Land tenure differences and adoption of agri-environmental practices: Evidence from Benin (West Africa)

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Abstract

This article uses a multinomial endogenous treatment effects model in combination with propensity score matching techniques to evaluate the impact of land tenure on the adoption of agri-environmental practices by smallholder farmers in Benin. We rely on a unique and detailed cross-sectional dataset that covers 2,800 smallholder farmers and 4,233 plots. The dataset was gathered from a household survey conducted in Benin by the World Bank between March and April 2011 covering all agro-ecological zones of the country. The results indicate that land tenure arrangement significantly influence farmers' decision to invest in agri-environmental practices. The intensity of the adoption is consistently higher on owned plots than borrowed, rented or sharecropped plots. We found strong evidence that the hypothesis of selectivity bias cannot be rejected. The adoption gap between plot owners and borrowers increases when implementing the matching techniques. The sample selection framework increases that gap further.

Keywords: Land tenure; Agri-environmental practices; multinomial endogenous treatment effects; Propensity score matching; Benin.

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1. Introduction

In many regions in the world, there is growing concern about the soil productivity and wider environmental implications of conventional agricultural practices (Knowler and Bradshaw, 2007). In Benin, soil fertility degradation has been identified as a major challenge to increasing agricultural productivity and poverty alleviation in the growth and poverty reduction strategy paper adopted in 2007. The degradation of agricultural land is driven by increasingly strong population pressure and the use of cultivation techniques that do not favor the regeneration of soil organic matter. Floquet and Mongbo (1998) argue that the cropping system in Benin, characterized by an overexploitation of farmlands, is unfavorable to the reconstitution of the fertility potential of the land, and therefore to the maintenance of high crop yields. In addition, there is a belief that the adverse effects of climate change are accentuating land degradation (Saidou et al., 2004).

The adoption of agri-environmental practices could be a potential solution to land degradation by improving soil fertility, water conservation and crop yields. This is particularly important in a context of climate change where agri-environmental practices can help smallholder farmers adapt to the variability of production and therefore contribute to food security (Thangataa and Hildebrand, 2012; Mbow et al., 2014). Generally speaking, agri-environmental practices include soil fertility management techniques such as fallowing and use of organic fertilizers, crop rotation, agroforestry and water conservation techniques such as plot leveling, cover crop planting, stone terraces, strip cropping and soil bunds (Lee, 2005; Mbow et al., 2014). In this article, we focus on the adoption of three major groups of agri-environmental practices: agroforestry practices, improved fallow, and soil or water conservation practices. These practices have been widely disseminated in Benin (Versteeg and Koudokpon, 1993; Versteeg et al., 1998; Honlonkou et al., 1999; Houngbo et al., 2012).

Agroforestry can contribute to soil fertility improvement and enhance farm households' resilience by providing additional products for sale or for home consumption (Thangataa and Hildebrand, 2012). Several studies have shown that agri-environmental practices can slow soil degradation, improve the management of water resources, contribute to food security and secure the livelihoods of poor rural households in developing countries coping with the effects of climate change, through the ecological and economic benefits they offer (Torquebiau, 2000; Kassie et al., 2008; Gockowski and Asten, 2012; Simelton et al., 2012; Thorlakson and Neufeldt, 2012; Nguyen et al., 2013; Skole et al., 2013).

Despite the ecological and economic benefits of agri-environmental practices, and extension efforts of the government and development agencies, the adoption of these practices remains low in Benin. However, farmers are aware of the degradation of their agricultural land, which is manifested by the increasing decline in their crop yields (Floquet and Mongbo 1998). It is therefore important to empirically identify the determinants of the adoption of agri-environmental practices and in particular assess the role of land tenure arrangements in the adoption process. This is especially important because Benin is currently preparing to launch a vast program of agricultural land certification. The pilot phase of the program was implemented between 2007 and 2012 through the access to land component of the Millennium Challenge Account (MCA-

Benin) program for Benin funded by the US government[1]. The pilot project covered 300 villages (approximately 10% of the villages of Benin) randomly selected in 9 of the 12 departments in the country.

The determinants of adoption of agri-environmental practices and in particular the role of land tenure in farmers' adoption decisions have been widely studied in the literature. Although the theoretical literature is unanimous on the positive relationship between tenure and adoption, empirical findings do not provide clear evidence of the impacts of land property rights on the adoption of agri-environmental practices; the results are mixed. No clear consensus emerges from empirical studies in various socio-economic contexts in sub-Saharan Africa on the potential effect of an increase land property rights on the incentive for farmers to adopt agri-environmental practices (Deininger and Jin, 2006; Place, 2009; Arnot et al., 2011).

Empirical studies on the impact of land property rights on the adoption of agri-environmental practices are distinguished by the evaluation methods used and how property rights are treated. Several studies that used cross-sectional data (as this study has) did not control for the endogeneity of property rights, whose existence was proven by Brasselle et al. (2002). Recent examples of these studies are those of Manyong and Houdékon (2000); Soule et al. (2000); Gebremedhin and Swinton (2003); Amsalu and De Graaff (2007) and Bandiera (2007). Other empirical studies including those of Deininger and Jin (2006), Saint-Macary et al. (2010); Abdulai et al. (2011); Ali et al. (2011) and Deininger et al. (2011) used estimation methods for correcting endogeneity but ignored the existence of selection biases on observed variables.

[1] See https ://www.mcc.gov/where-we-work/program/benin-compact. Website consulted on June 14, 2016.

Our study differs from previous studies because we control for selection biases on both observed and unobserved variables. We model land tenure arrangements as a multinomial selection process such that the choice of land tenure contract depends on the indirect utility it gives the farmer. In particular, we used a multinomial endogenous treatment effects model developed by Deb and Trivedi (2006) to account for the endogeneity of land property rights to the adoption of agri-environmental technologies. We then used the propensity score matching method to select observations with similar observable characteristics to account for selection bias on observed variables. The combination of the multinomial endogenous treatment effects model and the propensity score matching method allowed us to control for selection biases on observed and unobserved variables.

The rest of this article is organized as follows. In Section 2 we present the conceptual framework and the econometric model used. Section 3 describes the data and the variable used in the econometric estimates and provides some descriptive statistics. Section 4 presents the empirical results and discussions, and Section 5 concludes the article.

2. Conceptual and Econometric Framework

2.1. The multinomial endogenous treatment effects model

The reference model that we used in this article is the multinomial endogenous treatment effects model developed by Deb and Trivedi (2006). The multinomial endogenous treatment effects model is a two-stage model. In the first stage of the model, the farmer chooses a land tenure arrangement from four mutually exclusive options, namely (i) borrowing or gifting; (ii) renting; (iii) sharecropping and (iv) full ownership of the land. Specifically, we hypothesize that farmers seek to maximize their utility V_{ij} by comparing it with the utility provided by the alternative land tenure arrangement. Thus, a farmer *i* chooses a land tenure arrangement *j* as opposed to all other land tenure arrangements *k* if and only if $V_{ij} > V_{ik},\ j \neq k$.

