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Environmental and economic impacts of growing certified organic coffee in Colombia[+]

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Abstract. According to advocates, eco-certification can improve developing country farmers' environmental and economic performance. However, these notional benefits can be undercut by self-selection: the tendency of relatively wealthy farmers already meeting eco-certification standards to disproportionately participate. Empirical evidence on this matter is scarce. Using original farm-level survey data along with matching and difference-in-differences matching models, we analyze the producer-level effects of organic coffee certification in southeast Colombia. We find that certification improves coffee growers' environmental performance. It significantly reduces sewage disposal in the fields and increases the adoption of organic fertilizer. However, we are not able to discern economic benefits.

Key words: organic certification, coffee, Colombia, difference-in-differences matching

JEL codes: Q13, Q20, O13, Q56

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1. Introduction

Although agricultural production is an important source of income and employment for developing countries, it also is responsible for serious environmental damage, including aquifer depletion, land degradation, water pollution, soil erosion, deforestation, and biodiversity loss (World Bank 2008; Isik 2004; Sterner 2003). Addressing these problems using conventional command-and-control regulation is challenging because producers tend to be small, numerous, and geographically dispersed. Eco-certification is a nonregulatory environmental management approach that promises to both control for the negative environmental externalities and increase the income of rural poor (Giovannucci and Ponte 2005; Rice and Ward 1996). Third parties award eco-labels such as organic, Rainforest Alliance, Fair Trade, and UTZ to producers, conditional on their meeting specific environmental and social performance criteria. The labels in turn can confer financial rewards, including price premiums and access to expanded markets.

However, the producer-level environmental benefits of eco-certification may be limited because of self-selection—that is, because producers already meeting certification standards tend to disproportionately obtain certification (Blackman and Rivera 2011; Barbosa de Lima et al. 2009). Already-green producers have relatively strong incentives to participate: the costs are low because they do not have to change production practices to meet certification standards, and the benefits, including price premiums and improved market access, can be significant. But if the bulk of certified producers were already green before certification, then on average, certification will have only limited effects on production practices. Hence, it is not clear ex ante whether—after controlling for self-selection effects—eco-certification in developing countries actually has significant environmental benefits.

To date, there is limited empirical evidence on this issue (Blackman and Rivera 2011; Parrot et al. 2007; IFAD 2003). To our knowledge, the only quantitative study that both considers the producer-level environmental effects of coffee and purports to controls for self-selection effects is the one by Blackman and Naranjo (2010). They find that even after controlling for self-selection, certification has environmental benefits. It reduces agrochemical use and increases the use of sustainable farming practices. They contend that this finding stems in part from the fact that in Costa Rica, the vast majority of coffee growers rely heavily on agrochemicals and therefore do not meet organic certification standards. That is, opportunities for the type of self-selection described above are limited.

Several less rigorous studies analyze environmental impacts by comparing environmental outcomes for certified farms before and after certification or comparing outcomes for certified farms and unmatched uncertified farms. Most find few differences. Quispe Guanca (2007) uses survey data on changes in environmental management practices before and after certification (organic, Fair Trade, Rainforest Alliance, UTZ Kapeh, and C.A.F.E. Practices) for a sample of 106 certified farms in Costa Rica. He observes that although all farms reduced herbicide use after certification, most did not reduce the use of other agrochemicals. Philpott et al. (2007) compare ecological indicators for farms belonging to three certified organic, three certified organic and Fair Trade, and two uncertified cooperatives in Chiapas, Mexico. No effort is made to match the three types of cooperatives. Their study shows no differences among the farms in ecological indicators. Finally, Martínez-Sánchez (2008) compares ecological indicators for 10 certified organic and 10 unmatched uncertified farms in northern Nicaragua. He finds that organic farms do not have significantly different shade levels, bird diversity, or bird abundance.

Just as environmental effects of eco-certification are uncertain, so too are the economic effects. In principle, price premiums, market access, and technical assistance associated with eco-certification can boost growers' profits. But eco-certification also generally requires changes in production practices that raise some costs. For example, organic cultivation is typically more labor intensive than conventional farming (Lygbaeck et al. 2001; Van der Vossen 2005). In addition, eco-certification entails fixed transaction costs associated with red tape and variable transaction costs associated with monitoring and reporting. Finally, self-selection effects can dilute economic benefits: relatively wealthy producers may be more likely to obtain eco-certification because they can more easily cover the fixed transaction costs. Given all these factors, ex ante, the net effect of eco-certification on producers' economic status is uncertain.

Empirical evidence on the economic effects of organic certification is mixed. Focusing on Ugandan growers, Bolwig et al. (2009) find that certified growers have net revenues that are 75% higher than uncertified growers, all other things equal. However, because certified coffee has higher value added, the comparison with uncertified coffee is problematic. A study in Costa Rica by Lygbaeck et al. (2001) shows that the price premium from organic coffee partly compensates for lower yields. However, once the cost of certification is included, organic production generates lower net revenues than conventional production. Kamau et al. (2010) find that while UTZ coffee certification in Kenya does not imply higher income for producers as compared with a matched control group, it is associated with higher savings and investment and greater access to credit for coffee growers. Similarly, using matching estimators, Jena et al. (2012) find that Fair Trade coffee certification in Ethiopia does not have a significant effect on yield per hectare or income. Chiputwa et al. (2015) consider the case of Uganda. Using propensity score matching, they find that neither organic nor UTZ certification has significant impacts on poverty.

This paper investigates both the environmental and economic effects of organic certification in the southeastern part of Colombia, one of the world's leading coffee producers. We rely on an original panel data set and use matching and matched difference-in-differences (DID) estimators to control for selection effects (Rosenbaum and Rubin 1983; Smith and Todd 2005). We find that certification does have environmental benefits: it significantly reduces the disposal of sewage in field and spurs the adoption of organic fertilizer. However, we are not able to discern a positive economic effect. The price premiums that certified producers earn are just enough to compensate them for lower productivity from organic technologies and do not compensate them for the positive environmental effects generated.

