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An Economic Analysis of Tropical Forest Resource Conservation in a Protected Area

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Abstract: In this paper, we develop a reduced form model for factors influencing the conservation of forest resources. We then estimate it using a bivariate negative binomial regression model with cases of illegal farming and illegal cattle grazing in the W Reserve in West Africa. Our results show that population size and farm area in the periphery of the W Reserve are associated with an increase of 2.4% and 7.1% of the illegal farming, respectively. On the other hand, income level, the existence of a checkpoint, and the distance between the villages and the reserve decrease the illegal grazing activities by 7.3%, 63.2%, and 2.3%, respectively.

1. Introduction

The conservation of tropical forest resources is vital because they provide 25% of our medicines worldwide and account for over 50% of the planet's biodiversity, although they only cover less than 10% of the earth [1]. They sustain millions of people worldwide and contribute directly and indirectly to countries' economies. Despite their importance, the conservation of tropical forest resources is still lacking [2]. The degradation of these resources not only reduces the world genetic diversity and its carbon sequestration capacity but also puts at risk scientific progress and discoveries in the areas of medicine and pest controls [3]. Hence, understanding the factors that influence their conservation is critical in designing effective policies to reduce their degradation.

The objective of this study is to investigate the effect of the characteristics of villages in the periphery of a protected area in tropical regions on its degradation. This is important for several reasons. First, forest degradation is most persistent in tropical regions [4]. Second, some forest resources in tropical regions are conserved as protected areas dedicated for the maintenance of biological diversity [5]. Third, in these regions, villages represent the basic administrative units in the periphery of protected areas [6].

In the literature, the conservation of tropical forest resources has been extensively investigated. For example, Geist and Lambin [7] investigated the proximate causes and underlying forces of tropical deforestation as reported in 152 subnational studies. The results suggest that economic, technological, and institutional factors are the main causes of tropical forest degradation. Furthermore, while agriculture expansion is identified as the major proximate cause for forest cover loss across all tropical regions, wood extraction and infrastructure expansions are region-specific. In contrast, using evidence from 118 studies on protected areas in Africa, Bowker et al. [8] identified protected areas' locations, accessibility, and sizes as the key factors determining forest cover loss within their boundaries. In Latin America, Culas [9] observed that cattle ranching represents a major factor in forest degradation. In Malawi, Ngwira and Watanabe [10] used interviews and focus groups to analyze the underlying factors associated with agriculture expansion as the major proximate cause of deforestation. The results

suggest that population growth, poverty, and the market system are the underlying factors. In Uganda, L'Roe and Naughton-Treves [11] documented land-use change in the periphery of Kibale National Park, suggesting that market and infrastructures play a key role in the observed land-use change. These studies show that the factors influencing forest degradation in the tropics are diverse and vary within regions and countries.

In addition, several authors reported the complementarity and/or substitutability relationship between factors associated with tropical forest degradation. For example, at a global scale, Culas [12] (p. 16) noted that roundwood consumption, forest products exports, demand for cropland, and pasture are complementary in determining forest degradation. Similar observations are reported by Gieist and Lambin [7] (p. 143). However, few economic and empirical models of forest conservation explicitly account for this relationship in their analysis of the factors influencing forest degradation. For example, Perge and McKay [13], Pounfoun et al. [14], Babigumira et al. [15], Foster et al. [16], Godoy et al. [17], and Jones et al. [18] used the size of forest area cleared by households as the indicator of forest degradation in their studies. Diarrassouba and Boubacar [19] used the rate of forest loss as a proxy for forest degradation. Pichon [20] and Munoz [21] used the percentage of farmland in forest as the measurement of forest degradation.

The present study complements the existing literature by analyzing the characteristics of nearby villages in relation to the conservation of the W Reserve in West Africa. It uses both illegal farming and illegal cattle grazing as a proxy for the reserve degradation. The combination of more than one forest degradation attribute allows for accounting for possible complementarity and/or substitutability among the causes of forest resource degradation. Previous studies on the W Reserve and its periphery focused primarily on the biodiversity of the reserve (e.g., [22–28]) and land cover change in the periphery of the reserve (e.g., [29]).