Following Deb and Trivedi (2006), let *EV** denote the indirect utility associated with the j^{th} land tenure arrangement *j*= 0, 1, 2,…., *j* with j being a positive integer and:

$$EV_{ij}^{*} = z_i^{'}\alpha_j + \delta_j l_{ij} + \eta_{ij} \qquad \textbf{(1)}$$

Where z_i is a set of exogenous covariates with associated parameters α_j; η_{ij} are identically distributed error terms; l_{ij} is a latent factor that incorporated unobservable characteristics common to the farmer's choice of land tenure arrangement and adoption of agri-environmental practices such as the farmer's motivation, investment planning horizon or management and technical abilities (with δ_j the vector of corresponding parameters). The latent factor l_{ij} is assumed to be independent from the error term η_{ij}. Without loss of generality, let j = 0 denote farmers of the control group (farmers with full ownership of their land) and $EV_{i0}^{*} = 0$.

While EV_{ij}^{*} is not observed, we observe the farmer's choice of land tenure arrangement as a set of binary variables d_i representing the observed treatment choice, $d_i = (d_{i1}, d_{i2} \dots, d_{ij})$. Similarly, let $l_i = (l_{i1}, l_{i2} \dots, l_{ij})$. Then the probability of choosing a given land tenure arrangement, conditional on the latent variables can be written as:

$$\Pr(d_i \mid z_i, l_i) = f(z_i^{'}\alpha_1 + \delta_1 l_{i1}, z_i^{'}\alpha_2 + \delta_2 l_{i2}, \dots, z_i^{'}\alpha_J + \delta_J l_{iJ}) \qquad \textbf{(2)}$$

Where f is an appropriate multinomial probability distribution. Following Deb and Trivedi (2006), we assume that f has a mixed multinomial logit (MMNL) structure, defined as:

$$\Pr(d_i \mid z_i, l_i) = \frac{\exp(z_i^{'}\alpha_j + \delta_j l_{ij})}{1 + \sum_{k=1}^{j} \exp(z_i^{'}\alpha_k + \delta_k l_{ik})} \quad \textbf{(3)}$$

In equation (3), j= 0, 1,2…j. As in the standard multinomial logit model, the parameters in the MMNL are identified only up to scale. In addition, we assume that each treatment choice is affected by a single latent factor $\delta_j = 1$ and for all j in order to normalize the scale for each treatment choice equation.

In the second stage of the model, we evaluate the impact of land tenure differences on the adoption of agri-environmental practices. The agri-environmental practices include fallowing, agroforestry and adoption of soil or water resource conservation practices (plot leveling, cover crop planting, strip cropping, stone terraces, soil bunds) or the adoption of a combination of these innovations. The outcome variable **y** is the number of agri-environmental practices adopted. Hence, the outcome variable is a non-negative integer valued count variable, and the expected outcome equation for farmer i (i = 1, ..., N.) is formulated as follows:

$$E(y_i \mid d_i, x_i, l_i) = x_i^{'}\beta + \sum_{j=1}^{J} \gamma_j d_{ij} + \sum_{j=1}^{J} \lambda_j l_{ij} \quad \textbf{(4)}$$

Where x_i is a set of exogenous covariates with associated parameters β. The parameters γ_j denote the treatment effects (borrowing or gifting, renting or sharecropping) relative to the control choice (full ownership of the land). Specifically, γ_j gauges the effects of land tenure arrangements on the adoption of agri-environmental practices. Given that $E(y_i|d_i, x_i, l_i)$ is a function of each latent variable l_{ij}, the outcome is affected by observed characteristics that also affect the choice of a land tenure arrangement. When the factor-loading parameter λ_j is positive (negative), the treatment and outcome are positively (negatively) correlated through unobserved characteristics. In other words, there is a positive (negative) selection, with γ_j and λ_j the associated parameter vectors. Given that our outcome is a counting variable, we assume that it is generated by a Poisson-like process. As a result, we use a negative binomial regression-2 in the second stage of the model. The model was estimated using a Maximum Simulated Likelihood approach (MSL).[2]

According to Deb and Trivedi (2006), although for the identification of the model it is not necessary to include additional variables that are not in the vector of exogenous variables x_i, it is recommended to include variables in z_i that are not in x_i. In other words, it is recommended to include independent variables in the treatment equation ("*exclusion restriction*" variable) that are not included in the outcome equation for a more robust identification. We used two variables as exclusion restriction variables: ethnicity and whether the farmer resides in the village where the plot is located. The ethnic group is an indicator of a customary land management system. Therefore, the ethnic group of the farmer might affect his access to land, but is unlikely to have a direct effect on the adoption of agri-environmental practices. Abdulai et al (2011) show that whether the

[2] The model was estimated using the stata command *mtreatreg*. All estimations were made with 500 simulation draws, based on Halton sequences. Standard errors were clustered at the household level to address potential heteroskedasticity problems and correlation errors between plots belonging to the same household.

farmer resides in the village where the plot is located strongly influences land tenure arrangement choice but is orthogonal to soil quality, and therefore is uncorrelated to adoption. They argue that a dummy variable indicating whether or not the farmer resides in the village where the plot is located is a good exclusion restriction variable.

Note that the multinomial endogenous treatments effects model perfectly corrects for selection biases on unobserved variables but fails to control for selection bias on observed characteristics that might affect the treatment effect. Thus, in a third step, we control for selection bias on observed variables using the propensity score matching method. This method allows us to select, from among the three treatment groups, households that have the same socioeconomic characteristics along with similar plot characteristics.

2.2. Propensity score matching with multiple treatments

Our objective is to isolate the initial differences between farmers' and plots' characteristics from the real effect of each treatment on the adoption decision. The economic literature has demonstrated the effectiveness of the propensity score matching method to control for selection bias on observable characteristics.

In a binary treatment framework, the average treatment of individuals is written as follows:

$$\theta(x) = E(Y^T - Y^C \mid D=1, X=x) = E(Y^T \mid D=1, X=x) - E(Y^C \mid D=1, X=x) \quad \textbf{(5)}$$

Where Y^T and Y^C are respectively the outcome of the treated individuals (D=1) and the potential outcome of individuals in the control group (D=0) and X a set of exogenous covariates. The potential outcome of the counterfactual $E(Y^C \mid D=1, X=x)$ is unobservable. Therefore, $\theta(x)$ could be estimated through the matching method only if conditional to the exogenous covariates, the potential outcomes of the control individuals are independent from the treatment (Conditional Independent Assumption). Rubin (1977) and Rosenbaum and Rubin (1983) show that under the CIA, it is not necessary to match on the observable characteristics but only on the probability of being treated conditional on the observable characteristics (propensity score) reducing the size of the estimate to one.

