused certifications.	Index that aggregates: Rainforest Alliance, Organic, UTZ, 4C Common, Smithsonian Bird Friendly.

◆For the RCM participants labor related certifications basically refer to Fair Trade. The cooperative and almost all of their 700 members are certified (in the sample 96% affirmed to be Fair Trade certified). Any of them have Utz or 4C certifications. In the case of environmental related certifications, the most common is Organic, although, only 11.5% in the cooperative members are certified or in process of certification. This proportion is similar to the percentage of smallholders in the RCM participants' sample who affirm to be organic certified (12.8%).

Table 2. Input variables comparison between RCM-participants and non-participants. Original sample vs. refined sample

Input variables description	Original total sample			Refined sample after trimming[a]		
	Non-participants (N=186) Mean ± SD	RCM-participants (N=78) Mean ± SD	T-test	Non-participants (N=50) Mean ± SD	RCM-participants (N=14) Mean ± SD	T-test
Crop elevation	1805 ± 574	1709 ± 111	-1.46	1742.5 ± 123.7	1702.0 ± 103.6	-1.11
Soil-iron content	36.9 ± 32.7	21.1 ± 12.4	-4.14*	22.50 ± 11.84	21.05 ± 7.93	-0.43
Soil respiration	0.954 ± 0.21	1.03 ± 0.24	2.61*	0.96 ± 0.18	1.00 ± 0.24	0.73
Soil protein score	45.6 ± 15.5	52 ± 18.2	2.92*	46.55 ± 13.87	50.40 ± 16.58	0.87
Smallholders ’ health status	2.35 ± 1.59	2.44 ± 1.65	0.38	2.60 ± 1.71	2.26 ± 1.38	-0.68
Smallholders ’ training in agricultural production	0.85 ± 0.85	1.88 ± 0.88	8.89*	1.19 ± 0.91	1.40 ± 0.50	0.79
Grower’s housing infrastructure and access to facilities	7.93 ± 2.64	6.41 ± 1.38	-4.82*	6.71 ± 1.87	6.46 ± 1.72	-0.44
Ownership of coffee production machinery	3.51 ± 1.08	4.04 ± 0.95	3.71*	3.64 ± 1.18	3.73 ± 0.96	0.25
Informal savings	0.176 ± 0.38	0.372 ± 0.48	3.49*	0.49 ± 0.50	0.33 ± 0.48	-1.03
Application to credit in the informal sector	0.042 ± 0.20	0.025 ± 0.15	-0.66	0.03 ± 0.19	0.00 ± 0.00	-0.07
Social interactions	1.73 ± 1.28	2.49 ± 1.36	4.34*	2.35 ± 1.53	2.13 ± 1.24	-0.04
Percentage of coffee-crop area/farm	0.715 ± 0.34	0.548 ± 0.27	-3.82*	0.74 ± 0.46	0.74 ± 0.23	0.05
Remuneration to contracted workers	1713.4 ± 3491.4	1134.2 ± 1509.4	-1.41	1222.3 ± 1867.0	1325.3 ± 1582	0.18
Percentage of Arabica varieties	0.215 ± 0.34	0.070 ± 0.23	-3.29*	0.10 ± 0.25	0.155 ± 0.33	0.65
Certifications related to labor conditions and some environmental aspects	0.278 ± 0.52	0.974 ± 0.16	11.30*	0.471 ± 0.674	0.899 ± 0.282	2.30*
Environmentally-focused certifications[b]	0.193 ± 0.44	0.211 ± 0.41	0.3	0.372 ± 0.527	0.279 ± 0.452	-0.61
Farm size (hectares)[b]	4.10 ± 3.41	4.05 ± 3.25	-0.10	3.17 ± 2.24	2.39 ± 1.51	-1.26
Area planted to coffee (hectares)[b]	2.60 ± 2.29	1.75 ± 1.32	-3.03*	1.97 ± 1.25	1.72 ± 1.26	-0.69

[a] For the trimming process were dropped non-participants with propensity scores below the lowest probability estimated among participants, and RCM participants with *p-scores* above the highest propensity score estimated for non-participants.
[b] Input variables that we controlled for but were not required by Imbens and Rubin (2014) algorithm to predict RCM participation. These variables were not statistically different for the refined sample of comparable growers.
* Statistically significant differences at a 0.05 level. SD: Standard deviation.

