INTERNATIONAL CONFERENCE OF AGRICULTURAL ECONOMISTS
ICAE
29th | Milan Italy 2015
UNIVERSITÀ DEGLI STUDI DI MILANO AUGUST 8 - 14
AGRICULTURE IN AN INTERCONNECTED WORLD

Coffee certification and forest quality: A case in Ethiopia

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Shade coffee certification programs that aim to conserve the forest have attracted an increasing amount of attention. However, there is heated debate whether certification programs create an incentive for producers to expand their coffee-growing areas. This study conducted in Ethiopia aimed to evaluate the impact of a shade coffee certification on forest degradation. Additionally, to provide empirical evidence for the debate, we examined the spillover effects of certification to surrounding forest. We used remote sensing data to identify the forest quality and applied matching methods to compare forest coffee areas with and without the certification. We found that the certified areas significantly conserved forest quality compared with the areas without certification. Furthermore, our empirical results revealed that the certification had a positive impact on the forest areas within a 100 m radius. These results indicate that the certification program is effective in alleviating forest degradation.

1. Introduction

Deforestation and loss of biodiversity are widespread problems in less developed countries, particularly in the nations of sub-Saharan Africa and Latin America (Hosonuma et al. 2012; Mayaux et al. 2013; Tilman et al. 2001). Concurrently, many studies have noted the importance of traditional coffee production for forest conservation and biodiversity protection. Coffee is traditionally grown in the understory of shade trees, and the agroecosystems of shaded coffee preserve the forest and provide an important refuge for biodiversity (Buechley et al. 2015; Greenberg et al. 1997; Hundera et al. 2013; Mas and Dietsch 2004; Moguel and Toledo 1999; Perfecto et al. 1996; Perfecto and Snelling 1995; Tadesse et al. 2014; Wunderle Jr and Latta 1996).

However, because of the low yield of the shaded coffee system, many forest areas currently operating under the shaded coffee system are rapidly being converted into plantations for modern industrial coffee production (Jha et al. 2014). Although the modern coffee system improves yields, this improvement comes with increased environmental costs, such as forest reduction, increased erosion, chemical runoff (Perfecto et al. 1996; Rappole et al. 2003b; Staver et al. 2001).

To reduce coffee producers' incentives to convert to the modern coffee system, shade coffee certification programs have attracted increasing attention from conservation and development organizations (Fleischer and Varangis 2002; Perfecto et al. 2005; Philpott and Dietsch 2003; Taylor 2005). Certification programs seek to link environmental and economic goals by providing a premium price to producers who maintain shade trees and thereby contributing to the protection of forest cover and biodiversity.

Some empirical studies have examined the impact of certification programs. Blackman and Rivera (2011) reviewed the literature on benefits of coffee certification programs. However, previous studies cited in their study are mainly focusing on the economic benefits or impact of organic and fair trade certification. Hence, the environmental impact of shade coffee certification programs is still unclear.

Another study by Mas and Dietsch (2004) conducted Mexico attempted to evaluate the effect of coffee certification on biodiversity conservation. Unfortunately, because they studied an area that was likely to meet the criteria used by the major certification programs, their results could not prove that the certification program was the cause of the conservation effects.

In recent years, Takahashi and Todo (2013) rigorously evaluated the impact of shade coffee certification on deforestation in Ethiopia and found a significantly positive effect. Moreover, they revealed that the certification program examined in their study particularly affects the behaviors of economically poor producers in motivating them to conserve the forest (Takahashi and Todo 2014). Additionally, Rueda et al. (2014) also reported the positive effect of certification on forest cover using remote sensing data. However, the focus of these studies was the impact of coffee certification on forest quantity (e.g., size of forest area), not on forest quality (e.g., biomass and vegetation structure). Thus, whether coffee certification system successfully preserves forest quality remains unclear.

Meanwhile, a heated debate continues as to whether coffee certification may trigger forest degradation in surrounding non-coffee natural forest. As Rappole et al. (2003b) noted, one potential problem with certification programs is that they can create incentives for producers to convert an existing primary forest area into an area that produces shade coffee. However, Philpott and Dietsch (2003) dispute the claims of Rappole et al. (2003b) and argue that such degradation can be prevented. Because no studies have yet examined the spillover effect of the coffee certification system, the debate between Philpott and Dietsch (2003) and Rappole et al. (2003a) has not yet reached a consensus.