In the case of multiple treatments of $(M + 1)$ mutually exclusive treatments, the potential outcomes are represented by $\{Y^0, Y^1, \dots, Y^M\}$. For each individual, we can observe only one of the potential outcomes from $\{Y^0, Y^1, \dots, Y^M\}$. This means that for M=0, we observe Y^0 and the remaining M potential outcomes are counterfactuals. The average treatment effect of treatment m relative to treatment l for the participants in treatment m could be written as:

$$\begin{aligned}\theta^{m,l}(x) &= E(Y^m - Y^l \mid D=m, X=x) \\ &= E(Y^m \mid D=m, X=x) - E(Y^l \mid D=m, X=x)\end{aligned} \tag{7}$$

Where $D \in \{0,1 \dots, M\}$ represents the type of treatment. Equation (7) above represents the expected effect for an individual randomly drawn from the population of participants in treatment m. It shows that the evaluation problem is also a problem of missing data in the case of a multiple treatment because the potential outcome $E(Y^l|D=m, X=x)$ is not observable for the same individual (counterfactual). Either the individual is in treatment m or in treatment l. As in the binary treatments framework, the CIA assumption allows the use of outcomes of participants in treatment l (Y^l) to infer the outcomes of the counterfactual and to estimate $\theta^{ml}(x)$. Imbens (2000) and Lechner (2001, 2002) state that the CIA assumption implies that all potential outcomes are independent of treatment for any given value of the observable characteristics. and that the propensity score properties hold in the multiple treatments case as well.

The average treatment effect of treatment *m* relative to treatment *l* for the participants in treatment m specified in equation (7) can be estimated by:

$$\theta^{m,l} = E(Y^m \mid D=m) - E_{p^{l|ml}(x)}\left[E\left\{ Y^l \mid p^{l|ml}(x), D=l \right\} \mid D=m \right] \text{and} \tag{10}$$

$$p^{l|ml}(x) = p^{l|ml}(D=l \mid D \in \{m,l\}, X=x) = p^l(x) / \left[p^l(x) + p^m(x) \right] \tag{11}$$

As in the binary treatment framework, Equation 10 can be estimated by matching on the balanced propensity score $p^{l|ml}(x)$.

The empirical application of the multiple treatments is a bit complex. In the literature, two propensity score matching approaches have emerged. One approach is that of Imbens (2000) and Lechner (2001, 2002), where the propensity scores are estimated by a logit or probit multinomial method. Lechner (2001, 2002) has developed a protocol similar to the case of binary treatment to verify that the propensity scores balance between treatment groups. A second approach is to use a series of binomial models to estimate the propensity scores. The advantage of this approach is that the assumptions of the binomial models are less restrictive than the multinomial logit. Indeed, the multinomial logit is based on the assumption of independence of irrelevant alternatives (IIA); this can produce unreliable results when the categories modeled are substitutes. The IIA assumption implies that the probability of choosing a land tenure arrangement does not depend on the presence or absence of additional alternative land tenure arrangements other than the four options that we have considered. Moreover, Lechner (2002) asserts that binomial models are less sensitive to model specifications than is the multinomial model. The author also showed empirically that binomial models produce similar results to the multinomial model. However, one empirical study is not sufficient to generalize the results. For more flexibility in our estimates, we opt for binomial models.

We estimated the propensity scores with a logit binomial model for each pairwise combination of land tenure arrangements. Lechner (2002) argues that in this case one needs to model and estimate M (M-1)/2 binary conditional probabilities $p^{l|ml}(x)$. In total, six logit models were estimated. Propensity scores are simply a conditional probability that the household has access to land through the land tenure arrangement chosen as treatment, written as $P(T = 1|X, W)$. Propensity scores are estimated using a logit model where a vector of household characteristics, X, and village characteristics, W, are regressed on P, a household's land tenure arrangement, to obtain predictions of household propensity scores, where:

$$p^{*}_{w,h} = \beta X_{w,h} + \gamma W_{w,h} + \varepsilon_{w,h} \tag{12}$$

With each model, to ensure that the treatment and control groups are comparable for each covariate, we perform a balancing test. These tests consist of splitting the propensity scores into decile groups (blocks) and checking with a t-test in each group if there is a significant difference between treatment and control at the 0.10 significance level for each covariate. The balancing test is satisfied if no significant difference is observed. When the balancing test is not satisfied, we change the model's specification by removing variables that do not satisfy the balancing test or by adding interaction variables or excluding the problematic blocks of propensity scores (Rosenbaum and Rubin, 1984). This process helped us finding the best model specifications to estimate the propensity score, but led to different specifications between models.

The estimated propensity scores are used for the matching. Before the matching, we ensured that the common support hypothesis is verified. In a second step, we removed all observations whose propensity score is outside the common support. This implies that all observations whose propensity scores are outside the common support in at least one of the pairwise comparisons have been removed.

The third and final step is the matching for each pairwise comparison. Following Bravo-Ureta et al. (2012), with each pairwise comparison we matched treated individuals with control individuals using "1-1 nearest neighbor without replacement" technique. We used the command psmatch2 in Stata to perform the matching. We used the "nonreplacement", "common" and "caliper" (0.01) options. The "nonreplacement" option means that an observation in the control group can only be used once for matching. The "common" option means that before the match, we delete all observations in the treated group whose propensity scores are outside the range of propensity scores in the control group. The "caliper (0.01)" means that we match an observation in the treated group with an observation in the control group within 0.01

To test the quality of our match, we considered two factors. First, following Leuven and Sianesi (2003) and Bravo-Ureta et al. (2012), we performed means t tests between the treated group and the control group in each pairwise comparison to test the null hypothesis of equal means. The results presented in Tables A1, A2, A3, A4, A5 and A6 in appendix show that the average of most covariates were not statistically different, suggesting that the balancing property on covariates is satisfied (Leuven and Sianesi 2003; Bravo-Ureta et al., 2012). Second, following Calia et al. (2016) we considered the normalized median bias and pseudo-R^2. As shown in Table 1, for all pairwise comparisons the standardized median bias and pseudo-R^2 are smaller after the matching than before. In addition, after matching, the pseudo-R^2 is always close to zero, suggesting that with the data matched, the covariates have no predictive power on the farmer's land tenure arrangement choice (Calia et al., 2016). This confirms that matching has effectively eliminated the differences in observable characteristics (socio-economic characteristics and land characteristics) between farmers with different ownership.

<<<< Table 1 about here >>>>>

3. Variables, data and descriptive statistics

The data used in this article come from a household survey conducted in Benin by the World Bank between March and April 2011. The data cover a random sample of 2,800 farming households, 291 villages, and 4,233 plots after removing missing observations. After propensity score matching, we are left with 1907 households and 2,660 plots. Sampled households are spread in 9 departments covering all agro-ecological zones of the country. The household survey questionnaire covers a range of topics related to basic socio-demographic data, information on households' plots, off-farm activities, and agricultural production. The plot module collects detailed information on plot characteristics, land property rights and investment in the plot.