The remainder of the paper is organized as follows. The next section provides background on organic coffee cultivation in Colombia. Section 3 discusses our methodology. Sections 4 and 5 present our data and the results. The final section sums up and discusses our findings.

2. Coffee Cultivation in Colombia

Coffee is the most important agricultural product in Colombia, generating 12.4% of the total agricultural revenue and employing about 553,000 growers, 95% of whom cultivate farms smaller than 5 hectares (FNC 2011; Giovannucci 2002).

Traditionally, coffee was grown in the shade of natural or planted forests with few agrochemicals. Over the last 30 years, however, new coffee varieties have been developed that can be cultivated under full-sun exposure. Almost half of Colombian coffee is "sun-grown," and in some regions the fraction exceeds three-quarters (FNC 2008a). In Colombia, yields per hectare from sun-grown coffee are about four times those from shade-grown coffee (FNC 2008a).

But there is a disadvantage: sun-grown coffee has serious adverse environmental effects. The reduction in tree cover is associated with a loss in biodiversity. For example, Greenberg et al. (1997) found that full-sun coffee plantations support 90% fewer bird species than shade-grown coffee. In addition, sun-grown coffee is associated with higher rates of soil erosion, is more susceptible to weeds and pests, and requires chemical fertilizers and pesticides that can pollute surface and groundwater and cause worker health problems (Ataroff and Monasterio 1997; Babbar and Zak 1995; Bermúdez 1980). For example, in Costa Rica, sun-grown coffee uses 30 kilograms of nitrogen per hectare per year compared with little or no use in shade-grown plantations (UNDP 2010).

Concerns about the environmental impacts of coffee cultivation, among other things, spurred organic certification. Organic agriculture certification requires producers to adhere to five broad production principles (Van der Vossen 2005; IFOAM 2010):

- use of composted organic matter instead of chemical fertilizers to maintain soil quality;
- use of natural methods for controlling disease, pests, and weeds instead of synthetic insecticides and herbicides;
- use of soil conservation practices, including contour planting, terracing, planting cover crops, mulching, and planting shade trees;
- minimal use of fossil fuels in the production process; and
- minimal pollution during postharvest handling.

Organic certification requires growers to complete a transition period of two to three years, during which they must discontinue use of chemical inputs and adopt various conservation and pollution prevention practices. Certified producers are monitored at least once a year to ensure they continue to meet organic standards.

Colombia's first experiences with certified organic coffee were in the late 1980s. It was promoted by multiple organizations, including Instituto Mayor Campesino, Asociación de Caficultores Orgánicos de Colombia (ACOC), and Corporación Suna Hisca. Since then, the production of certified organic coffee has increased (Esguerra 2001). In 2010, Colombian growers produced 8,056 tons of certified organic coffee on 8,773 certified organic hectares (Ministerio de Agricultura 2012).

Our study focuses on organic growers in Cauca, a department (state) in the southeastern part of the country. Cauca, one of Colombia's leading centers of organic coffee production, is home to 16% of Colombia's coffee farms and 8% of its coffee acreage (FNC 2008a). We focus on five municipalities in Cauca with particularly high rates of organic certification: Inzá, Cajibío, Tambo, Timbío, and La Sierra. In all, 331 growers harvesting 587 hectares were certified organic in these municipalities in 2008 (FNC 2008b). In addition, 162 growers harvesting 211 hectares were in transition to certification (FNC 2008b). The vast majority of these growers were certified in the decade prior to our survey. Very few were certified prior to 1998. Three organizations certified the organic growers in our study area: Bio-Latina, Institute for Marketecology (IMO) Control, and Organic Crop Improvement Association. Each of these organizations holds multiple accreditations for multiple markets.[1]

[1] Bio-Latina is accredited by the German Deutsches Akkreditierungssystem Prüfwesen (DAP), the US Department of Agriculture National Organic Program (USDA NOP), Japan Agricultural Standards (JAS), and the Conseil des

3. Methodology

We evaluate the impact of organic certification on environmental and economic outcomes. Let y^{C}_{it+s} be an outcome variable for grower *i* at time *t+s* (for $s > 0$) conditional on a certification indicator variable *C*. The causal effect of certification for grower *i* at time period *t+s* is defined as

$$y^{1}_{it+s} - y^{0}_{it+s} \tag{1}$$

The average effect of certification on all certified growers is

$$\text{ATT}=E\{ y^{1}_{it+s} - y^{0}_{it+s} \big| C = 1\} = E\{y^{1}_{it+s} \big| C = 1\} - E\{ y^{0}_{it+s} \big| C = 1\} \tag{2}$$

The general challenge of causal inference is that the quantity y^{0}_{it+s} is unobservable for certified growers. Hence, we must construct the last term in Equation 2: the average outcome for certified growers had they not been certified. We rely on matching techniques to construct this counterfactual. That is, we pair each certified grower with an uncertified grower based on a vector of *Z* characteristics observed before certification.

It may not be possible to find uncertified growers with identical values of all elements of *Z*, however. Rosenbaum and Rubin (1983) demonstrate that it is necessary to match agents only on the basis of their propensity score, the probability of treatment (here certification) as predicted

Appellations Agroalimentaires du Québec (CAAQ). IMO Controlis accredited by the Swiss Accreditation Service (SAS), USDA NOP, and JAS. The Organic Crop Improvement Association is accredited by USDA NOP, the International Organic Accreditation Service, the European Union Equivalent Standards, JAS, and CAAQ.

by a probit regression. This prediction can be interpreted as a weighted average of the characteristics in *Z*, where the weights reflect the importance of each characteristic in explaining treatment. This approach collapses the thorny problem of exact matching on all observable characteristics to the much simpler problem of matching a single summary variable.