Therefore, the purpose of this study is to evaluate the impact of a shade coffee certification program on forest degradation and to focus on its spillover effects involving the surrounding forest without forest coffee. We selected Ethiopia as a case study. To evaluate the impact of certification rigorously, we applied matching methods, such as the Mahalanobis matching and the propensity score matching (PSM) with different algorithms, and controlled for selection bias. We estimated the impact of certification by comparing the forest coffee areas with and without the certification. Additionally, we tested the sensitivity of estimates to potential hidden biases.

2. Description of the Study Area

2.1. Description of the Belete-Gera RFPA

We selected the Belete-Gera Regional Forest Priority Area (RFPA) as the study area (Fig. 1). This region is part of the highland rainforest, and the natural vegetation in this area is subject to an annual precipitation of 1,500 mm and an annual average air temperature of approximately 20 degrees Celsius. The topography of the Belete-Gera RFPA is complex and consists of undulating hills that range from 1,200 to 2,900 m in height, with steep mountainous terrain in certain locations.

The Belete-Gera RFPA is one of the important biodiversity hot spots in Ethiopia. Within the forest, we can observe wild mammals, such as baboons, monkeys, and giant forest hogs, and different types of bird species. However, despite the government's prohibition of wood extraction in the forest area, the forest cover in the RFPA has decreased significantly in recent years. The satellite images show that 40% of the forest area has been cleared between 1985 and 2010 (Todo and Takahashi 2011).

2.2. Wild coffee production and coffee certification

Coffee (*Coffea arabica*) is a native species that grows wild in the Belete-Gera RFPA. Because coffee production is not economically practical at high elevations (above 2,300 m), wild coffee is typically found in the forest at an altitude of approximately 2,000 m (indicated by the light and dark gray areas in Fig. 1). The right to harvest each wild coffee area is granted to individual producers in accordance with traditional agreements among villagers. The right holders (producers) manage their coffee areas, e.g., maintaining shade trees and harvesting coffee gradually, but they rarely apply any chemicals. Producers commonly dry the wild coffee after harvesting it and sell it as sun-dried, shade-grown coffee to local markets, but the selling price for this coffee has typically been fairly low (approximately 1 US dollar/kg in 2007 and 2008).

In 2006, the Japan International Cooperation Agency (JICA), a Japanese foreign aid agency, began supporting a group of 555 coffee-producing households seeking to obtain shade coffee certification ("forest coffee certification") from the Rainforest Alliance. The Rainforest Alliance is a major international non-governmental organization (NGO) based in the United States that provides certifications for many type of products, such as coffee, tea, and bananas.

Although the Rainforest Alliance originally worked primarily with producers that owned larger plantations (Méndez et al. 2010), it also provided the certification program—which excludes modern industrial coffee producers—in an effort to encourage the shaded coffee system and to encourage coffee producers to move toward greater sustainability (Mas and Dietsch 2004). Hence, many studies defined the ecological certification provided by the Rainforest Alliance as the shade coffee certification (Giovannucci and Ponte 2005; Mas and Dietsch 2004; Philpott et al. 2007; Philpott and Dietsch 2003). The criteria used in the program include shade criteria for tree species richness and composition, tree height, tree density, number of strata in the canopy, and canopy cover. The details of the certification criteria are provided in the study by Philpott et al. (2007) and Rainforest Alliance (2009).

In 2007, two villages successfully received the certification from the NGO and obtained a price with the certification that was 15-20% higher than the regular price. Although most producers also produced coffee using the improved seeds at their homestead under the modern coffee system, such coffee is, of course, strictly eliminated from the certified coffee. Once each year, an auditor from the Rainforest Alliance visits to assess the condition of the certified area and the surrounding forest regions. If an expansion of the forest coffee area or degradation of the forest and biodiversity (e.g., logging of shade trees and loss of flora and fauna) is observed in the certified area, the auditor demands the improvement of the situation. The certification would be withdrawn if the situation is not improved in the following year.

3. Data

3.1. Remote sensing data and classification

For our analysis, we used the January 2005 and January 2010 satellite images of Landsat 7 ETM+ (path/row 170/55), with a resolution of 30 m. We used a two-step process to classify the forest areas based on forest density.

