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Factors Affecting the Adoption of Agroforestry Practices: Insights from Silvopastoral Systems of Colombia

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Abstract: In Colombia, one-third of the land is devoted to cattle farming, which is one of the main drivers of deforestation, land degradation, loss of biodiversity, and emissions of greenhouses gases. To mitigate the environmental impacts of cattle farming, agroforestry practices have been extensively promoted with mixed results. Despite research and extension efforts over the last 20-year period, agroforestry systems still involve a complex knowledge process among stakeholders that needs to be addressed. To understand the drivers of cattle farmers' behavior with regard to adopting agroforestry practices, we apply a double hurdle regression for different social, economic and productive information to capture the decision to adopt and the intensity of the adoption as a joint decision of such practices. For this purpose, we use data from a survey (implemented as part of an international project) administered to 1605 cattle farmers located in five agro-ecological regions in Colombia. Our dependent variables are defined by the adoption of four agroforestry practices: scattered trees, trees and shrubs for forage production, forestry plantations, and management of native forest. The adoption decision of agroforestry practices was influenced by the access and use of credit, location, and the implemented livestock system. Herd size and participation in development projects that involved tree planting had a positive influence on the adoption and intensity of agroforestry practices, while the variable associated with presence of water springs tended to boost the intensity of adoption. The diffusion of these technologies might be increased among farmers who have adopted and who are potential adopters, and social capital and networking can play a crucial role in spreading agroforestry as sustainable practice.

Keywords: agroforestry practices; livestock systems; adoption; conservation; hurdle model

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1. Introduction

The livestock sector uses approximately 3.9 billion hectares worldwide, of which about 52% are low-yield extensive pastures, 36% are high-productivity pasturelands, and the remaining 12% are cultivated for feed crops [1]. In developing countries, livestock takes place on the least productive lands, unsuitable for cropping, with low levels of productivity and profitability [2], thereby playing an essential role in the agricultural economy. It contributes to food supply for households, provides employment in rural areas, and is part of poverty alleviation policies. For small-scale farmers' livestock is the primary source of cash and generally supports agricultural diversification and farm investment [3]. Despite the socio-economic importance of livestock, this sector is associated with several negative environmental externalities, such as greenhouse gas emissions, water pollution, and accelerated land use change [4,5]. Deforestation to establish grazing and pasture land has been among the most critical changes in land use in tropical Latin America since the 1970s [6]. Once established, livestock systems drive changes in soil characteristics and in long-term land erosion and desertification [7].

Several policies worldwide have been developed to reduce the environmental impacts of livestock and to recover degraded soil and ecosystems [1]. Among them, agroforestry is a land use system that integrates pasture, trees, and animals, allowing ecological and economic interactions [8]. The environmental and productive benefits of agroforestry are well known from the recovery of degraded land and water to adaptation to climate change [9,10]; however, the rate of adoption of such production strategies is still low [11]. The large body of literature in farming technology adoption, summarized in Pattanayak et al. [12] and Knowler and Bradshaw [13], gives an overview of the complexity of the adoption process, which is influenced by social, economic, financial, and natural factors. Agroforestry becomes a more complex process since it involves a set of management decisions and several practices, such as selection of optimal combinations of species, tree and shrub plantations, and grassland control, requiring the use of inputs and careful timing [14,15].

Although several studies have addressed the adoption of agroforestry systems, finding that resource endowments, market incentives, and biophysical factors are relevant in the process, to the best of our knowledge there is a gap in understanding the adoption and the intensity of adoption as a joint decision. While most previous studies consider the adoption of agroforestry as a binary option [16–19], we argue that there exists an array of alternative and complementary practices to implement agroforestry systems that deserves to be acknowledged. The intensity of its implementation will drive different results, hence measuring as a binary variable will come up short in understanding the adoption of such systems. As alternatives, we assessed the following complementary practices: scattered trees, trees and shrubs for forage production, forestry plantations, and management of native forest. Our hypothesis is that social capital and networking variables play an essential role in spreading agroforestry as a sustainable practice among potential adopters.