Using this method, we first estimate the probability of being organic certified using a probit model. That is, we estimate

$$Prob(C_i = 1) = F(Z_i) \tag{3}$$

We use the estimated parameters to generate a propensity score for each grower in our sample. Various algorithms are available to pair certified growers with uncertified growers on the basis of their propensity scores (Caliendo and Kopeining 2008; Morgan and Harding 2006). To ensure robustness, we report results from five: (i) nearest neighbor 1-to-1 matching, wherein each certified grower is matched to the uncertified grower with the closest propensity score; (ii) nearest neighbor 1-to-4 matching, wherein each certified grower is matched to the four uncertified growers with the closest propensity scores and the counterfactual outcome is the average across these four; (iii) nearest neighbor 1-to-8 matching; (iv) nearest neighbor 1-to-16 matching; and (v) kernel matching, wherein a weighted average of all uncertified growers is used to construct the counterfactual outcome.

Propensity score matching depends on two identifying assumptions. The first assumption, "ignorability" or "conditional independence," is that conditional only on agents' observed characteristics, the treatment (certification) decision is ignorable for purposes of measuring outcomes. That is, we are able to observe and control for all potentially confounding variables that simultaneously affect the treatment decision and the outcome variables. This first assumption is untestable. The second assumption, “common support” or “overlap,” is that the distribution of observed characteristics for nonparticipants is similar to that for participants, such that agents with similar characteristics have a positive probability of being participants and nonparticipants. For all five models, we enforce a common support and allow matching with replacement.

The treatment effect for the treated (ATT) can be estimated using cross-sectional data as

$$E\{\, y^1_{it+s} - \, y^0_{it+s} \big| T = 1, P(Z_i)\} = E\{y^1_{it+s} \big| T = 1, P(Z_i)\} - E\{\, y^0_{it+s} \big| T = 1, P(Z_i)\} \qquad (4)$$

where $P(Z_i)$ is the estimated propensity score. That is, ATT is simply the difference between the mean outcomes for the sample of certified growers and a matched sample of uncertified growers selected using propensity scores. A disadvantage of this approach, however, is that a violation of the conditional independent assumption—that is, the assumption that we have controlled for the effects of unobservable confounding factors—can bias the results. For example, say the grower’s environmental consciousness is unobservable and highly correlated both with environmental outcomes and with selection into certification. In that case, ATT estimates may be biased upward.

To control for such unobservables, in addition to simple matching we also use a difference-in-differences (DID) matching estimator where our data permit. This estimator, which exploits information on changes in outcomes over time as well across growers, takes advantage of the fact that we have two-period panel data for some (but not all) outcome variables. Specifically, as discussed below, we have panel data for our environmental outcome variables, but not for our economic outcome variables. DID matching estimators control for time-invariant unobserved confounding factors and therefore are more robust than simple matching estimators (Smith and Todd 2005). The DID matching estimator is defined as

$$E\{\Delta\, y^1_{it+s} - \Delta y^0_{it+s} \big| T = 1, P(Z_i)\} = \\ E\{\Delta y^1_{it+s} \big| T = 1, P(Z_i)\} - E\{\Delta\, y^0_{it+s} \big| T = 1, P(Z_i)\} \quad (5)$$

where Δ is the before-after change in outcome. Hence, the DID matching estimator considers the difference between the mean before-after change in outcomes for the sample of certified growers and a matched sample of uncertified growers selected using propensity scores. Intuitively, this estimator indicates whether growers who adopted the organic certificate improve agricultural practices more than uncertified growers. We use kernel matching to implement the DID matching estimators.

Calculating standard errors for ATT estimated using propensity score matching is not straightforward because these errors should, in principle, account for the fact that propensity scores are estimated and for the imputation of the common support (Heckman et al. 1997, 1998). Therefore, following Dehejia and Wahba (2002) and others, we bootstrap standard errors (using 1,000 replications).

4. Data and Variables

4.1. Survey and sample

The data used for our analysis come from an original of survey of 379 coffee growers in five municipalities in the department of Cauca, Colombia. The survey was conducted between

March and June 2008. As noted above, we selected this department and these municipalities because they are home to a relatively large concentration of organic growers. We randomly selected our survey sample from lists of coffee growers. The survey questionnaire was administered on-site by trained enumerators in face-to-face sessions that typically lasted 40 minutes.

The survey solicited information on both grower characteristics (e.g., age, education) and farm characteristics (e.g., eco-certification, hectares cultivated, types of inputs used) for two years: 2007 and 1997.[2] All but seven of the organic growers in our survey sample were organic certified after 1997. Hence, for all but these seven growers, 1997 grower and farm characteristics predate and therefore are exogenous to the decision to obtain organic certification. As noted below, we dropped these seven growers from our regression sample.

Among the production practices on which we have data, six are monitored by organic certifiers. These are our environmental outcome measures. We divided them into four "negative" practices that must be discontinued for organic certification and two "positive" practices that must be adopted. Following are the four negative practices:

- the use of chemical fertilizers
- the use of chemical insecticides
- the use of chemical herbicides
- disposal of sewage in open fields

[2] Coffee prices in 1997 were the highest in the last two decades, reaching US$1.31 per pound. This price spike may have induced changes in agricultural practices, although we expect that transformation of the productive system is slow.

These are the two positive practices:

- the use of organic fertilizer
- the use of shade cover for coffee trees

In addition to these six negative and positive practices that are monitored by organic certifiers, we included another positive practice that is not:

- the use of coffee pulp to fertilize

We included this practice because there is some concern that the requirement to use organic fertilizer forces growers to buy additional organic matter. This seventh practice flags growers that use on-farm materials.