First, we distinguished the forest areas from the non-forest areas (such as agricultural lands, young fallow lands, rangelands, cleared areas, bare soil areas, and urban areas) by utilizing the normalized difference vegetation index (NDVI). The NDVI is a measure of vegetation biomass that is commonly used to identify forest degradation (Lyon et al. 1998; Mitchard and Flintrop 2013; Tucker et al. 1985). Following the studies by Southworth et al. (2004) and Takahashi and Todo (2012), we determined a threshold value of the NDVI for the forest areas on the basis of the information from the satellite images and fieldwork. We conducted ground-truthing to collect locational data for 17 points on the boundaries that delineated the forest regions from the non-forest areas that existed during the period of our study (according to interviews with several local residents). We chose the area with the highest NDVI value for each year as the threshold value for the forest areas.

Second, after eliminating the non-forest areas from the satellite images, we classified the images using an unsupervised classification technique in which one of the clustering algorithms split the images into classes based on the NDVI values. One advantage of using unsupervised classification is that it does not require the user to have foreknowledge of the classes. We first set the number of clusters and established the clustering criteria, such as the minimum number of pixels per cluster and the closeness criterion. In this study, we used the following specifications: the minimum number of pixels per cluster was 20, and the sample interval was 10 cells.

After establishing the criteria, cluster centers are randomly placed and each pixel is assigned to the closest cluster by Euclidean distance. Then, the centroids of each cluster are recalculated. Additionally, the established clusters are split into different clusters based on the standard deviation of the cluster or merged if the distance between the clusters is closer. These processes are repeated until the clustering criteria are satisfied. The unsupervised classification is commonly used in remote sensing to classify forests (Bray et al. 2004; Mertens et al. 2000).

We classified the forest areas into five categories that represent the forest density: class 5 (i.e., the cluster with higher NDVI values) indicates a dense deep forest and class 1 (i.e., the cluster with lower NDVI values) is a less dense forest. Because the NDVI is a measure of vegetation biomass, scaling down of classification directly indicates the loss of biomass. Hence, if the forest areas moved down the classification scale between 2005 and 2010, we defined such decrement as forest degradation.

To confirm the forest condition of each classification, we conducted a ground truth survey by using sample plots of 20 m by 20 m and collecting the following information: the number of trees, the tree species, the tree height for each species, the number of strata of trees, and the canopy cover. We tried to investigate the class 5 forest areas; however, we could not enter these areas due to their rugged terrain. According to local residents, neither humans nor wild animals can access the deep dense forest.

The description of each classification is presented in Table 1. We observed six different tree species in the class 1 forest area with a canopy cover that ranged from 60 to 70%. Although the number of trees in the lower classes (classes 1 and 2) was greater than in the upper ones (classes 3 and 4), the upper classes had more canopy cover than the lower ones because the upper classes were formed by a great forest canopy with bigger trees. Approximately 85 and 90% of the class 3 and 4 forest areas was covered by forest canopy, respectively.

Additionally, name of tree species in each classification is provided in Table 2. We recorded in total 12 tree species and all of them are indigenous forest trees. Although most of the villagers plant exotic trees, such as Eucalyptus, around their homestead area, tree plantation is not common in the forest area. In fact, other study conducted in the Belete-Gera RFPA by Ango et al. (2014) found that only 2 tree species out of recorded 49 tree species were exotic trees (Eucalyptus and Cupressus lusitanica) and they were mostly found in woodlot area, not in natural forest area. Therefore, forest in each classification in our study is formed by the indigenous tree species and invasion by the exotic tree is rarely happened in the study area.

Although it is important to assess the accuracy of the classification, we are not able to estimate the accuracy statistics because of the lack of the reference data. However, this should not cause significant problems. Even if the error existed, because same error would affect any locational unit within the same year, the change in forest quality with and without the certification would be over- or underestimated to the same extent. Therefore, the possible error in the estimation from satellite images does not lead to a bias in the estimation of the impact of the certification.

3.2. The forest coffee areas and observation grids

We selected four villages (the areas marked with a black color in Fig. 1) as the areas for our study: two villages involved with the certification program as the treatment group and two villages randomly selected from villages not involved with the certification program as the control group. To identify the location of each forest coffee area, we conducted a field survey using a global positioning system (GPS) device and collected data from all the forest coffee areas in the villages, i.e., 240 forest coffee areas in total. Of these forest coffee areas, 148 areas were certified in 2007.

The target forest areas were divided into square-shaped cells (30 m by 30 m). We used each grid as an observation for the analysis. A total of 1,733 observation grids were divided into two categories: the forest coffee areas with certification and the forest coffee areas without certification. The observation numbers for the forest coffee areas with and without certification are 1,141 and 592, respectively. The general characteristics of the observation grids are given in Table 3.