The analysis proceeds as follows. In Section 2, we develop a theoretical model useful to understand the relationship between the characteristics of villages in the periphery of a protected area and its degradation. This is followed by an econometric model. Section 3 presents the study area and the data. The results of the paper are presented and discussed in Section 4. The paper concludes with a summary of key findings and policy implications.

2. Model

2.1. Demand and Supply

The demand and supply framework has been used in the literature to explain economic agents' behavior in the areas of agricultural economics (e.g., [30–34]), education economics (e.g., [35]), environmental economics (e.g., [36]), and forest economics (e.g., [37–39]). The framework has several strengths: it is fundamentally consistent with socioeconomic theory and it can characterize markets and generate relevant hypotheses. In this paper, we use this framework to analyze the relationship between the periphery of a protected area and its conservation.

Suppose that a protected area produces two aggregate goods, namely ecosystem goods (e.g., recreation, biodiversity) and non-ecosystem goods. Particularly, let us assume the non-ecosystem goods include fertile lands and fodder that are of interest for farmers and cattle ranchers nearby. Farmers and/or cattle ranchers demand the non-ecosystem goods as an input to produce farm products and cattle. Suppose these non-ecosystem goods can be priced (P_g) with a demand function that depends on its own price (P_g), and demand shift variables such as population size ($\bar{x}$), income ($\bar{m}$), institutions (I) in the periphery of the protected area, and the distance ($\bar{d}$). Hence, the demand function can be expressed as follows:

$$Q_d = Q_d\left(P_g, \bar{x}, \bar{m}, I, \bar{d}\right) \tag{1}$$

The demand function is assumed to be a decreasing function of its own price ($\partial Q_d/\partial P_g < 0$), the income level ($\partial Q_d/\partial \bar{m} < 0$), institutions ($\partial Q_d/\partial I < 0$), and the distance between the protected area

and the villages in its periphery ($\partial Q_d / \partial \bar{d} < 0$). The demand of the goods increases with the population size ($\partial Q_d / \partial \bar{x} < 0$).

As the institutions in the periphery of the protected area include checkpoints and non-governmental organizations, the institutions production function can be represented as follows:

$$I = I(\bar{c}, \bar{z}) \tag{2}$$

The institutions are increasing function of the checkpoints ($\partial Q_d / \partial \bar{c} > 0$) and non-governmental organizations ($\partial Q_d / \partial \bar{z} > 0$).

The supply function of the good depends on its own price and is assumed upward sloping:

$$Q_s = Q(P_g) \quad (\partial Q_s / \partial P_g > 0) \tag{3}$$

The market clearing condition below completes the model:

$$Q_s = Q_d = Q \tag{4}$$

The model above comprises 3 endogenous variables Q, P_g, I and 5 exogenous variables $\bar{x}$, $\bar{m}$, $\bar{d}$, $\bar{c}$, $\bar{z}$.

Of key interest is the effect of the exogenous variables on the quantity of the non-ecosystem goods removed from the protected area. To this end, we first write Equations (1)–(4) in proportionate changes:

$$Q_d^* = \eta P_g^* + \eta_x \bar{x}^* + \eta_m \bar{m}^* + \eta_I I^* + \eta_d \bar{d}^* \quad \eta < 0, \eta_x > 0, \eta_I < 0, \eta_m < 0, \eta_d < 0 \tag{1'}$$

$$I^* = \alpha_c \bar{c}^* + \alpha_z \bar{z}^* \qquad \alpha_c > 0, \; \alpha_z > 0 \tag{2'}$$

$$Q_s^* = \varepsilon P_g^* \; \varepsilon > 0 \tag{3'}$$

$$Q_d^* = Q_s^* = Q^* \tag{4'}$$

The asterisk (*) indicates proportionate change (e.g., $Q_j^* = dQ_j / Q_j$); η and ε are the own-price elasticity of demand and supply for the non-ecosystem goods, respectively. η_x, η_m, η_I, η_d are the elasticities of demand for the non-ecosystem goods with respect to population size, income, institutions, and distance, respectively. α_c, α_z are the elasticities of the institutions with respect to checkpoints and non-governmental organizations in the periphery of the protected area. Next, we substitute Equation (2') into (1') and solve the reduced form model for price using Equation (4'):