Our survey data include detailed information on economic outcomes of coffee cultivation. Our six economic outcome measures are as follows:

- labor costs
- input costs
- total costs
- yields
- income
- net revenue

Starting with the 379 randomly selected growers whom we surveyed, we constructed our matched sample for the analysis of environmental outcomes as follows. First, we eliminated 94 growers who could not provide data for 1997 because their farms did not yet exist in 1997 or were not yet producing marketable coffee. Second, we eliminated 35 growers who obtained a certification other than, or in addition to, organic.[3] We dropped these growers so that we could disentangle the effect of organic certification from other types of certification. Third, we dropped four growers who were certified or transitioning to certification prior to 1998 to control for the endogeneity problem noted above. Fourth, we dropped five growers who were certified after 1997 but gave up their certifications prior to 2007. We dropped these growers because they would be counted as uncertified in our matching sample but may have had outcomes or characteristics that were affected by having been certified. Fifth, we dropped 22 growers who reported economic outcomes that were outliers. Finally, we dropped 9 growers who did not provide complete responses for 1997.

Having dropped these 169 growers, our regression sample comprises 210 growers, all of whom had been producing coffee since at least 1997, none of whom were organic certified in 1997, and none of whom had ever obtained an eco-certification other than organic. Of these 210 growers, 52 were organic certified in 2007, and 158 had never been eco-certified at any time.

4.2. Variables

Table 1 lists, defines, and presents descriptive statistics for the variables used in our matching analysis, including both outcome variables and grower and farm characteristics. We present sample means for the entire sample and certified and uncertified subsamples.

[3] These included 28 farms that were Rainforest Alliance certified and 7 that were Fair Trade certified.

[Insert Table 1 here]

Our 13 outcome variables correspond to those in the bulleted list in the previous subsection. The seven environmental outcome variables are *chemical fertilizer*, *insecticide*, *herbicide*, *sewage*, *organic fertilizer*, *shade*, and *pulp*. The six economic outcome variables are *labor cost*, *input cost*, *total cost*, *yield*, *income*, and *net revenue*.

To match certified and uncertified growers, we used propensity scores generated by regressing an organic certification dummy onto a rich set of grower and farm characteristics. The grower characteristics are *female*, a dichotomous dummy equal to one for female growers; *age*, the age of the grower in 2007; *education*, the highest grade completed in 2007; *family size*, the size of the family in 2007; and *cooperative*, a dichotomous dummy equal to one if the grower was a member of a coffee committee affiliated with the Federación Nacional de Cafeteros de Colombia in 1997.[4]

The farm characteristics, all of which correspond to the year 1997, are *own farm*, a dichotomous dummy equal to one if the grower owns (versus rents or leases) the farm; *no. trees*, the number of coffee trees on the farm; *farm size*, the total area of the farm in hectares; *area coffee*, the size of all coffee lots in 1997, *no. lots*, the number of geographically distinct lots on the farm; *organic matter*, an estimate of the number of kilograms of manure produced by all animals on the farm;[5] *capital index*, a count of the number of common capital items owned (depulper, mill, silo, fumigator, motor, other); *borbon*, *caturra*, *colombia*, and *castillo*, the

[4] A limitation of the survey is that it did not ask about family size for 1997.

[5] These estimates are based on the simple linear model in Muñoz and Moreno (2001) that relates the number and type of farm animals to the quantity of manure.

proportions of the farm's coffee trees that are the most common varieties in the study area; *pasilla*, *federacion*, *especial*, and *calidad*, the proportions of coffee sold in the four quality grades of Colombian coffee; *buyer intermediary*, a dichotomous dummy variable equal to one if the grower sells to an intermediary (versus a cooperative, association, or exporter); *transport with vehicle*, a dichotomous dummy equal to one if the grower transports the coffee by vehicle (versus by animal or on foot); *proportion on farm* and *proportion off farm*, the proportions of household members who work on and off the farm; and *Inzá*, *Cajibío*, *Tambo*, *Timbío*, and *Sierra*, dichotomous dummy variables indicating whether the farm is located in each of the five study municipalities.

4.3. Descriptive statistics

There was significant variation across growers in precertification (1997) use of the seven positive and negative practices that constitute our environmental outcomes. For the four negative practices, rates range from 4% for herbicide to 47% for sewage disposal.[6] For the positive practices, rates range from 26% for organic fertilizer to 91% for shade cover.[7] In 1997, for two of the seven environmental practices, growers that went on to obtain organic certification in subsequent years performed "better" than those who were never certified: they were significantly less likely to use chemical fertilizer and more likely to use organic fertilizer. Hence, it is

[6] Note that the mean of the outcome variables for certified farmers is positive, albeit small, implying that a handful of the 52 certified growers in our sample used chemical inputs or disposed of their sewage in their fields in 2007. Organic standards allow the occasional use of chemical inputs when deemed necessary and preauthorized by a certifying agency inspector.

[7] Note that the mean of the outcome variables for certified farmers is less than 1, implying that some of the certified growers in our sample had not adopted the two environmental management practices we consider. Organic inspectors relax certification requirements in certain cases. In general, inspectors enforce prohibitions against negative practices (e.g., use of agrochemicals) more stringently than they require the positive ones (e.g., soil conservation).

reasonable to expect that a disproportionate share of growers that in 1997 were de facto organic—that is, those already meeting many organic standards—self-selected into organic certification, and as a result certification had only limited effects on the environmental performance of the average grower in our sample. Our empirical analysis aims at determining whether that was the case.

Note that for both certified growers (i.e., those certified in 2007) and uncertified growers, mean use of negative practices fell between 1997 and 2007, and mean use of positive practices rose. The statistical analysis aims to establish whether the effect was significantly larger for certified producers once we control for potential self-selection.

Among our seven economic outcome variables, in four cases we observe significant differences in 2007 means for certified and uncertified growers. Means for two of our three cost variables are significantly lower for certified growers than uncertified growers. Specifically, mean input costs for certified growers are about three times lower than for uncertified growers, and total production costs per hectare are about one-third lower. Surprisingly, even though organic technologies are generally thought to be relatively labor intensive, labor costs for certified and uncertified growers are not statistically different. Mean yield per hectare for certified growers is about half that for uncertified growers, a significant difference. Mean income for certified growers is also significantly lower than for uncertified growers. Finally, mean net revenues for certified and uncertified growers are not statistically different.