3.1. Dependent and treatment variables

Our dependent variable is the number of agri-environmental practices adopted. We considered three major groups of practices: agroforestry, improved fallow soil and water conservation techniques. We considered innovations already adopted and those that the producer intends to adopt in the next agricultural season. Following Saltiel et al. (1994) and the literature that assume that farmers do not adopt at the same time (e.g. Läpple and Van Rensburg, 2011), we have given the score of 2 if the practice is adopted, 1 if under consideration and 0 if the practice was neither adopted nor being actively considered. Given that many practices can be adopted on the same plot; the dependent variable is the sum of the adoption scores.

Our primary independent variable (treatment variable) is the land tenure arrangement grouped into four mutually exclusive binary categories: borrowing or gifting, renting, sharecropping and full ownership. In the regressions, full ownership was chosen as the baseline category. Indeed, borrowing or gifting is a land tenure arrangement through which an individual temporary operates a land parcel without directly paying a fee to the landlord. As argued by Naba et al. (2006), in rural Benin benefiting from borrowing or gifting is based on a number of well-defined criteria, which include trust between the borrower and the landlord, having a good character, and the need to help the borrower for at least five years. Renting is a land tenure arrangement that involves land owners' renting out parcels to tenants. In rural Benin, the land lease contract is usually verbal. The sharecropping contract is a land tenure arrangement between the landlord and the operator, such that part of the harvest is given to the landlord as compensation for using the land. A household becomes the owner of a land parcel either by inheritance or purchase. However, inheritance remains the dominant land tenure arrangement in rural

Benin. Our data show that households own 63 percent of their agricultural land, of which 79 percent and 21 percent were obtained by inheritance and purchase respectively. Borrowing or gifting represents 24 percent of agricultural land, and 11 percent and 2 percent of agricultural land is operated under renting and sharecropping contracts respectively.

3.2.Control variables

In addition to the treatment variable, a series of control variables were also used. The selection of these control variables was based on previous empirical studies on the adoption of agro-environmental practices (Saltiel et al., 1994; Bekele and Drake, 2003; Gebremedhin and Swinton, 2003; Amsalu and De Graaff, 2007; Knowler and Bradshaw, 2007; Wollni et al., 2010; Abdulai et al., 2011; Noltze et al., 2012; Kassie et al., 2013; Wainaina et al., 2016). We classified these variables into two categories, namely socioeconomic characteristics of the household and characteristics of the land parcels.

Household socioeconomic characteristics

The main socioeconomic characteristics of the household considered are the age of the household head, gender of the household head, education, ethnicity, membership in a farmers' organization, household size, farm size and household off-farm income.

Age: The age of the household head is often associated with the level of experience in agricultural activities. Older farmers are likely to have more experience in agriculture and to respond positively to the adoption of innovation (Lapar and Pandey, 1999; Kassie et al., 2013). However, younger farmers who have longer planning horizons may be more likely to invest in soil conservation practices (Amsalu and De Graaff, 2007). Hence, the impact of age on adoption of agri-environmental practices is indeterminate.

Gender: Women are generally constrained in their access to markets and resources, so they adopt agricultural innovations slower than men do (Doss and Moris, 2000; FAO, 2011). We expect that female-headed households would be less likely to adopt agri-environmental practices than their male counterparts.

Education: Education promotes access to a diversified source of agricultural information. Kabunga et al. (2012) argue that better educated farmers tend to adopt new technologies more quickly, especially when they are human capital-intensive and require changes in traditional cropping practices. Hence, we expect a positive impact of education on the adoption of agri-environmental practices.

Membership in a farmers' organization: In Benin, agricultural extension activities are generally oriented toward farmers' organizations. Membership in a farmers' organization reflects both farmers' frequency of contact with extension services and the intensity of their contact with other farmers, allowing them to learn about new technologies from peers (Adegbola and Gardebroek, 2007). The effect of this variable on the adoption of agri-environmental practices is expected to be positive.

Household size: In developing countries where mechanized agriculture is rare, household size is usually an indicator of labor endowment. The larger the household, the lesser it faces labor constraint. Household size is an important control variable in our analysis to the extent that agri-environmental practices are labor intensive, and adoption depends on the availability of labor in the household (Wollni et al., 2010; Noltze et al., 2012).

Farm size: The size of the farm is an important measure of household wealth, and therefore may influence farmers' adoption decision. Agri-environmental practices can be land intensive, which could discourage smallholder farmers who are land constrained. Similarly, large land endowments could reduce the household incentive to adopt soil conservation measures (Gebremedhin and Swinton, 2003). However, high land availability may reflect a greater capacity that would encourage the adoption of soil conservation measures (Cramb et al., 1999). Thus, the expected sign of the farm size variable can be positive or negative.

Off-farm income: Mbaga-Semgalawe and Folmer (2000) found that off-farm income has a positive effect on the adoption of soil conservation practices in Tanzania. On the other hand, Amsalu and De Graaff (2007) found that access to off-farm income is inversely related to the adoption of sustainable agriculture practices in Ethiopia. From the perspective of labor constraint, household participation in off-farm activities could reduce family labor available for soil conservation activities. In contrast, income from off-farm activities could be used to hire labor for agri-environmental activities. Hence, the relationship between off-farm income and adoption of agri-environmental practice is indeterminate.

Ethnicity: The ethnicity variable is divided into 4 binary categories representing the major ethnic groups in Benin. The ethnicity variable is used only in the treatment equation (the first step in our model) as an exclusion restriction variable for more robust identification of the model.

Land parcels' characteristics

Soil type: We use soil type in the regressions to control the effect of soil fertility on adoption. According to Bekele and Drake (2003), the loss of productivity at the margin due to erosion can be high on plots with fertile land that have a high return on investment in the short term. Therefore, the fertility of the land could positively influence the adoption decision.

The slope: In our analysis, we used the slope as the proxy of the erosion potential. The slope variable has been grouped into three categories: lowland (with almost zero slopes), shallows and watershed, where the rugged nature of the plot makes it prone to erosion. We chose lowland as the baseline category. Given that the intensity of erosion increases with the slope of the plot, the watershed and bas-fond categories are expected to have a positive effect on the adoption of agri-environmental practices (Pender and Kerr, 1998; Gebremedhin and Swinton, 2003).

Plot distance from the homestead: There is a belief in the literature that due to increased transaction costs, plots located far from the household dwelling get less supervision and attention from the farmer (Bekele and Drake, 2003; Gebremedhin and Swinton, 2003). Consequently, the distance of the plot from the homestead is expected to have a negative effect on innovation adoption.