$$P_g^* = \frac{\eta_x}{\varepsilon - \eta} \bar{x}^* + \frac{\eta_m}{\varepsilon - \eta} \bar{m}^* + \frac{\gamma_c}{\varepsilon - \eta} \bar{c}^* + \frac{\gamma_z}{\varepsilon - \eta} \bar{z}^* + \frac{\eta_d}{\varepsilon - \eta} \bar{d}^* \tag{5}$$

where $\gamma_c = \eta_I \alpha_c$, $\gamma_z = \eta_I \alpha_z$.

Finally, the reduced form model for quantity is obtained by substituting (5) back into (3'):

$$Q^* = \acute{\omega}_x \bar{x}^* + \acute{\omega}_m \bar{m}^* + \acute{\omega}_c \bar{c}^* + \acute{\omega}_z \bar{z}^* + \acute{\omega}_d \bar{d}^* \tag{6}$$

where $\acute{\omega}_x = \frac{\varepsilon \eta_x}{\varepsilon - \eta} > 0$, $\acute{\omega}_m = \frac{\varepsilon \eta_m}{\varepsilon - \eta} < 0$, $\acute{\omega}_c = \frac{\varepsilon \gamma_c}{\varepsilon - \eta} < 0$, $\acute{\omega}_z = \frac{\varepsilon \gamma_z}{\varepsilon - \eta} < 0$, $\acute{\omega}_d = \frac{\varepsilon \eta_d}{\varepsilon - \eta} < 0$.

Equation (6) suggests that an increase in population size increases the equilibrium quantity of the good removed from the protected area. On the other hand, an increase in the income level in the periphery of the protected area decreases the equilibrium quantity of the good removed from the protected area. Similarly, the existence of checkpoints and non-governmental organizations in the periphery of the protected area decreases the equilibrium quantity of the good removed from the protected area. Finally, an increase in the distance between the protected area and its periphery decreases the equilibrium quantity of the good removed from the protected area.

2.2. Bivariate Negative Binomial Regression (BNBR) Model

In general, the elasticities in a reduced form equation are computed using the structural elasticities when they are available [40,41]. In the absence of the structural elasticities, the estimation of the reduced form Equation (6) of interest using the data can be used as an alternative.

In this study, we measured the W Reserve degradation using count data, namely, the number of cases of illegal farming and illegal cattle grazing. For count data, several models could be used (e.g., Poisson, negative binomial) [42]. Particularly, while Poisson model is recommended when the data meet the equidispersion assumption, the negative binomial model is appropriate when the data meets the overdispersion condition [43,44]. Table 1 presents the results of the test of overdispersion on the response variables (illegal farming and illegal cattle grazing), suggesting the negative binomial model as appropriate regression model.

Table 1. Test of overdispersion on the response variables.

$\hat{\mu}$	Coefficient	Standard Error	*p*-Value
illegal farming	2.6441	0.8941	0.004
illegal cattle grazing	1.3464	0.2994	0.000

Illegal activity cases such as illegal farming and illegal cattle grazing in the protected area may be correlated within village *i* because individuals can be involved in both illegal activities. To account for this correlation between both types of illegal activities, the bivariate negative binomial regression model can be appropriately used as a more efficient regression model to identify the factors determining these activities [42,45]. Furthermore, the model gains in efficiency over a univariate negative binomial regression by considering cross-equation correlations. In the literature, several authors have used the bivariate negative binomial regression model to analyze correlated count-dependent variables (e.g., [44,46]).