As for our control variables, our sample of growers is composed of small-scale growers with relatively low socioeconomic status. The average 1997 farm size in our sample was 2.19 hectares, and the average 2007 coffee net revenue per hectare was 849,000 Colombian pesos (US$422). The average grower had 3.7 years of school in 1997.

There are significant differences in the precertification (1997) means of eight control variables for certified and uncertified growers. Compared with uncertified growers, certified growers were more likely to have belonged to cooperatives, to have had farms comprising multiple lots, to have grown certain varieties of coffee and not others, to have produced certain grades of coffee and not others, and to have lived in certain municipalities and not others. These preexisting characteristics are likely to affect our outcomes. Hence, it is important to control for them in estimating our treatment effects.

5. Results

5.1. Propensity scores and balance tests

Table 2 presents the marginal effects from the probit regression (of organic certification on grower and farm characteristics) used to generate propensity scores. The results indicate that, all other things equal, certified growers are more likely to grow Borbon, Caturra, and Colombia coffee varieties and to sell calidad-grade coffee, and they are less likely to be located in Cajibío or Timbío municipality than in Tambo.

[Insert Table 2 here]

We used propensity scores from our probit regression to match organic certified producers with uncertified producers. Table 3 presents the balance test for the five matching estimators used. All the estimators balanced 29 out of 29 covariates; that is, they generated a statistically insignificant difference in means for certified and matched uncertified farms for all 29 covariates. Following Rosenbaum and Rubin (1983), we also used median standardized bias to measure matching quality.[8] The highest median standardized bias is 11% for the nearest neighbor 1–1 estimator, and the lowest is 3% for nearest neighbor 1–8. Although a clear threshold for acceptable median standardized bias does not exist, according to Caliendo and Kopeining (2008), a statistic below 3–5% is generally viewed as sufficient. These overall encouraging balance statistics are likely due to the fact that even though our probit selection model has 29 covariates, our sample includes more than three uncertified growers for each certified grower. As a result, we were able to find fairly close matches for each certified farm.

[Insert Table 3 here]

5.2. Average Treatment Effect on the Treated

We first discuss environmental outcomes and then examine economic outcomes. Table 4 presents results for the four negative environmental practices. Results are from five standard matching estimators (equation 4) and from the DID estimator (equation 5). The standard matching estimators indicate that certification reduces use of three of the four negative practices: chemical fertilizer, chemical insecticides, and sewage disposal in fields. For each, ATT from at least three of the five standard matching estimators (nearest neighbor 1–1 and so forth) is negative and significant. The results suggest that certification reduces the use of chemical fertilizer by 25 to 38 percentage points, chemical insecticides by 12 to 17 percentage points, and sewage disposal in fields by 18 to 19 percentage points. Qualitative results from the DID matching estimators comport with those from the standard matching estimators only in the case of sewage disposal in the field. The DID suggests that certification reduces sewage disposal in

[8] Standardized bias is the difference of the sample means in the certified and uncertified subsamples as a percentage of the square root of the average of sample variances in both groups.

fields by 26 percentage points. Given the discrepancy between our matching and matched DID results, our results for chemical fertilizer and insecticide must be interpreted with caution.

[Insert Table 4 here]

Table 5 presents results for the three positive practices. They suggest that certification increases use of organic fertilizer and pulp fertilizer. For organic fertilizer, all five standard matching ATTs are positive and statistically significant. The magnitude of the effect is substantial, ranging from 30 to 44 percentage points. The DID ATT is 34 percentage points. For the use of pulp fertilizer, all five standard matching ATTs are positive and statistically significant suggesting that certification boosts the practice by15 to 21 percentage points. The DID estimator indicates a 26 percentage point increase. For shade, none of the simple matching ATTs or the DID estimator is statistically significant. This is not surprising, given that 96% of the matching sample, including 96% of the uncertified growers, use shade.

[Insert Table 5 here]

Table 6 presents results for economic effects of certification. As noted above, for these outcome variables, we are not able to use a DID estimator because we do not have 1997 data. The results suggest that organic certification decreases the input costs and yields but does not have a significant effect on labor costs, total costs, income, or net return. For input costs, ATT is both negative and significant for four of the five matching estimators. The magnitude is substantial, ranging from –154 to –170 thousand pesos per hectare. For yield, ATT is both negative and significant for one of five estimators. The insignificance of ATT for total costs, income, and net return probably reflects the fact that lower yields associated with certification are offset by lower input costs and potentially by higher price premiums. Given these results, it is clear that because of the prices and other conditions that existed in Cauca during our study period, economic incentives for certification were limited.

[Insert Table 6 here]

5.3. Sensitivity analysis

Might endogeneity drive our results? As noted above, the effectiveness of our matching estimators in controlling for selection bias depends on the untestable identifying assumption that we are able to observe confounding variables that simultaneously affect growers' decisions to obtain organic certification and to use (or not use) the production practices that serve as our outcome variables. That is, we essentially assume endogeneity is not a problem. We calculate Rosenbaum bounds to check the sensitivity of our results to the failure of this assumption (Rosenbaum 2002; Aakvik 2001).[9] Rosenbaum bounds indicate how strongly unobserved confounding factors would need to influence growers' decisions to obtain organic certification in order to undermine the matching result. To be more specific, the Rosenbaum procedure generates a probability value for Wilcoxon sign-rank statistic (in the case of continuous variables) or a Mantel and Haenszel statistic (in the case of binary variables) for a series of values of Γ, an index of the strength of the influence unobserved confounding factors have on the

[9] An example of an unobserved confounder might be environmental consciousness or managerial skill. Each could cause growers to select into organic certification and—independent of certification—to use fewer negative practices and more positive ones.

selection process. $\Gamma = 1$ implies that such factors have no influence, such that pairs of growers matched on observables do not differ in their odds of obtaining organic certification; $\Gamma = 2$ implies that matched pairs could differ in their odds of certification by as much as a factor of 2 because of unobserved confounding factors; and so forth. The probability value on the Wilcoxon sign-rank or Mantel and Haenszel statistic is a test of the null hypothesis of a zero ATT given unobserved confounding variables that have an effect given by Γ. So, for example, a probability value of 0.01 and a Γ of 1.2 indicate that ATT would still be significant at the 1% level even if matched pairs differed in their odds of certification by a factor of 1.2 because of unobserved confounding factors.