Plot distance from the nearest input and output market: According to Kaissie et al. (2013), distance to market can affect the availability of new technologies. The distance of the plot from the market also increases transaction costs and can negatively affect investment in soil conservation practices (Gebremedhin and Swinton, 2003; Bandiera, 2007). Hence, a negative effect of distance to market on the adoption of agri-environmental innovation is expected.

Distance from an all-weather road: Following Gebremedhin and Swinton (2003), we use the plot distance from an all-weather road as the proxy of opportunity cost of labor. The effect of that variable on adoption could be positive or negative.

Number of years of use of the plot: We assume that the number of years of use of the land parcel by the farmer is a proxy of land security, which will impact the planning horizon of investment in the plot. This will be more important for farmers who do not have full ownership of their land. We assume that this variable will have a positive effect on the adoption of agri-environmental practices.

3.3. Descriptive statistics

Descriptive statistics on the variables used in the analysis are presented in Table 2. Statistics show that sample households own 63% of operated parcels, while 24% of the plots are acquired through borrowing or gifting, 11% and 2 % are under renting and sharecropping contracts respectively.

Household heads in our sample are on average 46 years old, and a minority are women (15 percent). About one household head in four is literate, and fewer than one in five is a member of a farmers' organization. Sample households have an average of 6 members. In general, farm size does not exceed 3.5 hectares and is less than one hectare per capita. About three in four households have access to off-farm income. Descriptive statistics show that operated plots are characterized mainly by red lateritic soils and *ferralitic* soils.

The plots are located generally within 60 minutes of the homestead and over an hour from the nearest markets. The average duration of use of cultivated plots is 14 years.

<<<<< Table 2 about here>>>>

4. Empirical results and discussion

The main goal of this article is to analyze the marginal gain of the double correction of biases on observed and unobserved variables in the analysis of the relationship between customary land tenure arrangement and the adoption of agri-environmental practices. The steps below are implemented sequentially to correct for selection biases on both observable and unobservable variables:

1. All available data are used to estimate the impact of land tenure on adoption with a negative binomial regression that considers land tenure arrangements as an exogenous treatment. This model ignores any type of biases;
2. With the unmatched sample, we estimated a multinomial endogenous treatment effects model where land tenure arrangements were considered as endogenous variables, and thus corrected for the selectivity bias on unobservable variables. This was done in two steps:
    a. In the first step of the model, we estimated the determinants of land tenure arrangements with a mixed multinomial logit model;
    b. The second step of the model estimates the effect of multinomial endogenous treatment with a negative binomial regression that considers land tenure

arrangements as endogenous covariates. Thus, the model in this step corrects only for bias from unobserved variables.

3. All available data are used to implement the propensity score matching technique which provides the basis for correcting for biases from observed characteristics.
4. With the matched subsample, two separate models are estimated:
    a. One model with a negative binomial regression considering land tenure arrangements as an exogenous variable. This model corrects only bias from observed variables.
    b. A second model with a negative binomial regression that treats land tenure arrangements as an endogenous variable and thus controls for selection biases on both observable and unobservable variables.

4.1. Treatment effect of land tenure arrangements correcting for biases from unobserved variables

The average treatment effects of land tenure arrangements were estimated with a two-stage multinomial endogenous treatment effects model. In the first stage, the model estimates the determinants of land tenure arrangements (the treatment variable) with mixed multinomial logit estimates. The second stage of the model uses a negative binomial regression to estimate the average effect of land tenure arrangements on the adoption of agri-environmental practices.

4.1.1. Determinants of land tenure arrangements

Table 3 shows the results of the first stage of the multinomial endogenous treatment effects model where a mixed multinomial logit regression (MMNL) is used to predict land tenure arrangements, and where the baseline category of the dependent variable is full land ownership. The model fits the data used: The Wald test indicates that, $\chi^2 = 149{,}57\ and\ p > \chi^2 = 0{,}00$. This implies that the null hypothesis that all the regression coefficients are jointly equal to zero is rejected.

<<<<< Table 3 about here>>>>>>

The results show that the ethnicity of the household head affects his mean access to land. This confirms our hypothesis about the difference between ethnic groups in terms of customary management practices. Older household heads are less likely to access land through borrowing or gifting than are younger household heads.

The estimates illustrate that female-headed households have a higher probability of accessing land through borrowing or gifting than their male counterparts. In other words, women farmers are less likely than their male counterparts to have full ownership over their agricultural land. These estimates imply that women farmers are disadvantaged in the land sales market or access to land ownership through inheritance, and therefore rely more on borrowing or being gifted land. Studies of customary land resource management systems in various localities in Benin have revealed discrimination in inheritance rights against women farmers (Neef and Heidhues, 1994; Edja, 2001). Another disadvantage is that women farmers also have less control over productive resources than men, preventing them from buying land. Our data show that among agricultural plots sold, only 14 percent were bought by women farmers. In the Benin context, borrowing or gifting is a land tenure arrangement that gives the tenant a temporary right to use the land without the right to transfer the land to a descendant. Accordingly, the results of our model imply that female-headed households have fewer property rights over their agricultural land than do their male counterparts.

In the model specifications using land under a renting or sharecropping contract as the dependent variable (models II, and III, Table 3), age of household head has no effect on land tenure arrangement. There is no discrimination by the age of household head for renting or sharecropping contracts. By contrast, literate household heads are less likely to access land through renting. This could be explained by the high value of royalties. The coefficient of the variable gender of household head, although not significant, has a positive sign. This reflects the more active participation of women farmers in the rental land market, as shown by other empirical studies in Benin, including that of Edja (2001).

Off-farm income and land endowment (farm size) have no effect on the probability of the household's holding a renting or sharecropping contract. The lack of effect of land endowment on the household's propensity to rent-in or engage in sharecropping is not surprising. Indeed, Edja (2001) showed that in Benin, households that own large areas of agricultural land through the system called *Zunda* can rent out/sharecrop part of their land while they rent land from other households to enjoy the soil fertility difference between the land they own and those they rented. This shows that in the Benin local context, yet both households well-endowed in land and landless households are engaged in the land rental market. Moreover, in a context where the land sales market is very underdeveloped, it is normal that, all things being equal, off-farm income (an indicator of household wealth) has no significant effect on land tenure arrangement. All things being equal, plot-level characteristics such as soil fertility and slope have no effect on land tenure arrangement.

4.1.2. Average treatment effect of land tenure arrangements

This section presents the results of the second stage of our multinomial endogenous treatment effects model. For comparison purposes, we estimated the treatment effects under the assumptions of exogeneity and endogeneity land tenure arrangement. Table 4 compares the results of two models of negative binomial regression. The first model considers land tenure arrangements as exogenous variables, while the second model treats land tenure arrangements as endogenous variables and therefore controls for bias from unobservable variables. The comparison between the two models will shed light on the effects of endogenous bias and their impact on the estimates.