Following references [44,45], the joint density function of the bivariate negative binomial model can be specified as follows:

$$f\left(y_{1i},\ y_{2i}\middle|x_{1i},\ x_{2i},\ \beta_1,\ \beta_2\right)\ =\ \left[\prod_{j=1}^{2}\frac{\left(Z_{ji}\right)^{\left(y_{ji}\right)}}{\Gamma\left(y_{ji}+1\right)}\right]\frac{\Gamma\left(y_{ji}+1\right)}{\Gamma(\alpha)}\ \alpha^{-y_{.i}}\left(1+\frac{Z_{.i}}{\alpha}\right)^{-(\alpha+y_{.i})} \tag{7}$$

where:

y_j is the *j* response variable with *j* = {number of cases of illegal farming, number of cases of illegal cattle grazing}; $Z_{ji}\ =\ \exp\left(x'_{ji}\beta_j\right)\ =\ E\left(y_{ji}\middle|x_{ji}\right)$ is the conditional mean parameter associated with the *j* response variable for village *i*; $y_{.i}=\sum_{j=1}^{2}y_{ji}$; $Z_{.i}=\sum_{j=1}^{2}Z_{ji}$. x_{ji} is a ($k_j \times 1$) vector of covariates; and β_j a ($k_j \times 1$) vector of unknown parameters. In addition to the variables defined in the theoretical model, the variables cash crop and farm area are included in the illegal farming equation to account for their effect on illegal farming activities [47]. Table 2 presents the definition of the variables used to estimate the bivariate negative binomial model.

Table 2. Variables definition.

Variables	Description
illegal farming	Illegal farming (number of cases)
illegal cattle grazing	Illegal cattle grazing (number of cases)
population	Population divided by 1000
income	Income divided by 100 (in West African CFA)
farm area	Farm area (in hectares)
cash crop	Cash crop = 1 if yes; 0 otherwise
env_ngo	Environmental non-governmental organization
financial institutions	Number of financial institutions
checkpoints	Checkpoint = 1 if yes; 0 otherwise
distance	Distance (in kilometers)

3. Study Area and Data

The W Reserve was chosen as the study area because it is one of the largest reserves in West Africa and crosses three countries, namely Benin, Burkina Faso, and Niger with a wide range of villages in its periphery. Covering an area of 1,024,280 hectares with 563,280 hectares in Benin; 235,000 hectares in Burkina Faso; and 226,000 hectares in Niger, the W Reserve is located between 11° and 12°35 north latitude and 2° and 3°50 east longitude [26].

The fauna in the W Reserve is one of the richest on the continent and includes emblematic species such as lions (*Panthera leo*), giraffes (*Giraffa camelopardalis*), gazelles (*Gazella rufifrons*), Buffon's kobs (*Kobu kob*), and reptiles [27]. Moreover, it is one of the rare places in Africa where endangered species such as cheetahs, wild African dogs, and African elephants are living. Its vegetation comprises savannah, gallery forests, and grasslands.

The periphery of the W Reserve comprises about 210 villages with a human population estimated at 405,000 [48]. This population belongs to different ethnic groups who share several ties and cultures. Particularly, the population in the periphery of the reserve has a long history of relationships with their natural environment with farming, hunting, cattle grazing, and wood and non-wood resources as their main source of livelihood. Although there are collaborations and concertation in the management principles of the reserve, each country managed the areas of the reserve on its territory based on its national legislation. Figure 1 presents the study area.

Data used in the identification of factors influencing the degradation of the W Reserve cover the period January 2016 to May 2017. Data on illegal farming and illegal cattle grazing were obtained from the reserve surveillance administrations in Benin, Burkina Faso, and Niger. Illegal farming refers to any encroachment and/or land clearing within the reserve limits for farming while illegal cattle grazing refers to any grazing by domestic cattle in the reserve. These statistics were compiled by the reserve administrations in all three countries during their surveillance patrols. The socioeconomics and institutional characteristics of 93 villages in the periphery of the W Reserve were obtained and used for the study. Particularly, the average income level, population, number of financial institutions, and number of non-governmental organizations promoting nature preservation were obtained from the administrations of the municipalities in the periphery of the reserve. Finally, the data on the existence of checkpoints, and the distance between the reserve and the villages were obtained from the W Reserve administrations in the three countries.