We calculate Γ^*, the critical value of Γ at which ATT is no longer significant at the 10% level, in each case—that is, for each combination of production practice and matching estimator—where ATT is significant (Tables 4, 5, and 6, fourth column). Among the negative environmental practices, Γ^* is greater than 3 in the case of all but one of the 15 estimators for chemical fertilizer use, insecticide, and sewage disposal in fields. Among the positive practices, Γ^* is no lower than 2.26 for organic fertilizer and is no lower than 2.6 in the case of pulp fertilizer. For economic effects, Γ^* is larger than 3 for all of the five statistically significant estimators (four for input costs and one for yield). Hence, our sensitivity tests suggest that unobserved confounders would need to be quite strong to undermine our statistically significant matching ATTs. In other words, endogeneity is unlikely to drive these results.

6. Conclusion

We have used rich original survey data on 210 coffee farms in southeast Colombia to identify the environmental impacts of organic coffee certification. We have used propensity score matching and DID estimators to control for self-selection bias.

Our findings strongly suggest that certification reduces the use of one of the negative practices for which we have data—disposal of sewage in fields—and increases the use of two of the three positive practices for which we have data: use of organic fertilizer and pulp fertilizer. In each case, our conventional matching estimators and DID matching estimator generate a positive and significant ATT that is robust to possible hidden bias. For two additional negative practices—the use of chemical fertilizer and insecticide—our results also suggest that certification reduces use. However, these results are weaker. In each case, our conventional matching estimators generate a positive ATT that is not sensitive to hidden bias, but our DID matching estimator, which purports to control for unobserved confounders, is not significant. Hence, overall, we find that organic certification improves some, but not all, facets of coffee growers' environmental performance.

These findings are consistent with those of Blackman and Naranjo (2010), who performed what is to our knowledge the only other quantitative analysis of such effects that purports to control for self-selection bias. They also find that organic certification has environmental benefits and attribute this to the fact that in Costa Rica, growing coffee is highly technified, so most farms must change their management practices to obtain organic certification. In Cauca, Colombia, by contrast, growing coffee is less technified. As noted above, except in the case of organic fertilizer use, the lion's share of the uncertified growers in our sample use practices consistent with organic certification. Hence, one would expect that the environmental effects of certification would be diluted by self-selection. Contrary to this intuition, however, we find that organic certification has at least some positive environmental impacts.

Thus our study suggests that the effectiveness of organic certification in spurring environmental benefits has less to do with the preexisting characteristics of coffee growers than with the design characteristics of the certification program. While many eco-certification programs feature fuzzy standards, self-monitoring, and participation by cooperatives, we have examined one that has relatively well-defined, stringent standards enforced at the individual farm level by independent third-party monitors. Previous studies suggest that these are the hallmarks of certification programs that tend to generate significant producer-level benefits (Rivera et al. 2006; de Leon and Rivera 2009; Darnall and Sides 2008). Hence, our study indicates that commodity certification schemes with these characteristics can have significant environmental benefits, even in areas where self-selection threatens to dilute these benefits.

Our results regarding organic certification's economic effects are much less encouraging. We are not able to discern robust effects of certification on labor costs, total costs, yields, or income. Only in the case of input costs does certification have a significant impact. These findings reflect the emerging conventional wisdom that organic cultivation has mixed effects on production costs, raising some and reducing others, so that the net benefits are limited (Lygbaeck et al. 2001; Van der Vossen 2005). The fact that organic certification has limited economic benefits is likely to be a major obstacle to the promotion of certified organic technologies.

As a caveat to these conclusions, we hasten to note that our study is among the first to examine these issues using quantitative methods that purport to control for sample selection. More evidence from other study sites is needed before we can draw general conclusions about whether and under what circumstances eco-certification, or even just organic certification, has environmental and economic benefits.

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Table 1. Variables, Definitions, and Means