<<<<<<< Table 4 about here>>>>>>

With the exogeneity assumption of land tenure arrangements (see model I in Table 4), the results show that on average, households that have access to land through borrowing or gifting, renting and sharecropping are less likely to adopt agri-environmental practices than those who have full ownership of their farmland. However, the exogeneity assumption of land tenure arrangements can lead to biased estimates because initial differences between farmers' characteristics can explain the difference in adoption behaviors. Moreover, the difference in the rate of adoption of agri-environmental practices can be explained by unobservable characteristics of farmers such as motivation, managerial ability and investment planning horizon. We controlled for selection biases from unobservable characteristics by estimating a multinomial endogenous treatment effect model (model II in Table 4).

The coefficient (λ) of borrowing/gifting in Model II in Table 4 is positive and significant at 5%. This demonstrates the existence of a positive selection bias. The coefficient (λ) thus indicates that the unobservable characteristics that increase the likelihood of the farmer's choosing borrowing/gifting as a land tenure arrangement are associated with higher adoption of agri-environmental practices than what could be expected when this land tenure arrangement was randomly assigned to the farmers. The results also point to a negative selection bias that suggests that the unobserved variables that increase the likelihood of a farmer's renting-in the land or engaging in a sharecrop contract are associated with lesser rates of adoption of agri-environment practices.

Results in Model II in table 4 show that when the selection bias from unobserved variables is controlled, ownership of the land has a positive and significant effect on the adoption of agri-environmental practices. Accordingly, landowners adopt respectively 36%, 16% and 10% more agro-environmental practices than land borrowers, tenants and sharecroppers. However, ownership of land has a higher effect on adoption compared to borrowing and a lesser effect compared to renting or sharecropping. We explain these results by the fact that farmers who obtained agricultural land through borrowing or gifting have unobserved characteristics that favor adoption of agri-environmental practices (compared with those who own their farmland), which would amplify the effect of the latter land tenure arrangement on the adoption decision. Moreover, although the negative effect of renting/sharecropping persists in both models, the results in model II in Table 4 indicate that the effect is lower when the selection bias from unobserved variables is controlled. These results suggest that when the selection bias from unobserved variables is not controlled, it could lead to an underestimation or overestimation of the effect tenure arrangement on the adoption of agri-environmental practices.

4.2. Treatment effect of land tenure arrangement correcting for biases from observed and unobserved variables

To correct biases from both observed and unobserved variables, we combined the propensity score matching method with the multinomial endogenous treatment effects model. With the matched subsamples, we estimated two separate models shown in Table 5. Model III in Table 5 considers land tenure arrangements as exogenous variables while controlling for observable characteristics. Model IV controls for biases from both observable and unobservable characteristics by combining a propensity score matching method and the multinomial endogenous treatment effects model.

<<<<<<< Table 5 about here>>>>>>

Results in model II and model IV in Table 5 clearly show that landowners adopt more agri-environmental practices than farmers who acquired the land by borrowing, gifting, renting and sharecropping. The results show that landowners adopt between 26% and 38% more agri-environmental practices than borrowers. The difference is between 15% to 22% and 10 to 12% respectively for tenants and sharecroppers. Compared to models I and II in Table 4, the results show land ownership has a higher impact on adoption when controlling for initial differences in observable variables. In case of positive selection (e.g. land borrowers), the effect is even higher when the selection bias on unobservable characteristics is corrected.

4.3. Discussion

Two important results emerge from our estimates. The factor-loading parameter (λ_j) is statistically significant in all models using the unmatched and matched sample. This suggests that the hypothesis of self-selection could not be rejected. Therefore, the use of a multinomial endogamous treatment effects framework is justified. In all models, borrowing, renting and sharecropping have a negative and significant effect on adoption of agri-environmental practices compared to land ownership. This implies that farmers are less likely to adopt agroforestry and other soil conservation practices on borrowed, rented or sharecropped land than on land that they own. We argue that, because borrowers and tenants do not have indefinite tenure of the land, they do not face the true opportunity cost of using the land's attribute. In addition, the fact that the coefficient of the variable duration of continuous use of the land parcel is negative for renting or sharecropping but positive for adoption means that tenants or sharecroppers rarely have long-term contracts and that they would increase their adoption rates if they could use the land for a long time. We interpret this result by the fact that because of the fear of not being able to collect a long-term profit on investment in soil conservation, tenants and sharecroppers seek to maximize their short-term production at the cost of soil fertility degradation. Our finding corroborates that of Bandiera (2007) in Nicaragua, who found that smallholder farmers are more likely to adopt agroforestry on land they own compared to land they rent. Abdulai et al. (2011) affirm that compared to landowners, tenants are more likely to adopt practices that have short-term returns to investment (such as mineral fertilizers) than agro-environmental practices.

Our finding is consistent with the positive effect of tenure security on the adoption of agri-environmental practices reported in the literature. Land tenure differences significantly influence farmers' decision to invest in agri-environmental practices. The intensity of the adoption of agri-environmental practices is consistently higher on owned plots than on borrowed, rented or sharecropped plots.

Other exogenous variables in our models also explain the adoption of agro-environmental practices. Our estimates show that everything being equal, there is no statistically significant difference between female-headed households and male-headed households in terms of adopting agro-environmental practices. Literacy of the household head has a positive effect on adoption. Households headed by a literate person adopted between 9% and 12% more agro-environmental practices than those headed by a non-literate person. Literacy promotes access to a diversified source of agricultural information (Kabunga et al., 2012) on the benefits of agri-environmental practices. This makes literate people more likely to adopt them. Our results also support the results of previous studies that showed that farmers have a higher propensity to adopt soil conservation measures on land that is vulnerable to erosion.

5. Conclusion and implications

In Benin, farmers face several constraints including soil fertility degradation, which results in lower agricultural yields and instability of agricultural production; this has a severe impact on food security. Several studies have shown that adoption of agro-environmental practices is a potential response to land degradation and food insecurity. However, in the empirical literature on the determinants of adoption of agri-environmental innovations, very little attention has been paid to understanding the role of land property rights on farmers' adoption decision.

The vast majority of empirical studies that examined the effects of land tenure arrangement on farmer investment in agro-environmental practices have ignored the presence of selectivity biases. Studies that controlled for selection bias from unobserved variables failed to control for initial differences on observable characteristics among farmers, which could bias the effects observed. Accordingly, the literature does not provide clear empirical evidence on the impacts of land property rights on farmers' agri-environmental adoption behaviors. This article contributes to the empirical literature by examining the impact of land tenure arrangement on adoption of agri-environmental practices in rural Benin using a multinomial endogenous treatment effects model combined with a propensity score matching technique. We relied on a unique and detailed household survey data collected from a sample of 2,800 farm households.

The results indicate that the socio-economic characteristics that influence land tenure arrangement in rural Benin are age of the household head, gender, ethnic group and literacy. Women farmers have less access to land and are more active in the land rental market and sharecropping. The household wealth level measured by off-farm income and farm size has no effect on land tenure arrangement. Plot-level characteristics do not affect land tenure arrangement choice.