Livestock plays an essential role in the rural economy of Colombia. The sector generates approximately 3.6% of GDP, 27% of total agriculture GDP, and 28% of employment in rural areas [20]. Cattle ranching is carried out in diverse climates and agroecological regions, including mountain and savanna. Livestock production systems and grasslands have expanded from 14.6 to 24 million hectares (21% of the national area) in the last 50 years [21,22]. Among the historical causes of the growth of cattle farming, we highlight three important drivers: (1) the cancellation of the international coffee agreement, which decreased coffee grain prices, producing a higher substitution toward livestock production [23]; (2) the implementation of free trade agreement policies that allowed the entry of cheaper agricultural products, such as wheat and barley, which increased the replacement of these crops by cattle farming [24]; and (3) the governmental program to curb illicit coca cultivation, which encouraged the establishment of cattle farming as an alternative development program, giving subsidies to farmers to establish grasslands in areas used previously for illegal crops [25].

As a case study, we use data compiled by the Mainstreaming Biodiversity in Sustainable Cattle Ranching Project (MBSCR) in Colombia [26]. The project aimed to increase the economic efficiency and environmental sustainability of the cattle farming sector through the adoption of silvopastoral production systems. Considering previous analyses, this study examines the role of social capital and networking, technical assistance, and participation in forestry projects, among other factors affecting adoption.

2. Background

2.1. Agroforestry Systems

Agroforestry systems involve at least two species of plants, one of which is a woody perennial, and always have two or more commercial products. The components have a significant economic or ecological interaction, implying greater complexity than mono-crop systems [27]. Agroforestry practices have been supported in several locations around the globe to diversify production and improve ecological benefits of farm systems [18,19,28,29].

Silvopastoral systems are a type of agroforestry that brings together animal production and native or introduced trees, which may have different uses (woody, rubber, palm, fruit, or animal feeding). These systems have been designated as a sustainable alternative to the open grazing regime of cattle farming because of the environmental and productive benefits that they provide [30]. Improved pastures and silvopastoral systems have been shown to be an alternative for carbon sequestration and the recovery of degraded areas in humid forest and Andean hillsides in tropical Latin America [31]. Soils with higher organic matter and the establishment of leguminous species have shown higher amounts of stored carbon [27,31–33]. The introduction of trees and shrubs in pastures changes biological conditions that serve as shelter and place of reproduction for local fauna. According to Bhagwat et al. [34], silvopastoral systems allow the survival of 50–80% of the wildlife that typically lives in a specific ecosystem. However, the level of biodiversity recovered is correlated with the density and type of trees introduced. Furthermore, silvopastoral systems can help reduce pressure on protected areas, expanding the habitat for plants and animals and creating corridors for persistence and movement of species [34].

Agroforestry systems have been implemented in Colombia in the last decade. For instance, a silvopastoral system project advanced in "La Vieja" river watershed supported the increase of 146 to 193 bird species, some of them vulnerable or threatened. The number of species and the population of birds were significantly higher in pastures with agroforestry compared to degraded pastures and pastures without trees [35]. On the other hand, an assessment in the Caribbean region of Colombia compared animal performance in open grassland and silvopastoral systems. Grazing time in daily hours (+1.8 daily hours), milk production per surface unit (+3 L), and the carrying capacity per hectare (+13% ± 25%) were significantly higher in silvopastoral schemes in contrast to grassland without trees [36].

2.2. The MBSCR Project

Loss and degradation of forests in Colombia are driven particularly by the interactions between the use of fire, cultivation of illicit crops, and the establishment of pastures [37]. A landscape-level analysis done by Dávalos et al. [38] shows that proximity to new coca plots and a higher proportion of an area planted with coca increased the probability of forest loss in southern Colombia. Sanchez-Cuervo and Aide [39] identified reforestation hotspots located mainly in the highlands of the Andes and deforestation hotspots located in the lowlands; for all cases, environmental and armed conflict explained most of the variations in forest cover.

Based on the economic importance and environmental impacts of the livestock sector, the Colombian Cattle Ranching Federation (FEDEGAN), the Centre for Research on Sustainable Agricultural Production Systems (CIPAV), the Action Fund (Fondo Acción), The Nature Conservancy (TNC), Global Environmental Facility (GEF), and The World Bank implemented a project with the ultimate objective of promoting a sustainable approach to cattle production. The goal of the project was to increase the economic efficiency and environmental sustainability of the cattle farming sector through the adoption of silvopastoral production systems that include a range of agroforestry practices, including trees in pasture, fodder banks (concentrated areas of protein-rich trees or scrubs), living fences, and grazed timberlands [40]. The project sought to encompass small and medium-scale farmers from five regions, and it focused on four components to broaden adoption of sustainable cattle ranching approach project: improving productivity; enhancing connectivity and reducing land degradation through the establishment of silvopastoral systems; institution strengthening; and dissemination, monitoring and evaluation [40].