Variable	Definition	1997 Mean all (n=210)	1997 Mean cert07 (n=52)	1997 Mean uncert07 (n=158)	2007 Mean all (n=210)	2007 Mean cert07 (n=52)	2007 Mean uncert07 (n=158)
TREATMENT							
certified	organic certified	0.25	0.00	1.00	0.25	0.00	1.00
OUTCOMES							
Negative practices							
chemical fertilizer	applies chemical fertilizer (0/1)	0.46	0.23	0.53 ***	0.37	0.10	0.46***
insecticide	applies insecticide (0/1)	0.20	0.13	0.23	0.13	0.02	0.16***
herbicide	applies herbicide (0/1)	0.04	0.04	0.04	0.11	0.08	0.13
sewage	disposes of sewage in field (0/1)	0.47	0.52	0.46	0.28	0.15	0.32**
Positive practices							
organic fertilizer	applies organic fertilizer (0/1)	0.26	0.38	0.22 **	0.53	0.87	0.42***
shade	uses shade (0/1)	0.91	0.9	0.92	0.96	0.96	0.96
pulp	uses pulp to fertilize (0/1)	0.53	0.46	0.55	0.84	0.96	0.80***
Economic effects							
labor cost	total cost wages (000 COP)				783.04	693.90	812.38
input cost	total cost inputs (000 COP)				262.00	101.93	314.68***
total cost	total production cost (000 COP)				1,045.04	795.83	1,127.06**
yield	number of arrobas per hectare				38.32	24.96	42.72***
income	total income from coffee (000 COP)				1,894.22	1,450.69	2,040.19*
net revenue	net revenue from coffee (000 COP)				849.18	654.87	913.13
CONTROLS							
Grower							
female	female (0/1)				0.28	0.21	0.30
age	age (years)				51.69	52.40	51.46
education	highest grade completed				3.63	3.83	3.57
family size	total persons in family				4.99	5.27	4.89
cooperative	member coffee cooperative (0/1)	0.28	0.21	0.34*			
Farm							
own farm	own (vs. rent/lease) farm (0/1)	0.96	0.94	0.96			
no. trees	number coffee trees	3,272.37	3,322.50	3,255.86			
farm size	farm size (ha)	2.19	2.50	2.09			
area coffee	area cultivated in coffee (ha)	1.63	1.62	1.64			
no. lots	no. lots farm comprises	1.64	1.88	1.56**			
organic matter	organic material available (kg)	2,955.54	3,660.28	2,723.60			
capital index	no. capital items owned (1–6)[a]	1.08	1.15	1.06			
borbon	prop. coffee trees borbon variety	0.04	0.097	0.02***			
caturra	prop. coffee trees caturra variety	0.57	0.49	0.60			
colombia	prop. coffee trees colombia variety	0.10	0.11	0.10			
castillo	prop. coffee trees castillo variety	0.01	0.01	0.01			
pasilla	prop. coffee sales pasilla grade	0.25	0.63	0.13*			
federacion	prop. coffee sales federacion grade	0.84	0.59	0.93			
especial	prop. coffee sales especial grade	0.01	0.01	0.01			
calidad	prop. coffee sales calidad grade	0.01	0.25	0.05***			
buyer intermediary	sold coffee to intermediary (0/1)	0.46	0.52	0.44			
transport with vehicle	transp. to market w/ vehicle (0/1)	0.68	0.63	0.69			
prop. on farm	prop. household works on farm	0.57	0.57	0.57			
prop. off farm	prop. household works off farm	0.20	0.21	0.20			
Inzá	municipality Inzá (0/1)	0.36	0.56	0.30***			
Cajibío	municipality Cajibío (0/1)	0.16	0.058	0.20**			
Tambo	municipality Tambo (0/1)	0.15	0.15	0.16			
Timbío	municipality Timbío (0/1)	0.14	0.02	0.18***			
Sierra	municipality La Sierra (0/1)	0.18	0.21	0.17			

Notes: *Cert07* refers to growers who were certified as organic in the period 1997 and 2007. *Uncert07* refers to growers who were not certified as organic in the period. *Prop.* stands for *proportion*.

[a] Capital items are depulper, mill, silo, fumigator, motor, and other.

Table 2. Probit Regression Results
(dependent variable = organic certification)

Variable	Marginal effect	S.E.
Grower		
female	0.014	0.065
age	0.001	0.003
education	0.011	0.014
familysize	0.021	0.013
cooperative	–0.059	0.062
Farm		
area coffee 97	–0.005	0.011
own farm	–0.025	0.114
no. trees	–0.000	0.000
farm size	–0.002	0.013
no. lots	0.084***	0.028
organic matter	0.000	0.000
capital index	–0.003	0.027
borbon	0.416***	0.148
caturra	0.143*	0.081
colombia	0.250**	0.113
castillo	0.032	0.371
pasilla	0.076	0.063
federacion	–0.007	0.021
especial	0.118	0.264
calidad	0.379***	0.091
buyer intermediary	–0.031	0.069
transport with vehicle	–0.032	0.058
prop. on farm	0.002	0.065
prop. off farm	0.005	0.067
Inzá	0.002	0.088
Cajibío	–0.248**	0.119
Timbío	–0.313**	0.137
Sierra	0.000	0.091
N	210	
Pseudo R^2	*0.272*	
LR $chi^2(28)$	*63.840*	

*, **, *** denote significance at 10%, 5%, and 1% level, respectively.

Table 3. Matching quality: Number of covariates achieving balance (N) and median standardized bias (MSB) after matching, for five propensity score matching methods[a,b,c]

Method	N	MSB
(i) Nearest neighbor 1–1	29	11.453
(ii) Nearest neighbor 1–4	29	6.077
(iii) Nearest neighbor 1–8	29	3.168
(iv) Nearest neighbor 1–16	29	5.764
(v) Kernel	29	4.446

[a] The model includes 29 covariates.

[b] For a given covariate, the standardized bias is the difference of means in the certified and matched uncertified subsamples as a percentage of the square root of the average sample variance in both groups. We report the median standardized bias for all covariates.

[c] Median standardized bias before matching is 17.691.

Table 4. Negative environmental practices: Average treatment effect on treated (ATT) estimates, by outcome variable and matching method; critical value of Rosenbaum's Γ

	Propensity score matching				DID matched	
	Mean certified	ATT	S.E.[a]	Γ*[b]	Coef.	S.E.[a]
Chemical fertilizer						
(i) Nearest neighbor 1–1	0.091	–0.250**	0.110	>3.00		
(ii) Nearest neighbor 1–4	0.091	–0.278***	0.0940	>3.00		
(iii) Nearest neighbor 1–8	0.091	–0.307***	0.0895	>3.00		
(iv) Nearest neighbor 1–16	0.091	–0.384***	0.0859	>3.00		
(v) Kernel	0.085	–0.340***	0.0941	>3.00	–0.129	0.111
Insecticide						
(i) Nearest neighbor 1–1	0.023	–0.136	0.084	>3.00		
(ii) Nearest neighbor 1–4	0.023	–0.119**	0.056	>3.00		
(iii) Nearest neighbor 1–8	0.023	–0.119**	0.056	>3.00		
(iv) Nearest neighbor 1–16	0.023	–0.173***	0.065	>3.00		
(v) Kernel	0.021	–0.120***	0.044	>3.00	–0.0961	0.088
Herbicide						
(i) Nearest neighbor 1–1	0.091	0.000	0.083	—		
(ii) Nearest neighbor 1–4	0.091	–0.040	0.081	—		
(iii) Nearest neighbor 1–8	0.091	–0.026	0.068	—		
(iv) Nearest neighbor 1–16	0.091	–0.028	0.067	—		
(v) Kernel	0.085	–0.046	0.073	—	–0.024	0.066
Sewage						
(i) Nearest neighbor 1–1	0.182	–0.091	0.123	—		
(ii) Nearest neighbor 1–4	0.182	–0.182*	0.100	>3.00		
(iii) Nearest neighbor 1–8	0.182	–0.193**	0.095	>3.00		
(iv) Nearest neighbor 1–16	0.182	–0.197**	0.094	>3.00		
(v) Kernel	0.170	–0.180**	0.092	>3.00	–0.261**	0.116