Table 3. Outcome Variables Description

Environmental Outcomes	Resource management	Water saving techniques	Index that aggregates techniques for saving water and treatment of residual water (goes from 0 to 3).
		Awareness of the use of biological control methods	Compare with other smallholders in the area the farmer considers that he/she uses more biological control methods.
	Landscape management	Crop-tree diversity	Number of tree species identified in the total quadrant.
		Biomass per hectare	Tones of total biomass per hectare
		Inga-edulis trees	Number of Inga-edulis individuals in the total quadrant.
	Biological indicators	Birds abundance and genus	Observed number of specimens from the southwest quadrant point at each farm.
		Bird species diversity	Total number of species detected on a farm
		Soil potassium content	Particles per million
Technological Outcomes	Environmental friendly practices	Preparation of own fertilizer	Smallholder prepares organic fertilizers in the farm
		Use of organic fertilizer	Smallholder used organic fertilizers during the last crop.
		Use of organic fumigation	Smallholder used organic fumigation alternatives against coffee rust.
	Connection to global markets	Knows the final buyer/Exporter	The smallholder knows who are the final buyer and/or exporter of the coffee that he produces (goes from 0 to 2).

Socio-Economic Outcomes	Price and income	Price per kilogram	Price received per kilogram of coffee produced during the last crop in Colombian pesos.
	Health and safety	Use of protection equipment	Index that aggregates protection gear used during agro-chemicals application. Includes: gloves, mask, coveralls, glasses, boots and caps.
		> 50% of consumed food came from its own farm	In a regular day more than half of food consumed come from the own farm.
		Products different from coffee, are sold and self consumed	Index that aggregates items that are produced for consumption and sell. Includes: cassava, plantain, banana, corn, rice, cane, chickens, pigs, cattle, vegetables, legumes and fruits.
	Physical capital accumulation	Access to microcredit	Smallholder received a credit from a cooperative or small financial entity during the past 12 months.
	Expectations	Smallholder expects children will be involved in coffee activities	Smallholder wants that his son(s) and/or daughter(s) will be involved in coffee activities.

Table 4. Outcomes differences between RCM-participants and non-RCM participants according to Imbens and Rubin (2014).

Outcome variables description	**Single propensity score Homoscedasticity Mean ± SD**	**Single propensity score Heteroscedasticity Mean ± SD**	**Matching single covariate Mean ± SD**	**Two-match propensity score Mean ± SD**	**Three-match propensity score Mean ± SD**	**Four match propensity score Mean ± SD**
			Environmental Outcomes			
Water saving techniques	0.57 ± 0.62	0.57 ± 0.44	0.65 ± 0.42	1.03 ± 0.52**	1.05 ± 0.47**	1.02 ± 0.46**
Awareness of the use of biological control methods	0.561 ± 0.26**	0.56 ± 0.36	0.18 ± 0.17	0.53 ± 0.22**	0.36 ± 0.21*	0.37 ± 0.20*
Crop-tree diversity	1.37 ± 1.07	1.37 ± 1.38	1.16 ± 0.60*	1.94 ± 0.87**	1.10 ± 0.84	0.67 ± 0.75
Above-ground biomass	-1.22 ± 11.35	-1.22 ± 12.07	8.48 ± 6.38	6.53± 9.56	0.52 ± 8.95	4.48 ± 8.07
Inga-edulis trees	1.42 ± 3.94	1.42 ± 8.26	6.07 ± 2.46**	8.23 ± 4.38*	5.35 ± 3.52	4.06 ± 2.87
Soil potassium content (PPM)	-52.91 ± 59.31	-52.91 ± 17.83***	-50.37 ± 32.47	-51.79 ± 47.82	-55.65 ± 41.82	-55.23 ± 38.58
			Technological Outcomes			
Preparation of own organic fertilizers	0.42 ± 0.23*	0.42 ± 0.06***	0.27 ± 0.15*	0.42 ± 0.19**	0.42 ± 0.17**	0.38 ± 0.16**
Use of organic fertilizers during the last crop	0.51 ± 0.31	0.51 ± 0.38	0.53 ± 0.14***	0.59 ± 0.24**	0.43 ± 0.21**	0.47 ± 0.19**
Uses organic fumigations against coffee roast	0.65 ± 0.28**	0.65 ± 0.36*	0.28 ± 0.11**	0.35 ± 0.21	0.28 ± 0.18	0.20 ± 0.16