4. Methods

We evaluated the impact of forest coffee certification on forest degradation using a matching methods to reduce selection bias. Matching methods are commonly applied to estimate the causal treatment effects by comparing outcome between treatment and control groups.

One of the common matching methods used in the evaluation study is the PSM method (Caliendo and Kopeinig 2008). For example, Blackman and Naranjo (2012) rigorously analyzed the environmental impacts of organic certification by using the PSM method. Usually, the standard errors for the PSM estimation are estimated by using bootstrapping as suggested by Lechner (2002). However, recent studies demonstrated that bootstrapped standard errors may not be valid in the case of non-smooth, nearest neighbor matching (Abadie and Imbens 2008; Imbens 2004).

Therefore, we chose to use a covariate matching with the Mahalanobis distance metric and the PSM estimations with different matching algorithms were used for the robustness check. Specifically, we employed four different matching algorithms for the PSM estimations: (1) nearest neighbor 1-to-1 matching with caliper which each certified grid is matched to the uncertified grid with the closest propensity score; (2) nearest neighbor 1-to-4 matching with caliper which each certified grid is matched to the four uncertified grids with the closest propensity score and the counterfactual outcome is the average across these four; (3) nearest neighbor 1-to-8 matching with caliper; (4) kernel matching which a weighted average of all uncertified grids is used to estimate the counterfactual outcome. Following Bernhard et al. (2008) and Fabling and Sanderson (2013), we used a caliper size of 0.001.

To obtain the PSM estimator of the effect of the treatment, we first used a probit model to examine how a target area for the procurement of certification is selected. Based on the propensity score from the probit estimation, we created a new control observation group to ensure that the treatment group and the new control group would have similar environmental characteristics. As mentioned, the standard error is obtained by bootstrapping in most studies (Caliendo and Kopeinig 2008). Hence, we also used the bootstrapping standard error based on 100 replications, following Smith and Todd (2005).

To check the characteristics of the treatment group and the control group after the matching procedure, we conducted two types of balancing tests. First, a *t*-test was used to compare the mean of each covariate between the treatment and control groups after the matching procedure. If the matching was successfully accomplished, the mean difference after matching should be insignificant. Second, we compared the pseudo R-squared values between before and after the matching procedure, suggested by Sianesi (2004). If the matching was successful, then the pseudo R-squared after the matching should have a lower value than that before the matching.

In this study, we specifically examined the average effect of treatment on the treated (ATT), as developed by Rosenbaum and Rubin (1983). In the matching estimations, we compared the change in forest classification scales between the certified forest coffee areas and the areas without certification that served as the control area. Following the study by Cropper et al. (1999) and Takahashi and Todo (2013), the following variables were used as covariates in the estimation: distance to the village, distance to the main road, average elevation, average slope, a dummy variable for fertile soil, a dummy variable for facing south, and a dummy variable for facing north.

The dummy variable for fertile soil includes the nitisol and fluvisol soil types, which are suitable for crop production. The dummy variables for facing south take a value of 1 if the slope face of a grid faces the south; this variable controls for the high likelihood of catching the sun. Additionally, we included the dummy variable for facing north to control for the likelihood of sunless conditions.

Although we controlled the selection bias by using the observable environmental variables, the effects of the certification may be contaminated by unobserved factors (hidden bias). In our case, because we do not have the village level variables, the village characteristics may be the possible hidden bias and affect our results. To check the sensitivity of our results, we calculated Rosenbaum bounds (Rosenbaum 2002). Rosenbaum bounds indicate how strongly unobservable factors must influence the selection process in order to undermine the matching results.

In the case of the spillover effect of the certification, we employed the nearest neighbor 1-to-1 matching method with caliper and compared the change in forest quality among the natural forest areas (i.e., forest areas without forest coffee) around the forest coffee areas and natural forest areas with similar environmental characteristics. In this study, we first created six buffer zones from the forest coffee area boundary to 150 m by 25 m interval. Second, we created six buffer dummy variables with a value of 1 if a grid was within the buffer. Then, we selected those grids in the buffer zone as the treatment group and compared them with other grids outside of the buffer. Thus, we performed six PSM estimations, using the grids in each buffer as a treatment group, and evaluated the spillover effects by comparing the change in forest quality.