Our estimates show that land tenure differences significantly influence farmers' decision to invest in agri-environmental practices. The intensity of the adoption of agri-environmental practices is consistently higher on owned plots than borrowed, rented or sharecropped plots. A borrowing, renting or sharecropping contract is a land tenure arrangement based on an oral contract without any legal value, and does not guarantee that the tenants can enjoy a long-term advantage of investments in conservation soils through the adoption of agri-environmental practices. We speculate that the insecurity of a rental or sharecropping contract would push tenants to seek to maximize their short-term production at the cost of degradation of the soil's potential fertility.

We conclude that land ownership is highly correlated to the propensity of farmers to invest in sustainable farming management methods such as the adoption of agri-environmental innovations. Therefore, we anticipate that the ongoing land certification program in Benin is a response to the low level of adoption of agroforestry and soil conservation practices. Land titles will strengthen owners' rights over their land and promote land rental market. We find that among other factors, tenants and sharecroppers adopt fewer agro-environmental practices because of the short length of their contract. Hence, to accelerate the impact of property rights on adoption, an alternative would be to promote written land rental or sharecropping contracts that strengthen the rights of tenants and sharecroppers, giving them assurance that they could benefit from their long-term investment.

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List of tables

Table 1. Measure of quality of matching (Nearest neighbor without replacement)

Comparison	Treated	Control	# Obs outside common support	Pseudo-R^2		Median Bias	
				Before	After	Before	After
Borrow vs rent	449	1028	58	0.201	0.093	13.5	5.0
Borrow vs sharecrop	70	1028	212	0.117	0.011	14.4	2.2
Borrow vs own	1028	2721	10	0.072	0.012	8.6	2.6
Rent vs sharecrop	70	449	44	0.197	0.092	18.5	8.8
Rent vs own	449	2721	323	0.262	0.009	17.1	2.3
Sharecrop vs own	70	2721	1036	0.120	0.072	11.1	9.1

Table 2. Descriptive statistics of variables used in the analysis

Variables	Mean	SD	Description
(1) Socioeconomic characteristics			
Age of household head	46.20	14.96	Age of household head in full year
Female-headed household	0.14	0.35	Household head is female (1= yes; 0= Otherwise)
Literacy	0.28	0.45	Household head can read and write (1= yes, 0= Otherwise)
Membership in farmers' organization	0.14	0.35	Household head is member of a farmers' organization (1= yes, 0= Otherwise)
Household size	6.41	3.29	Number of persons in the household
Number of plot	1.52	0.84	Number of plot cultivated by household
Farm size	3.80	5.11	Total size in hectare of all parcels of the household
Off- farm income	0.74	0.44	Household has off farm income (1= yes, 0= Otherwise
(2) Land parcel characteristics			
Plot location	0.82	0.38	The farmer resides in the village the plot is located (1= yes, 0= Otherwise)
Plot size (ha)	2.5	3.67	Size of the plot in hectares
Sandy Soil	0.17	0.38	Binary, 1= yes, 0= Otherwise
Lateritic Soil	0.31	0.46	Binary, 1= yes, 0= Otherwise
Hydromorphic Soil	0.19	0.39	Binary, 1= yes, 0= Otherwise
Ferralitic Sol	0.28	0.45	Binary, 1= yes, 0= Otherwise
Other soils	0.05	0.22	Binary, 1= yes, 0= Otherwise
Slope: bas-fond	0.08	0.27	Binary, 1= yes, 0= Otherwise
Slope: lowland	0.74	0.44	Binary, 1= yes, 0= Otherwise
Slope: watershed	0.18	0.38	Binary, 1= yes, 0= Otherwise
Plot distance from homestead	4.17	1.72	Walking distance in minutes (1=less than 5 mn; 2=between 5 and 15 mn; 3=between 15 and 30 mn; 4=between 30 and 45 mn; 5= between 45 and 60 mn, 6= more than 1 hour)
Distance from all-weather road	5.61	1.01	Walking distance in minutes (1=less than 5 mn; 2=between 5 and 15 mn; 3=between 15 and 30 mn; 4=between 30 and 45 mn; 5= between 45 and 60 mn, 6= more than 1 hour)
Distance from market	5.52	1.07	Walking distance in minutes (1=less than 5 mn; 2=between 5 and 15 mn; 3=between 15 and 30 mn; 4=between 30 and 45 mn; 5= between 45 and 60 mn, 6= more than 1 hour)
Plot age	14.32	12.45	Number of year of use of the plot
Borrowing or gifting	0.24	0.43	=1 if borrowed/gifted land, 0 Otherwise
Renting	0.11	0.31	=1 if rented land; 0 Otherwise
Sharecropping	0.02	0.13	=1 if sharecropped land; 0 otherwise
Full ownership	0.63	0.48	=1 if owned land; 0 otherwise
# observations households	2800		
# observations parcels	4233		

Table 3. Mixed Multinomial Logit model (first equation) of the determinants of land tenure arrangements in Benin

Variables	(1) Borrowing /Gifting	(2) Renting	(3) Sharecropping
Age of household head/10	-0.0982* (0.0516)	0.0946 (0.0693)	-0.00325 (0.132)
Female-headed household	0.900*** (0.167)	0.191 (0.239)	-0.415 (0.444)
Literacy	0.167 (0.129)	-0.746*** (0.229)	-0.310 (0.384)
Membership in farmers' organization	0.225 (0.162)	-0.203 (0.272)	-0.451 (0.539)
Number of adult in the household	-0.0326 (0.0509)	-0.0423 (0.0782)	-0.195 (0.149)
Farm size	0.00794 (0.0170)	0.0186 (0.0253)	-0.00425 (0.0379)
Off- farm income	-0.0636 (0.141)	0.364 (0.244)	-0.465 (0.339)
Number of plot	-0.101 (0.0868)	0.274*** (0.0986)	0.0619 (0.125)
Plot size (ha)	-0.00517 (0.0213)	-0.140*** (0.0452)	0.115** (0.0522)
Soil type (Baseline : sandy soil)			
Lateritic/red soil	-0.257 (0.163)	-0.244 (0.241)	1.840* (1.098)
Hydromorphic soil	-0.438** (0.190)	-0.681** (0.323)	2.517** (1.099)
Ferralitic soil	-0.101 (0.159)	0.0788 (0.249)	2.570** (1.073)
Other soils	0.361 (0.262)	-1.000* (0.552)	3.859*** (1.144)
Slope (baseline: Lowland)			
Bas-fond	-0.251 (0.206)	-0.390 (0.380)	0.293 (0.487)
Watershed	-0.0786 (0.138)	0.0913 (0.260)	0.463 (0.371)
Plot distance from homestead	0.0285 (0.0345)	0.194*** (0.0643)	0.148* (0.0868)
Distance from all-weather road	-0.0778 (0.0572)	-0.00310 (0.0946)	-0.212 (0.157)
Distance from market	0.0325 (0.0560)	0.206** (0.104)	0.00269 (0.169)
Plot age	-0.0500*** (0.00772)	-0.204*** (0.0220)	-0.168*** (0.0387)
Plot location	-0.111 (0.148)	-0.568*** (0.195)	0.0911 (0.401)
Ethnic groups (Baseline: Adja and related)			
Bariba, Dendi, Yoa ….	0.898*** (0.250)	-1.584*** (0.453)	-4.304*** (1.116)
Fon and related	0.463** (0.189)	-0.0687 (0.240)	-1.256*** (0.430)
Yoruba and other	0.785*** (0.242)	0.702** (0.293)	-1.721** (0.669)
Constant	-0.0557 (0.496)	-2.330*** (0.812)	-2.655 (1.714)
Observation	4233	4233	4233