Table 3 presents the summary statistics on the number of cases of illegal farming and illegal cattle grazing recorded by the reserve surveillance administrations in the three countries during the period January 2016 to May 2017. Illegal cattle grazing was the most important case of infraction recorded. The predominance of illegal cattle grazing cases could be explained by the importance of cattle in the economy of local communities, and the extensive mode of animal husbandry in place in the region. Natural fodders and water streams being the main source of food and water for the livestock, the W Reserve, due to its abundant resources of plants and water resources (e.g., Niger River), represented an ideal place for grazing.
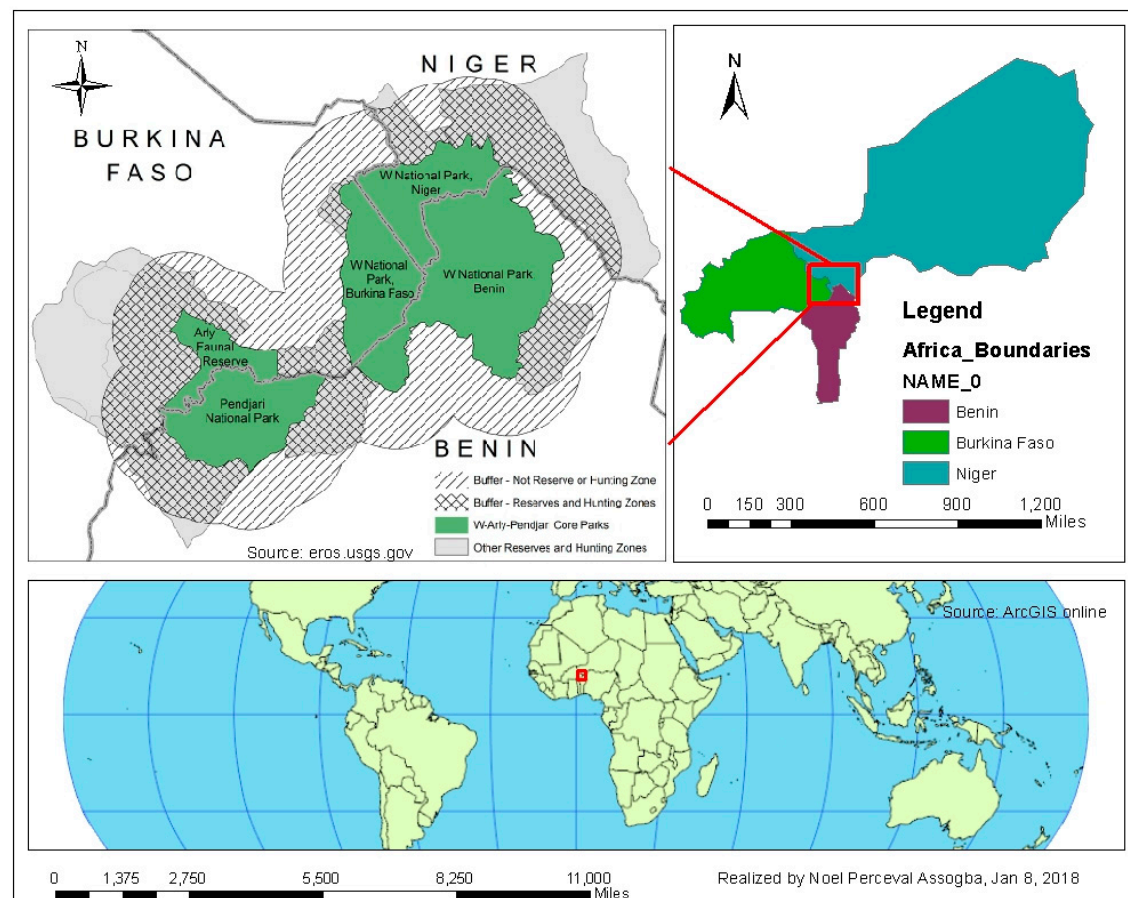
Figure 1. Study area.

Table 3. Socioeconomics and institutional characteristics of the villages in the periphery of the W Reserve.