5. Results

5.1. Matching procedure

We performed probit estimations, and the majority of the variables had significant effects (Table 4). The goodness of fit can be measured by the pseudo R-squared value, and our probit estimation showed fairly large pseudo R-squared values, such as 0.27.

Based on the propensity score from the probit estimation, we created a new control observation group to ensure that the treatment group and the new control group would have similar environmental characteristics. A common support condition must be implemented to satisfy the overlap assumption. In other words, in the treatment group, we omitted observations from the treatment group whose propensity scores were higher than the maximum score or lower than the minimum score of the observations in the control group. The treatment effect was calculated by comparing the average outcome for all treated observation on common support with a weighted average of all control observations on the common support.

To check the characteristics of the treatment group and the control group after the matching procedure, we conducted two types of balancing tests. The results of *t*-test showed that the differences in all covariates became insignificant after the matching procedure, which indicates that the characteristics of the control group were sufficiently similar after matching. Furthermore, we found that the pseudo R-squared values drastically decreased from 0.27 to 0.01 after matching, which indicates that the after-matching probit had no explanatory power. These balancing tests confirmed that there was no systematic difference among the covariates used for matching between the treatment and after-matching control groups (new control group).

5.2. Impact of the forest coffee certification

Mahalanobis matching indicated that the certified forest coffee areas conserved or slightly increased their quality (Table 5), implying that the certified producers managed their coffee areas in a sustainable manner.

By contrast, the forest areas without the certification suffered forest quality decline measuring 1.61, which means that the difference between two groups is 1.75. Since our matching estimation compared the change in forest classification scales (i.e., scale range between 0 and 5), this result indicated that the non-certified forest coffee areas moved down the classification scale by at least one level during the study period. One of the reasons for the drastic degradation in the control group is transformation to the modern coffee system. The high yield of the modern coffee system motivates non-certified producers to convert forest coffee areas to the modern system with fewer shade trees, which results in forest degradation.

The results of the PSM estimations with different matching algorithms also showed the similar results, indicating that the certified forest coffee areas conserved the forest quality compared with the non-certified areas by approximately 1.86. These results suggest that our results are robust.

Finally, we check the sensitivity of our results by calculating Rosenbaum bounds. The amount of the hidden bias is specified as Γ. While $\Gamma=1$ is equivalent to the scenario of no-hidden bias, $\Gamma=1.5$ indicates that hidden bias would increase the odds of obtaining the certification for the treatment group compared to the control group by an additional 50%. In other words, large value of Γ indicates the robustness of the existence of the certification effect, even under unobserved elements. In this study, we calculate the critical value of Γ shown as $\Gamma^{\dagger}$ in Table 5, which alter the results of our statistical inference at 10% level.

The critical value of odds ratio (i.e., amount of the hidden bias) took values between 6.2 and 9.1 ($\Gamma^{\dagger}$ row, Table 5). Although there is no-clear standard threshold value to determine the existence of hidden bias, Apel et al. (2010) report that the estimation results in applied research often become sensitive to Γ as small as 1.15. Therefore, we judge that our results are not sensitive to unobserved characteristics.

In summary, obtaining the certification prevents the degradation of forest when compared with areas without the certification. Thus, these results lead to the conclusion that the forest coffee certification program had a significant impact on the forest degradation.

5.3. Spillover effects to the surrounding forest areas

To evaluate the spillover effect of the certification on the surrounding natural forest, we followed the same matching procedure discussed above. We tested six PSM estimations and all of them passed the balancing tests.

The results provided in Table 6 showed that although the quality of forest in the closest buffer zone (such as with a range of 0 m to 25 m) slightly declined, forest degradation in the matched control areas was larger than that of the treatment group. These results indicated that the forest areas around the certified coffee areas preserved the forest quality compared with the natural forest areas under same environmental conditions. Furthermore, the difference between the treatment and control groups grows as the buffer area increased to the 25 m to 50 m range. After 100 m distance from the forest coffee boundary, we could not find any significant difference, which implies that the quality of forest in the treatment group is not significantly different from the control group.

These results demonstrate that providing coffee certification did not induce the forest degradation in the surrounding forest areas. In fact, the forest areas within a 100 m radius showed significantly alleviated forest degradation.

6. Discussion

We applied the matching methods to evaluate the impact of a forest coffee certification program on the forest degradation. Whereas the certified forest coffee areas slightly increased forest density, forest coffee areas without the certification decreased in quality. Overall, the quality of forest was preserved by 1.75 by obtaining the forest coffee certification.