Knows final buyer/exporter of his coffee	1.48 ± 0.43***	1.48 ± 0.73**	1.37 ± 0.22***	1.43 ± 0.35***	1.09 ± 0.38***	1.12 ± 0.33***
Socio-Economic Outcomes						
Price per coffee kilo	-209.84 ± 399.69	-209.84 ± 235.48	81.71 ± 219.19	-54.7 ± 305.19	-39.97 ± 261.95	54.06 ± 300.10
Access to micro credits	0.65 ± 0.24***	0.65 ± 0.38*	0.28 ± 0.16*	0.61 ± 0.2***	0.36 ± 0.22	0.43 ± 0.19**
Use of protective equipment during fumigation	2.90 ± 1.07***	2.90 ± 0.76***	1.83 ± 0.67***	2.35 ± 0.97**	2.02 ± 0.89**	2.06 ± 0.78***
>50% of consumed food came from its own farm	0.56 ± 0.25**	0.56 ± 0.38	0.03 ± 0.13	0.21 ± 0.26	0.36 ± 0.22	0.43 ± 0.19**
Products different from coffee, are sold and self consumed	0.68 ± 1.25	0.68 ± 0.75	0.63 ± 0.33*	0.87 ± 0.78	0.90 ± 0.63	1.28 ± 0.57**
Smallholder wants his/her children to be involved in coffee production	0.63 ± 0.24***	0.63 ± 0.14***	0.21 ± 0.16	0.62 ± 0.2***	0.55 ± 0.20***	0.35 ± 0.21*

S.D: Standard deviation *, $p < 0.1$; **, $p < 0.05$, and *** $p<0.01$

Matching criteria includes: a single match on *p*-score with no bias reduction assuming homoscedasticity for the standard errors; a single match on *p*-score with no bias reduction assuming heteroscedasticity; a *Mahalanobis* distance matching designed to minimize differences on all covariates employed in estimating the *p* scores; and multiple matches based on *p* scores using two, three and four matches (Imbens and Rubin, 2014; Morgan and Harding, 2006).

Table 5. Bird-survey differences between RCM-participants and non-RCM participants

Variables description	Original total sample			Refined sample after trimming		
	Non-participants (N=169) Mean ± SD	RCM-participants (N=63) Mean ± SD	T-test [a]	Non-participants (N=41) Mean ± SD	RCM-participants (N=13) Mean ± SD	T-test
Abundance	28.68 ± 16.51	34.92 ± 12.76	2.71***	33.14 ± 17.17	32 ± 14.26	-0.21
Diversity	14.34 ± 6.81	18.73 ± 5.68	4.54***	16.60 ± 7.36	19.46 ± 7.64	1.20
Setophaga	1.19 ± 1.32	1.38 ± 1.50	0.91	1.19 ± 1.34	1.92 ± 1.75	1.57
Basileuterus	0.029 ± 0.22	0.095 ± 0.42	1.49	0.048 ± 0.31	0 ± 0	-0.55
Pheugopedious	0.24 ± 0.61	0.36 ± 0.65	1.32	0.51 ± 0.89	0.23 ± 0.43	-1.08

[a] Significance levels adjusted by Bonferroni correction. S.D: Standard deviation *, $p < 0.1$; **, $p < 0.05$, and *** $p<0.01$

Appendix

Table A1. Estimated parameters of Propensity Score

Variable	Abbreviation	Coefficient	Std. Error	t-stat
Intercept		8.30	18.31	0.45
Linear Terms				
Crop elevation	elevation	0.01	0.01	1.06
Percentage of non-rust resistant Arabica varieties	nrarab	-30.72	12.10	-2.54
Smallholders’ health status	health	-3.67	1.55	-2.36
Smallholders’ training in agricultural production	training	0.62	1.00	0.61
Percentage of coffee-crop area/farm	coffee	4.61	2.78	1.66
Ownership of coffee production machinery	machine	0.32	0.47	0.69
Social interactions	social	3.74	1.08	3.45
Remuneration to contracted workers	remuneration	0.00	0.00	-1.72
Soil respiration	respiration	-116.41	37.56	-3.10
Soil protein score	protein	1.54	0.49	3.13
Soil-iron content	iron	2.22	1.09	2.04
Informal savings	saving	13.74	4.39	3.13
Application to credit in the informal sector	credit	-6.31	2.77	-2.28
Certifications related to labor conditions	certification	31.98	8.37	3.82
Grower’s housing infrastructure and facilities	house	-1.63	0.62	-2.62
Second Order Terms				
nrarab_ protein		0.35	0.17	2.07
certification _social		-2.43	0.83	-2.93
certification _ nrarab		-23.37	6.56	-3.56
certification _ coffee		-22.08	6.57	-3.36
elevation _iron		0.00	0.00	-2.09
nrarab _social		6.92	2.27	3.06
social _ saving		-3.24	1.17	-2.76
training _ nrarab		1.24	0.51	2.43
house _ nrarab_		0.31	0.16	2.01
Number of Observations	265		*LR chi2 (24)*	277.94
Log likelihood	-21.62		*Prob > chi2*	0
			Pseudo R2	0.87