Variables	Mean	Std. Dev.	Min	Max
illegal farming	0.3763	0.8712	0	4
illegal cattle grazing	1.7312	2.4143	0	9
population	1577.2350	1679.4870	55	10,315
income	16,715.0500	6440.9520	10,000	30,000
farm area	2.1411	1.0880	1	4
financial institutions	1.0430	0.8200	0	2
env_ngo	1.2043	0.7598	0	2
distance	15.3180	16.0764	0	66.3843

The number of infractions was unevenly distributed across the three countries. While the cases of illegal farming (35) in the reserve were only recorded in Benin, illegal cattle grazing cases (161) were observed in the three countries. Figure 2 presents the distribution of cattle grazing cases in the region. The highest number of illegal cattle grazing cases were recorded in Benin, representing 55% of the total number of cases followed by Burkina Faso with 29% of the cases. The lowest number was recorded in Niger, 16%. Note that the average distance between the villages and the reserve was estimated at 15.32 kilometers.
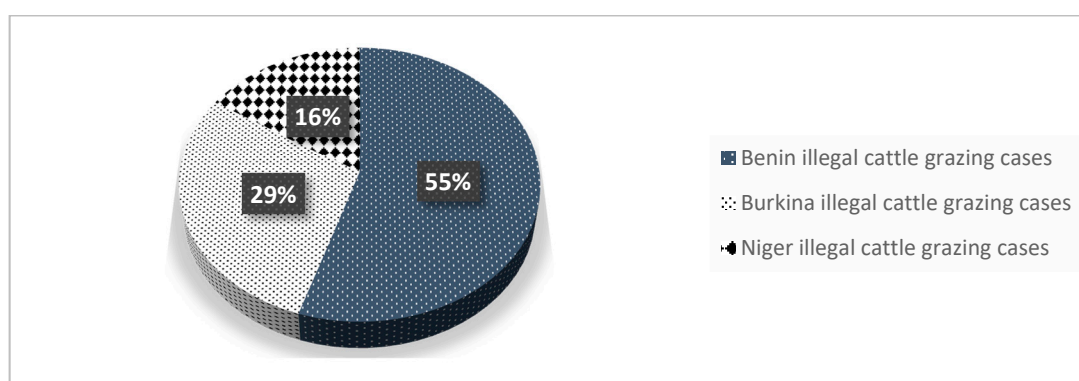
Figure 2. Repartition of number of cases of illegal cattle grazing in the region.

4. Results and Discussion

The bivariate negative binomial regression estimation results are presented in Table 4. Model 1 and Model 2 in Table 4 are similar with the exception that country fixed effects are included in Model 2. The Wald test of overall significance is statistically significant in both models (*p*-value = 0.0001, *p*-value = 0.0016), suggesting that the models are globally significant. The results in Model 1 suggest that the characteristics of the villages in the periphery of the reserve, namely, population size, average income, average farm areas, the existence of check points, and distance influence its degradation.

Table 4. Negative binomial estimation results of factors influencing the W Reserve degradation.

Variables	Model 1		Model 2	
	Illegal Farming	Illegal Cattle grazing	Illegal Farming	Illegal Cattle Grazing
Socioeconomic characteristics				
population	0.0237 *	0.0122	0.0129	0.0122
	(0.0144)	(0.0090)	(0.0130)	(0.0094)
income	0.0210	−0.0729 *	0.0506	−0.0740 *
	(0.0581)	(0.0387)	(0.0503)	(0.0391)
farm area	0.0713 **	-	0.0295	-
	(0.0305)	-	(0.0260)	-
cash crop	0.2821	-	0.7114	-
	(0.6312)	-	(0.5283)	-
Institutions				
financial institutions	−0.2837	0.1904	−0.3987	0.2094
	(0.4316)	(0.2447)	(0.3865)	(0.2551)
env_ngo	−0.0296	0.2758	−0.2823	0.2681
	(0.6896)	(0.2329)	(0.3954)	(0.2755)
checkpoints	−0.8157	−0.6324 *	−0.7669	−0.6624 *
	(0.7236)	(0.3703)	(0.6188)	(0.3865)
Location				
distance	−0.0296	−0.0225 *	−0.0346 **	−0.0234
	(0.0200)	(0.0136)	(0.0166)	(0.0142)
Country Fixed Effect	No	No	Yes	Yes
Constant	−2.6000 ***	1.3895 ***	−1.6800 **	1.4079 **
	(0.9001)	(0.5644)	(0.7682)	(0.5707)
Observations	93	93	93	93
Wald chi2		43.5600		40.9400
p-value		0.0001		0.0016
LR chi2		54.3400		55.4600
p-value		0.0000		0.0000

*** 1% significance level, ** 5% significance level, * 10% significance level. Standard error reported in parentheses.

Particularly, the variables determining illegal farming activities in the reserve in Model 1 are the population size and farm area. These variables are statistically significant at the 10% and 5% levels, respectively. The sign of the coefficients of both variables is positive and consistent with theory. While an increase in the population size of one unit is associated with an increase in the number of

cases of illegal farming by 2.4%, an increase in the average farm areas by one unit is associated with an increase in the number of cases of illegal farming by 7.1%.