Additionally, we investigated the spillover effects of the certification on the surrounding forest areas without forest coffee. The results revealed that the forest areas within a 100 m radius of a certified coffee boundary significantly reduced forest degradation when compared with other forest areas under similar environmental conditions. However, such positive and significant impact diminished after 100 m.

Our empirical results provide insights into the debate between Philpott and Dietsch (2003) and Rappole et al. (2003a). Although Rappole et al. (2003b) noted the probability of converting natural forest to shade coffee, Philpott and Dietsch (2003) argued that this type of degradation can be prevented by providing financial incentives for coffee producers and establishing rigorous certification criteria.

In the area under study, the certified producers sold their coffee at a price 15 to 20% higher than regular coffee. Additionally, the Rainforest Alliance requests a high standard of criteria for the certification and monitors the conditions of the certified areas once a year. We assume that the economic incentive and rigorous certification criteria accompanied with the audit system may motivate the certified producers to conserve their forest coffee areas.

From these results, we conclude that the forest coffee certification system had a positive impact on preventing forest degradation in the certified areas and the surrounding forest regions. Although we found empirical evidence to support the effectiveness of the certification system, our current analysis could not assess which elements of the certification program have a significant impact on preventing degradation. Therefore, further study is necessary to investigate the mechanism by which forest quality is conserved.

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Table 1: Characteristics of the four levels of forest disturbance/degradation at the forest coffee sites in the Belete-Gera RFPA, Ethiopia

	Number of trees	Number of tree species	Range of height (m)	Number of strata of trees	Canopy cover (%)
Class 1	14	6	20−35	2	60−70
Class 2	21	4	15−35	2	80
Class 3	10	6	20−45	2	85
Class 4	11	6	15−50	3	90

Note: No class 5 areas studied in the study region.

Table 2: The presence/absence of major tree species in forest areas under various degrees of degradation in the Belete-Gera RFPA, Ethiopia

	Class 1	Class 2	Class 3	Class 4
Syzygium guineense	X	X	X	X
Futeria	–	X	X	X
Olea welwitschii	–	X	X	X
Ficus sur	X	–	X	X
Polyscias fulva	X	X	–	–
Accacia abyssinica	X	–	–	–
Ficus vasta	X	–	–	–
Cordia africana	X	–	–	–
Millettia ferruginea	–	–	X	–
Albizia gummifera	–	–	X	–
Apodytes dimidiata	–	–	–	X
Schefflera abyssinica	–	–	–	X

Note: X indicates the presence of tree species, while – means absence of the species.

Table 3: Geographical characteristics of the studied plots in certified and non-certified forest coffee areas in the Belete-Gera RFPA, Ethiopia

Characteristics	Forest coffee areas with certification	Forest coffee areas without certification	Total
Number of plots	148	92	240
Size of forest coffee area (*Are*)	56.4	40.3	50.2
	(107.7)	(75.9)	(96.9)
Number of observation grids	1,141	592	1,733
Distance to village (m)	377.7	235.4**	329.1
	(417.0)	(195.9)	(363.4)
Distance to main road (km)	1.1	2.1**	1.5
	(1.1)	(1.2)	(1.2)
Average elevation (m)	1,913.7	1,882.8**	1,903.2
	(125.1)	(96.3)	(116.9)
Average slope (%)	11.9	12.2	12.0
	(6.3)	(5.3)	(6.0)
Proportion of fertile soil over the observations (%)	98.0	97.9	97.9
Proportion of grid facing South (%)	58.3	21.1	33.8
Proportion of grid facing North (%)	0.3	3.1	2.1

Note: Numbers are means; numbers in parentheses are S.D. values. ** indicates statistically significant differences at the p<0.01 level.

Table 4: Results from the probit estimation

	Benchmark estimation	
Distance to village (km)	0.971**	(7.11)
Distance to main road (km)	−0.556**	(−13.03)
Average elevation (m)	0.004**	(10.67)
Average slope (%)	0.017**	(2.63)
Fertile soil dummy	−0.117	(−0.32)
South dummy	−0.786**	(−10.27)
North dummy	1.336	(2.36)
Constant	−7.467**	(−8.01)
Observations	1,733	
Pseudo R^2	0.27	

Note: Numbers in parentheses are z-statistics. ** indicates statistically significant differences at the p<0.01 level.