Table A2. Balancing test for RCM-participants and non-participants' input selected variables according to Imbens and Rubin (2014) algorithm.

Input variables description	**Balancing Method 1** **T-test (z-values)** [a]	**Balancing Method 2** **F-test (z-values)** [b]
	Geographical and Environmental conditions	
Crop elevation	-1.092	-0.589
Soil-iron content	-0.631	0.075
Soil respiration	0.745	-0.106
Soil protein score	0.897	-0.326
	Production and Technology conditions	
Health status	-0.643	0.055
Agricultural training	0.905	-0.338
Housing infrastructure and access to facilities	-0.512	0.279
Ownership of production machinery	0.402	0.492
Informal savings	-0.874	-0.294
Application to credit in the informal sector	-0.743	-0.102
Social interactions	-0.628	0.079
Percentage of coffee-crop area/farm	-0.028	2.005*
Remuneration to contracted workers	-0.278	0.778
Percentage of non-rust resistant varieties	0.636	0.066
Certifications related to labor conditions and some environmental aspects	2.264 *	-1.931
◆ Environment and sustainability focused certifications	-0.467	0.362

[a] Non-satisfactory input balance when values are substantially larger in an absolute value than one.
[b] The p values associated with the F statistic are converted to a z-value. Non-satisfactory balance when there are large positive values.
◆Not selected as an input by Imbens and Rubin algorithm, but balanced between RCM participants and non-participants.

Table A3. Overlapping test for RCM-participants and non-participants' input selected variables

Input variables description	Mean differences [a]	SD sample ratio [b]	Proportion outside quartiles for covariate distribution [c]	
			Non-participants	RCM-participants
Geographical and Environmental conditions				
Crop altitude	-0.355	0.837	0.392	0.067
Soil-iron content	-0.144	0.670	0.098	0.067
Soil respiration	0.204	1.328	0.000	0.133
Soil protein score	0.252	1.196	0.000	0.133
Production and Technology conditions				
Health status	-0.219	0.811	0.020	0.000
Agricultural training	0.275	0.553	0.294	0.000
Housing infrastructure and access to facilities	-0.138	0.923	0.098	0.067
Ownership of production machinery	0.080	0.814	0.098	0.000
Informal savings	-0.316	0.966	0.000	0.000
Application to credit in the informal sector	-0.283	1.040	0.000	0.000
Social interactions	-0.157	0.812	0.020	0.000
Percentage of coffee-crop area/farm	0.018	0.501	0.059	0.000
Remuneration to contracted workers	0.060	0.847	0.059	0.000
Percentage of non-resistant varieties	0.182	1.335	0.000	0.133
Certifications related to labor conditions and some environmental aspects	0.828	0.419	0.098	0.000
◆ Environment and sustainability focused certifications	-0.189	0.857	0.020	0.000

[a] Values around zero reflect a better overlapping.
[b] Ratio close to 1 if control and treatment covariates have similar standard deviation (SD).
[c] In a randomized experiment this measures are equal to α in expectation and only $\alpha \times 100\%$ of units have covariate values that make the prediction of missing potential outcomes relatively difficult. Higher values imply that it will be relatively difficult to predict missing potential outcomes for participants and non-participants groups since there will be a higher proportion of comparable observations at the tails of the distributions.
◆Not selected as an input by Imbens and Rubin algorithm, but overlapped between RCM participants and non-participants.