Notes: The baseline category of land tenure arrangement is full ownership. The sample size is 2,800 households and 4,233 parcels. The estimates are based on 500 simulations draw per observation based on a Halton sequence. Standard errors in parentheses were clustered at the household level to address potential problems of heteroskedasticity and correlation errors between plots belonging to the same household. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4. Multinomial endogenous treatment effects model of land tenure arrangements impact on adoption of agri-environmental practices: Unmatched sample

Variables	Model I Exogenous rights	Model II Endogenous rights
(1) Land tenure arrangement		
Borrowing or gifting	-0.257*** (0.039)	-0.358*** (0.0668)
Renting	-0.209*** (0.056)	-0.159** (0.0713)
Sharecropping	-0.120 (0.126)	-0.101 (0.163)
(2) Socio-economic characteristics		
Age of household head/10	-0.01 (0.01)	-0.007 (0.015)
Female-headed household	0.065 (0.048)	0.0757 (0.0561)
Literacy	0.121*** (0.035)	0.128*** (0.0400)
Membership in farmers' organization	0.048 (0.043)	0.0528 (0.0489)
Number of adult in the household	-0.002 (0.011)	-0.00231 (0.0136)
Farm size	-0.009** (0.004)	-0.00865 (0.00542)
Off- farm income	0.173*** (0.037)	0.171*** (0.0456)
Number of plot	0.059*** (0.014)	0.0549*** (0.0171)
(3) Land parcel characteristics		
Plot size (ha)	0.024*** (0.007)	0.0241*** (0.00722)
Soil type (Baseline : sandy soil)		
Lateritic/red soil	-0.083* (0.046)	-0.0888 (0.0547)
Hydromorphic soil	0.060 (0.053)	0.0539 (0.0594)
Ferralitic soil	0.066 (0.046)	0.0645 (0.0535)
Other soils	-0.430*** (0.089)	-0.422*** (0.115)
Slope (baseline: Lowland)		
Bas-fond	0.006 (0.059)	0.00429 (0.0653)
Watershed	-0.013 (0.042)	-0.0148 (0.0462)
Plot distance from homestead	0.041*** (0.010)	0.0405*** (0.0103)
Distance from all-weather road	-0.043*** (0.017)	-0.0443** (0.0189)
Distance from market	0.046*** (0.017)	0.0458** (0.0206)
Plot age	0.010*** (0.001)	0.0101*** (0.00149)
Constant	-0.182 (0.125)	-0.139 (0.141)
Ln (δ)		-1.473*** (0.227)
λ_1 [Borrowing or gifting]		0.120** (0.0480)
λ_2 [Renting]		-0.0748** (0.0303)
λ_3 [Sharecropping]		-0.0330*** (0.0109)
Observations	4233	4233

Notes: The baseline category of land tenure arrangement is full ownership. The sample size is 2,800 households and 4,233 parcels. The estimates are based on 500 simulations draw per observation based on a Halton sequence. Standard errors in parentheses were clustered at the household level to address potential problems of heteroskedasticity and correlation errors between plots belonging to the same household. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5. Multinomial endogenous treatment effects model of land tenure arrangements impact on adoption of agri-environmental practices: Matched sample

Variables	Model III Exogenous rights with correction from observables	Model IV Endogenous rights with correction from observables
(1) Land tenure arrangement		
Borrowing or gifting	-0.260^{***} (0.046)	-0.381^{***} (0.0794)
Renting	-0.219^{***} (0.064)	-0.148^{**} (0.0805)
Sharecropping	-0.121 (0.134)	-0.0957 (0.166)
(2) Socio-economic characteristics		
Age of household head/10	-0.003 (0.018)	-0.007 (0.021)
Female-headed household	0.055 (0.061)	0.0697 (0.0678)
Literacy	0.084^{*} (0.047)	0.0971^{*} (0.0519)
Membership in farmers' organization	0.049 (0.056)	0.0525 (0.0608)
Number of adult in the household	-0.016 (0.017)	-0.0156 (0.0189)
Farm size	-0.006 (0.006)	-0.00551 (0.00731)
Off- farm income	0.224^{***} (0.052)	0.222^{***} (0.0633)
Number of plot	0.060^{***} (0.019)	0.0516^{**} (0.0235)
(3) Land parcel characteristics		
Plot size (ha)	0.028^{***} (0.010)	0.0291^{***} (0.0109)
Soil type (Baseline : sandy soil)		
Lateritic/red soil	-0.081 (0.060)	-0.0839 (0.0668)
Hydromorphic soil	0.066 (0.073)	0.0615 (0.0754)
Ferralitic soil	-0.020 (0.060)	-0.0249 (0.0660)
Other soils	-0.496^{***} (0.110)	-0.490^{***} (0.136)
Slope (baseline: Lowland)		
Bas-fond	0.030 (0.089)	0.0346 (0.0922)
Watershed	-0.003 (0.057)	-0.00571 (0.0628)
Plot distance from homestead	0.026^{**} (0.013)	0.0243^{*} (0.0138)
Distance from all-weather road	-0.038^{*} (0.023)	-0.0406 (0.0256)
Distance from market	0.063^{***} (0.023)	0.0619^{**} (0.0276)
Plot age	0.010^{***} (0.002)	0.0116^{***} (0.00241)
Constant	-0.228 (0.168)	-0.173 (0.189)
Ln (δ)		-1.203^{***} (0.265)
λ_1 [Borrowing or gifting]		0.149^{**} (0.0634)
λ_2 [Renting]		-0.0971^{**} (0.0412)
λ_3 [Sharecropping]		-0.0426^{***} (0.0143)
Observations	2660	2660

Notes: The baseline category of land tenure arrangement is full ownership. The sample size is 1,907 households and 2,660 parcels. The estimates are based on 500 simulations draw per observation based on a Halton sequence. Standard errors in parentheses were clustered at the household level to address potential problems of heteroskedasticity and correlation errors between plots belonging to the same household. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$