The positive effect of population size on illegal farming cases could be explained by the fact that a higher population increases the competition for land, making the W Reserve attractive. This result is consistent with the results of Foster et al. [16] who observed a positive relationship between population and the reduction of forest areas in India. Similar relationships between population and forest degradation are also found in Nepal, Thailand, and at a global scale [49–51]. Similarly, the positive effect of the average farm area in the villages with the number of cases of illegal farming could be explained by the farming system in the region. Farming in the region is still traditional with low use of technology and inputs such as fertilizers. Hence, farmers, to increase the production of their farms, could find the W Reserve fertile lands attractive. This result is also consistent with the findings of Angelsen [52] in subsistence economies with low levels of agricultural productivity.

In contrast, three variables determine illegal cattle grazing in the reserve, namely, the average income level, the existence of checkpoints, and the distance between the villages and the reserve. These variables are statistically significant at the 10% significance level. The sign of the coefficients of these variables is negative and consistent with theory. Particularly, an increase in the average income level of one unit is associated with a decrease in the number of cases of cattle ranching by 7.3%. Similarly, while the existence of checkpoint between the reserve and the villages in its periphery decreases the number of cases of illegal cattle grazing by 63.2%, an increase in the distance by one unit is associated with a decrease in the number of cases of illegal cattle ranching by 2.3%.

The negative effect of the existence of checkpoints on illegal cattle grazing could be explained by the increase in the private costs of (illegal) cattle ranchers. The existence of checkpoints raises the risks for the (illegal) cattle ranchers to be caught by the reserve surveillance units and face the penalties such as fines and/or jails. This is also consistent with the results of Borner et al. [53], Lober [54], Gibson et al. [55], and Bruner et al. [56] who identified enforcement as an effective conservation instrument. Similarly, the negative effect of distance on illegal cattle grazing cases may suggest that when the distance between the reserve and the villages in its periphery increases, herders may resort to other places closer for grazing. However, the negative effect of the average income level on illegal cattle grazing could suggest that cattle ranching activities are income-generating activities of low-income level individuals.

5. Conclusions

This paper contributes to the existing literature on forest resource conservation in several ways. First, it accounts for the relationship between forest degradation activities such as illegal farming and illegal cattle grazing in a protected area. Second, we developed a reduced form model using demand and supply framework to analyze the effects of the periphery of the W Reserve on its degradation. Our results are consistent with theory and other empirical results that socioeconomics, institutions, and locational characteristics of the villages in the periphery of forest resource or protected areas influence their degradation. Particularly, we find that population size and farm area increase the illegal farming activities in the reserve degradation while the average income level, the existence of checkpoints, and distance decrease its degradation in terms of illegal grazing.

As policy implication, the findings in this paper suggest that the characteristics of villages in the periphery of a protected area play a critical role in its conservation. For better preservation and conservation of tropical forest resources in general, and in particular the W Reserve, significant emphasis should be put on improving the socioeconomic and institutional setting in the villages closer to the reserve as well as the farming system. The installation of checkpoints and the promotion of policy aiming at improving farm performances in the area could be effective policies to reduce the pressure faced by the reserve if and when the marginal costs associated with the investments are less than the marginal benefits associated with the reserve conservation. Further, policies aiming at improving the average income level in the villages in the periphery of the reserve could have a positive

effect on the preservation of the reserve. These are some concrete measures that should be taken first to reduce the anthropogenic pressure on the reserve. As a final note, it should be pointed out that the results of this study need to be interpreted with caution because we used reported data for illegal activities as our dependent variable, and in cases where the illegal cattle grazers and/or farmers are not apprehended, they would not be reported.

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