Supplementary material

Initial Input Variables Set

One of the main advantages of propensity score methodology is that it matches numerous observable characteristics among RCM participants and non-participants to a single measure, reducing the dimensionality problem. Following Imbens and Rubin (2014) algorithm, we verified whether the inclusion of each input variable and their interaction with other input variables improved the goodness of fit (measured by the likelihood ratio test statistic), and contributed to preserve similar input characteristics (i.e. mean, standard deviations) between RCM participants and non-participants. All the input variables were considered in this process and are summarized in the following table

Table S1. Input variables description

Group	Variable
Location	Department
Topography	Altitude
Soil Characteristics	Aggregate Stability (%), Available Water Capacity (m/m), Organic Matter (%), Active Carbon (ppm), pH, Extractable Phosphorus (ppm), Extractable Potassium (ppm), Magnesium (ppm), Iron (ppm), Manganese (ppm), Zinc (ppm), Sand, Clay, Silt, Textural Class, Protein (mg/g soil), Protein "Score", Respiration (mg/g soil, 4day Total), Protein "Score" (not texture adjusted)
Biophysical/Landscape	Percentage of non-rust resistant Arabica varieties in the quadrant. Includes: Caturra, Typica, Borbon, Catuai and Pacamara Percentage of rust resistant varieties in the quadrant. Includes Colombia, Castillo, Catimor, F1, F4, F6, F8, "suprema", 2000 Numbers of trees in the quadrant.
Natural Disasters and Pests	Exposure to natural disasters. Includes: floods, droughts, land slides (last crop, last 3 crops). Pest exposure and incidence during the last 3 crops. Includes coffee berry borer (CBB) and rust

Family Structure	Age Number of economically dependent members
Health	Aggregation of the pre-existing conditions: diabetes, heart, dental eyes, pressure, circulation, gastric or respiratory problems or diseases.
Education	Years of education The farmer knows institutions that provide technical assistances and number of institutions that knows. Number of institutions farmer assisted for technical capacitation.
Fixed Assets	Owner of his own farm Legal document that supports landholding. Farm size Coffee hectares Percentage of coffee hectares in relation to farm size House, apartment, land and/or car possession index.
Variable Assets	Index that aggregates the number of animals: weighted according to market value
House	Household infrastructure and access to utilities index
Saving	Saving in the financial sector Number of formal financial services used for saving. Saving in the informal sector: Includes not regulated borrowers, family, friends
Credit	Applied for a credit in the last two years Applied to credit in the financial sector Applied to microcredit Requested a credit at the informal sector.
Fixed Capital	Index that aggregate the ownership of the following machines: coffee cherry de-pulping machine, mucilage-taker, dryer (3 types), fumigation equipment, lawn trimmer, power saw, grass-sting, silo
Political Institutions	Level of participation in presidential, state and city elections, coffee guild representatives, cooperative and federations delegates.
Social interactions	Level of participation in civic organizations. Includes: coffee

	growers, religious, recreational, certification, and educational groups or organizations. Coordinate communal work with other coffee groups.
Tradition and Expectations	Farmer's parents where involve in the coffee production.
Security	The security conditions in the regions are bad or worse than before. The farmer has suffered displacement, extortion over assets, or extortion over profits.
Cooperatives	Belong to a cooperative of smallholders where members are under RCM Time that a cooperative has been involved with the RCM
Diversification	Total of food products produced in the farm different than coffee for consumption Total of food products produced in the farm different than coffee for sale
Income	Household total income below a specific income line
Production Factors Remuneration	Payment for coffee beans collection: kilograms produced times payment per kilogram Payment to per day workers (*jornales*): Days times payment per day Total labor remuneration: Payment for coffee beans collection plus payment to per day workers (*jornales*) Household members who help in the coffee production
Harvest & Post-Harvest Practices & Management	Tech processing plant to process coffee bean Percentage of the coffee crops associated with other products.

Balancing and Overlapping Tests

We used two methods to test for similar means -*balancing*- between participants and non-participants. First, for each input variable, we tested the hypothesis that the difference in means between participants and non-participants was not statistically different than zero. Generally, if values of this statistic are substantially larger in absolute value than one, the stratification does not lead to satisfactory balance in the covariates. Second, we tested the hypothesis that the input variable means do not depend on program participation. Negative values relative to a normal distribution indicate lack of balance.

Furthermore, we verified that input variables for RCM participants and non-participants overlapped and shared similar dispersions on their distributions. We reported four measures to assess overlapping for each input variable: 1) the difference in means by treatment group normalized by the square root of the average within group variance; 2) the ratio of the participants and non-participants standard deviations; 3) the proportion of participants outside the 0.025 and 0.975 quantiles of the non-participants' distribution; and 4) the proportion of non-participants outside the 0.025 and 0.975 quantiles of the participants' distribution. In general, higher values in measures three and four imply that it will be relatively difficult to predict missing potential outcomes for participants and non-participants groups since there will be a higher proportion of comparable observations at the tails of the distributions.