Table 5: Forest quality comparison between forest coffee areas with and without certification in the Belete-Gera RFPA, Ethiopia

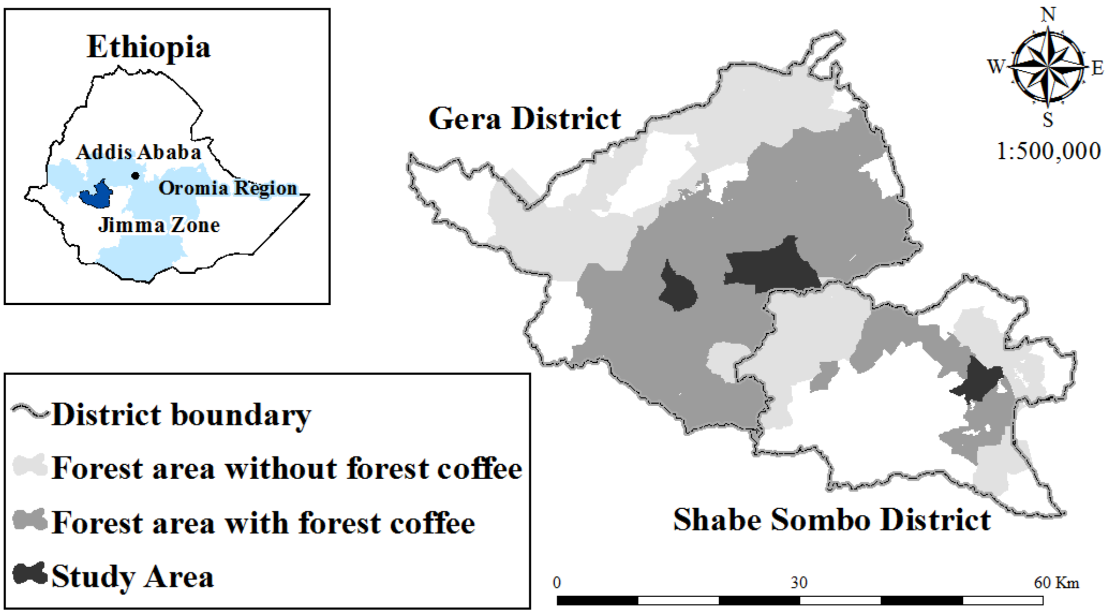
Matching method	Mahalanobis matching	Nearest neighbor 1-1	Nearest neighbor 1-4	Nearest neighbor 1-8	Kernel matching
Mean of treatment group	0.136	0.141	0.141	0.141	0.141
Mean of matched control group	−1.613	−1.713	−1.724	−1.722	−1.719
Difference: ATT	1.748	1.854	1.865	1.863	1.86
Standard error	0.124	0.144	0.143	0.143	0.143
Student's *t*	14.12	12.90	13.01	12.99	13.01
p−value	0.00	0.00	0.00	0.00	0.00
Rosenbaum bounds critical level of odds ratio ($\Gamma^{\dagger}$)	6.2	8.8	9.0	9.1	9.1
Observations	1,184	1,184	1,184	1,184	1,184

Table 6: A comparison of forest quality between natural forest areas around the certified forest coffee plots at various distances and other natural forest areas in the Belete-Gera RFPA, Ethiopia

Matching method	0 m – 25 m buffer	25 m – 50 m buffer	50 m – 75 m buffer	75 m - 100 m buffer	100 m - 125 m buffer	125 m - 150 m buffer
Mean of treatment group	−0.265	−0.351	−0.437	−0.520	−0.614	−0.651
Mean of matched control group	−0.531	−0.668	−0.688	−0.635	−0.693	−0.707
Difference: ATT	0.266	0.317	0.251	0.116	0.079	0.056
Standard error	0.063	0.053	0.06	0.056	0.054	0.061
Student’s *t*	4.24	5.96	4.20	2.07	1.45	0.93
p−value	0.00	0.00	0.00	0.04	0.15	0.35
Observations	2,880	5,508	4,794	4,668	4,572	4,048

Figure Captions

Figure 1: A map of the Belete-Gera Regional Forest Priority Area, Ethiopia, with an indication of the studied forest coffee-growing areas



The areas shown in dark gray represent the sub-villages that produce forest coffee, and the light gray areas are the sub-villages without forest coffee. The areas marked with a black color are the study areas for this investigation.