*, **, and *** denote significance at 0.1, 0.05, and 0.01, respectively.
[a] Standard errors computed using bootstrap with 1,000 repetitions.
[b] Critical value of odds of differential assignment to organic certification due to unobserved factors (i.e., value above which ATT is no longer significant).
[c] Not estimated.

Table 5. Positive environmental practices: Average treatment effect on treated (ATT) estimates, by outcome variable and matching method; critical value of Rosenbaum's Γ

	Mean certified	Propensity score matching ATT	S.E.[a]	Γ*[b]	DID matched Coef.	S.E.
Organic fertilizer						
(i) Nearest neighbor 1–1	0.864	0.295**	0.127	2.26		
(ii) Nearest neighbor 1–4	0.864	0.347***	0.103	>3.00		
(iii) Nearest neighbor 1–8	0.864	0.389***	0.095	>3.00		
(iv) Nearest neighbor 1–16	0.864	0.440***	0.087	>3.00		
(v) Kernel	0.872	0.392***	0.102	>3.00	0.337***	0.110
Shade						
(i) Nearest neighbor 1–1	0.955	0.046	0.075	—		
(ii) Nearest neighbor 1–4	0.955	0.023	0.057	—		
(iii) Nearest neighbor 1–8	0.955	0.009	0.050	—		
(iv) Nearest neighbor 1–16	0.955	0.001	0.046	—		
(v) Kernel	0.957	0.053	0.073	—	0.029	0.067
Pulp fertilizer						
(i) Nearest neighbor 1–1	0.977	0.182**	0.088	2.69		
(ii) Nearest neighbor 1–4	0.977	0.153**	0.071	2.55		
(iii) Nearest neighbor 1–8	0.977	0.162***	0.060	>3.00		
(iv) Nearest neighbor 1–16	0.977	0.185***	0.062	2.99		
(v) Kernel	0.979	0.206***	0.074	2.77	0.256**	0.105

*, **, and *** denote significance at 0.1, 0.05, and 0.01, respectively.

[a] Standard errors computed using bootstrap with 1.000 repetitions.

[b] Critical value of odds of differential assignment to organic certification due to unobserved factors (i.e., value above which ATT is no longer significant).

Table 6. Economic effects: Average treatment effect on treated (ATT) estimates, by outcome variable and matching method; critical value of Rosenbaum's Γ

	Mean certified	Propensity score matching ATT	S.E.[a]	Γ*[b]
Labor cost (000 COP)				
(i) Nearest neighbor 1–1	729.819	45.194	135.350	–
(ii) Nearest neighbor 1–4	729.819	104.487	117.930	–
(iii) Nearest neighbor 1–8	729.819	45.319	110.095	–
(iv) Nearest neighbor 1–16	729.819	40.957	102.494	–
(v) Kernel	710.412	47.401	110.790	–
Input cost (000 COP)				
(i) Nearest neighbor 1–1	115.483	–108.300	101.563	–
(ii) Nearest neighbor 1–4	115.483	–157.528**	74.779	>3.00
(iii) Nearest neighbor 1–8	115.483	–154.338**	60.530	>3.00
(iv) Nearest neighbor 1–16	115.483	–164.792***	52.554	>3.00
(v) Kernel	108.544	–170.608***	56.220	>3.00
Total cost (000 COP)				
(i) Nearest neighbor 1–1	845.301	–63.106	204.297	–
(ii) Nearest neighbor 1–4	845.301	–53.042	171.590	–
(iii) Nearest neighbor 1–8	845.301	–109.019	152.293	–
(iv) Nearest neighbor 1–16	845.301	–123.835	133.371	–
(v) Kernel	818.956	–123.208	146.986	–
Yield				
(i) Nearest neighbor 1–1	24.992	–11.002	7.041	–
(ii) Nearest neighbor 1–4	24.992	–7.767	6.057	–
(iii) Nearest neighbor 1–8	24.992	–8.244	5.483	–
(iv) Nearest neighbor 1–16	24.992	–8.998	5.577	–
(v) Kernel	24.624	–9.248*	5.409	>3.00
Income (000 COP)				
(i) Nearest neighbor 1–1	1,461.452	–284.485	390.999	–
(ii) Nearest neighbor 1–4	1,461.452	–108.498	342.808	–
(iii) Nearest neighbor 1–8	1,461.452	–161.224	310.030	–
(iv) Nearest neighbor 1–16	1,461.452	–178.745	317.528	–
(v) Kernel	1,431.189	–193.327	323.651	–
Net return (000 COP)				
(i) Nearest neighbor 1–1	616.151	–221.380	302.383	–
(ii) Nearest neighbor 1–4	616.151	–55.457	246.607	–
(iii) Nearest neighbor 1–8	616.151	–52.205	254.707	–
(iv) Nearest neighbor 1–16	616.151	–54.911	245.324	–
(v) Kernel	612.234	–70.119	246.079	–

*, **, and *** denote significance at 0.1, 0.05, and 0.01, respectively.
[a] Standard errors computed using bootstrap with 1.000 repetitions.
[b] Critical value of odds of differential assignment to organic certification due to unobserved factors (i.e., value above which ATT is no longer significant).