In general, the first balancing method tests the hypothesis that the block-weighted difference between participants and non-participants means is not statistically different than zero.

$$z_k = \frac{\sum_{j=1}^{J} \frac{N_{nj} + N_{pj}}{N} . (\bar{X}_{pkj} - \bar{X}_{nkj})}{\sqrt{\hat{V}_k}} \qquad (A1)$$

Where $\bar{X}_{pkj}$ is the participants (p) k input mean in sub-block j, $\bar{X}_{nkj}$ is the non-participants (n) k input mean in sub-block j, N_{nj} the number of non-participants in sub-block j, N_{pj} the number of participants in sub-block j, N the total number of participants and non-participants in the original trimmed block and $\hat{V}_k$ the estimated sampling variance for input k. However, with only one block this test can be simplified to:

$$z_k = \frac{(\bar{X}_{pk} - \bar{X}_{nk})}{\sqrt{\hat{V}_k}} \quad (A2)\ ; \qquad \hat{V}_k = s_k^2\left(\frac{1}{N_n} + \frac{1}{N_p}\right) \quad (A3)$$

$$and\ s_k^2 = \frac{1}{N_n + N_p - 2}\left(\sum_{i:W_i=0}\left(X_{ik} - \bar{X}_{pk}\right)^2 + \sum_{i:W_i=1}(X_{ik} - \bar{X}_{nk})^2\right) \ (A4)$$

In addition, expression (A5) contributes to understand the intuition behind the second balancing test. In this expression the dependent variable is the k input variable X for grower i (X_{ik}) while $(B_j.W)$ represents the interaction of the sub-block B_j and the treatment variable W

$$X_{ik} = \alpha_{kj}.B_{ij} + \tau_{kj}\ (\ B_{ij}.W_i) \qquad (A5)$$

According to this test, if any input variable is balanced in a particular sub-block, it is expected that this input variable depend on the sub-block (coefficient $\alpha_{kj} \neq 0$), but not on the interaction between that sub-block and the treatment (coefficient $\tau_{kj} = 0$). In other words, the mean of any input variable for participants and non-participants can be different across sub-blocks but not within sub-blocks. With only one block, this test helps to verify that the inputs average values do not depend of participation in the program.

In relation to overlapping, the first test is represented in equation (A6) where the difference in means by treatment group is normalized by the square root of the average within group standard deviations.

$$\Delta_{pn}= \frac{\bar{X}_p - \bar{X}_{np}}{\sqrt{(s_{np}^2 + s_p^2)/2}} \qquad (A6)$$

In contrast with the first balancing test, which is heavily impacted by N, in this normalized difference the number of treatment and control individuals (N_n and N_p) do not divide the estimated standard deviations. The advantage is that we can obtain a good measure of the differences in location of the distribution due to small differences in the covariates and not necessary explained by a larger N.

Labor related certifications comparable groups

Table S2. Balancing and Overlapping tests for certified-participants and non-participants. Using the input variables that were considered to predict RCM participation

Input variables description	Balancing Method 1 T-test (z-values) [a]	Balancing Method 2 F-test (z-values) [b]	Mean differences [c]	SD sample ratio [d]	Proportion outside quartiles for covariate distribution [e]	
					Non-participants	RCM-participants
Geographical and Environmental conditions						
Crop altitude	0.003	2.852*	0.001	0.741	0.243	0.000
Soil-iron content	-0.232	0.905	-0.123	0.518	0.459	0.000
Soil respiration	0.431	0.434	0.234	0.443	0.351	0.000
Soil protein score	0.483	0.334	0.256	0.508	0.351	0.000
Production and Technology conditions						
Smallholders' health status	1.334	-0.882	0.449	1.863	0.000	0.167
Smallholders' training in agricultural production	0.169	1.109	0.080	0.829	0.108	0.000
Grower's housing infrastructure and access to facilities	0.469	0.362	0.176	1.462	0.000	0.167
Ownership of coffee production machinery	0.203	0.995	0.098	0.766	0.108	0.000
Informal savings	0.617	0.101	0.249	1.237	0.000	0.000

Application to credit in the informal sector	-0.709	-0.047	-0.414	0.000	0.081	0.000
Social interactions	0.375	0.551	0.181	0.761	0.162	0.000
Percentage of coffee-crop area/farm	-0.119	1.315*	-0.062	0.549	0.189	0.000
Remuneration to contracted workers	-0.349	0.608	-0.188	0.455	0.135	0.000
Percentage of non-rust resistant varieties	0.761	-0.126	0.304	1.271	0.000	0.000
RCM participation	-0.402	0.493	-0.182	0.939	0.000	0.000

[a] Non-satisfactory input balance when values are substantially larger in an absolute value than one.
[b] Non-satisfactory balance when there are large positive values.
[c] Values around zero reflect a better overlapping.
[d] Ratio equal to 1 when control and treatment covariates have the same standard deviation (SD).
[e] $\alpha \times 100\%$ of units have covariate values that make the prediction of missing potential outcomes relatively difficult.

Table S3. Outcomes differences between certified and non-certified participants

Input variables description	Single propensity score Homoscedasticity Mean ± SD	Single propensity score Heteroscedasticity Mean ± SD	Matching single covariate Mean ± SD	Two-match propensity score Mean ± SD	Three-match propensity score Mean ± SD	Four match propensity score Mean ± SD
			Environmental Outcomes			
Water saving techniques	0.58 ± 0.54	0.58 ± 0.61	0.44 ± 0.52	0.51 ± 0.52	0.22 ± 0.51	0.26 ± 0.52
Awareness of the use of biological control methods	0.09 ± 0.24	0.09 ± 0.21	0.23 ± 0.23	0.16 ± 0.23	0.16 ± 0.21	0.12 ± 0.21
Crop-tree diversity	-0.58 ± 0.82	-0.58 ± 0.59	-0.67 ± 0.71	-0.70 ± 0.77	-0.54 ± 0.75	-0.64 ± 0.74
Above-ground biomass	18.86 ± 12.67	18.86 ±20.32	8.42 ± 12.56	12.7 ± 11.82	22.16 ± 12.86*	16.16 ± 13.13
Inga-edulis trees	0.83 ± 1.28	0.83 ± 1.94	0.83 ± 1.02	0.65 ± 1.18	1.68 ± 1.37	1.24 ± 1.33
Carbon storage	0.012 ± 0.011	0.012 ± 0.02	0.01 ± 0.009	0.008 ± 0.01	0.021 ± 0.01	0.016 ± 0.01
Soil potassium content (PPM)	-77.78 ± 60.22	-77.78 ± 30.60**	-83.73 ± 55.42	-88.73 ± 60.21	-92.15 ± 60.22	-89.25 ± 61.05
			Technological Outcomes			
Preparation of own organic fertilizers	0.02 ± 0.24	0.02 ± 0.21	0.23 ± 0.17	0.15 ± 0.22	0.18 ± 0.20	0.22 ± 0.20
Use of organic fertilizers during the last crop	-0.09 ± 0.21	-0.09 ± 0.20	0.04 ± 0.22	0 ± 0.20	-0.04 ± 0.19	0.02 ± 0.20
Uses organic fumigations against coffee roast	-0.04 ± 0.12	-0.04 ± 0.06	-0.02 ± 0.11	-0.04 ± 0.11	-0.02 ± 0.12	-0.03 ± 0.12

Knows final buyer/exporter of his coffee	0.11 ± 0.39	0.11 ± 0.40	0.30 ± 0.25	0.16 ± 0.34	0.32 ± 0.35	0.33 ± 0.34
Socio-Economic Outcomes						
Price per coffee kilo	-183.61 ± 353.87	-183.61 ± 404.79	-237.14 ± 371.89	-169.71 ± 366.31	-148.22 ± 369.12	-186.73 ± 351.89
Access to micro credits	-0.02 ± 0.25	-0.02 ± 0.21	-0.18 ± 0.16	-0.09 ± 0.21	-0.14 ± 0.19	-0.16 ± 0.18
Use of protective equipment during fumigation	2.81 ± 0.83***	2.81 ± 0.64***	2.46 ± 0.93***	2.72 ± 0.85***	2.41 ± 0.89***	2.59 ± 0.88***
>50% of consumed food came from its own farm	-0.09 ± 0.10	-0.09 ± 0.04*	-0.07 ± 0.08	-0.08 ± 0.09	-0.07 ± 0.09	-0.08 ± 0.09
Products different from coffee, are sold and self consumed	-0.37 ± 0.40	-0.37 ± 0.47	-0.34 ± 0.30	-0.48 ± 0.41	-0.17 ± 0.41	-0.35 ± 0.42
Farmer want his/her children to be involved in coffee production	-0.14 ± 0.22	-0.14 ± 0.208	0.023 ± 0.24	-0.105 ± 0.23	0.008 ± 0.218	-0.029 ± 0.221

S.D: Standard deviation *, $p < 0.1$; **, $p < 0.05$, and *** $p<0.01$

Georeference RCM participants and non-participants farms

Figure S1. Colombia - Georeference RCM participants and non-participants farms

Figure S2. Cauca - Georeference RCM participants and non-participants farms

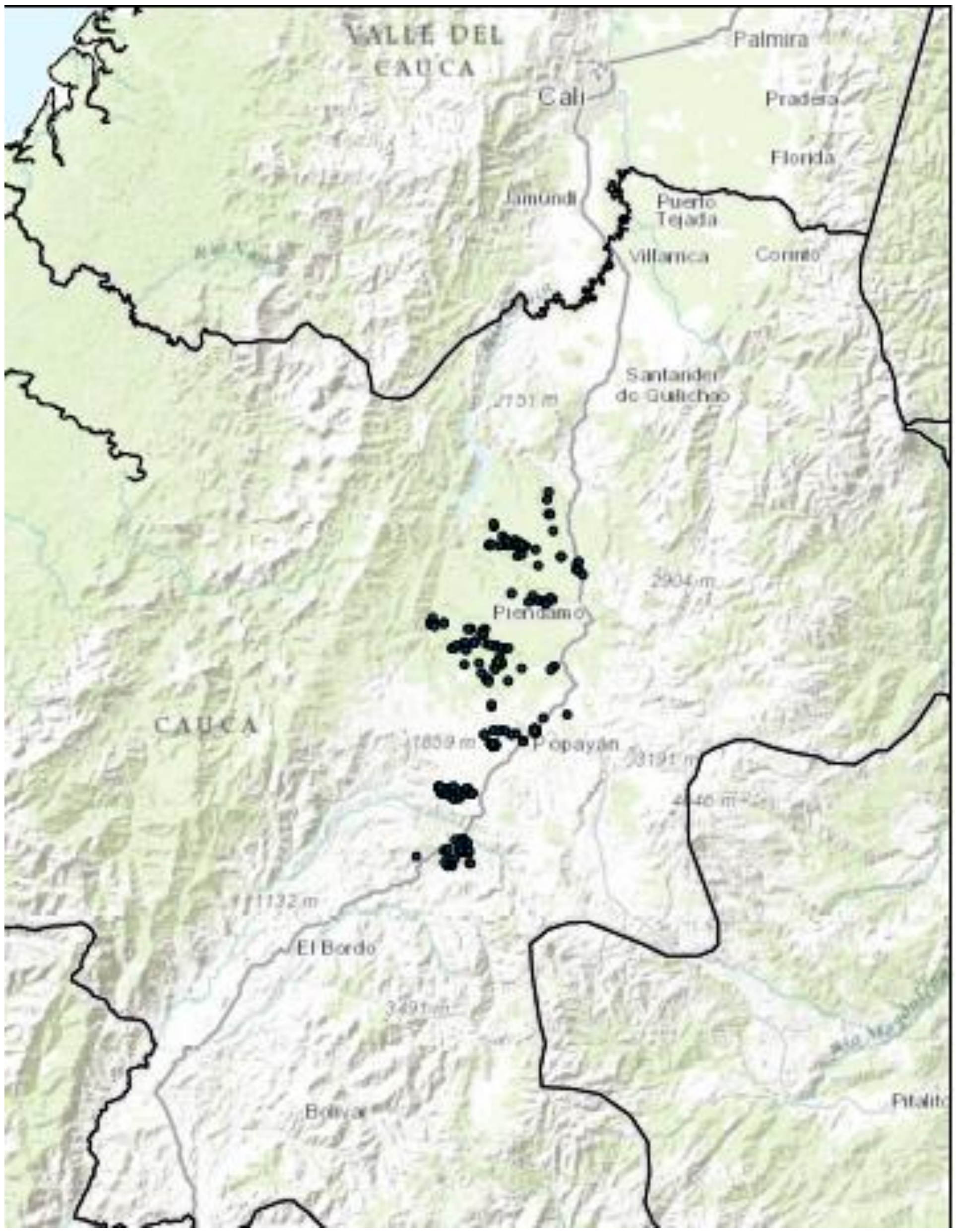

Figure S3. Antioquia - Georeference RCM participants and non-participants farms