3. Materials and Methods

3.1. Data and Study Area

The data used in this study consist of social, economic, and productive information obtained from a farm-level survey administered in the field to cattle farmers participating in MBSCR project between November 2012 and June 2013, the survey was part of the baseline of the project. From 1709 initial surveys, the database was reduced to 1605 due to missing values. The area under study includes five regions, as described in Table 1, that were selected according to the following criteria: the main economic activity is livestock, areas with high conservation value, proximity to protected areas, and the existence of wildlife corridors [40,41]. The regions selected also show high heterogeneity in climatic, biophysical, and geographic conditions, giving rise to the implementation of different production systems.

Table 1. Climatic characteristics of the Mainstreaming Biodiversity in Sustainable Cattle Ranching (MBSCR) project eco-regions in Colombia.

Regions	Departments	Altitude (m.a.s.l.)	Rainfall (mm Per Year)	Average Temperature (°C)	Climatic Classification
Cesar River Valley	CesarLa Guajira	20–175	1300–1926	26–29	Hot and dry
Lower Magdalena River Basin	BolivarMagdalena	20–250	810–2100	26–28	Hot, very dry, dry, and wet
Dairy Farm Region	BoyacáSantander	1290–2800	726–3281	13–21	Cold and dry, cold and wet, temperate wet and very wet
Coffee region and Cauca River Valley	Caldas, Quindío, Risaralda, Tolima, Valle del Cauca	915–2900	966–2829	13–24	Cold and wet, temperate wet and very wet
Low Foothills of Eastern Cordillera	Meta	220–600	2613–5200	24–27	Hot wet and very wet

Source: based on information from Chará et al. (2011) [40] and Murgueitio et al. (2011) [41]

According to Mahecha et al. [42], livestock production systems are classified based on their use of resources and technological infrastructure. Extractive systems are developed in low fertility soils, where natural grasslands with minimum agricultural practices are used to maintain a low carrying capacity per hectare. Extensive systems incorporate any animal husbandry activities, improved pastures, fertilization, breeding plans, and genetic improvement to increase productivity. Semi-intensive grassland systems manage pasture with high performance, irrigation, electric fences, and feed supplementation.

In the study area, cattle farms may produce milk, meat, or both, depending on climatic characteristics, the cattle farmer's preferences, and available resources. Thus, extractive and extensive systems are carried out in the eastern savanna (Meta Department) and the Caribbean lowlands in Bolivar, Magdalena, Cesar, and Guajira, where meat and dual-purpose farms are concentrated. Milk is produced in semi-intensive systems in departments of Boyacá, Santander, and Valle del Cauca. Cattle farmers included in the dataset were invited to participate in the selection process through two open calls made by FEDEGAN, CIPAV, TNC, and Fondo Acción, and they were chosen in accordance with the requirements, conditions, and reference terms of the MBSCR project.

3.2. Econometric Approach

In previous agroforestry adoption studies, logistic and probabilistic regressions have been commonly used [16–19,43–46]. However, to analyze the factors that influence the decisions to adopt and the intensity of adoption, a count model is more suitable. The hurdle model proposed by Cragg [47] assumes that the decision to adopt may precede a decision about the intensity of use, and both decisions may be explained by different factors or by the same factors but with different effects [48–50]. Thus, applying Cragg's hurdle model, the first decision (adoption) is estimated using a logistic regression model, and the second choice (intensity) is estimated thought a count regression model.

The models are expressed as:

$$\left.\begin{array}{l} d^{*} = z_{i}^{\prime} \propto +\varepsilon_{i} \\ d_{i} = 1\, if\; d_{i}^{*} > 0\; and\; 0\; if\;\; d_{i}^{*} \le 0 \end{array}\right\} \text{First Hurdle (decision to adopt)} \tag{1}$$

$$\left.\begin{array}{l} y^{*} = x_{i}^{\prime}\, \beta + \mu_{i} \\ y^{*} = y_{i}^{*}\;\; if\; y_{i}^{*} > 0\; and\; d_{i}^{*} > 0 \\ y_{i} = 0\; otherwise \end{array}\right\} \text{Second hurdle (intensity of adoption)} \tag{2}$$

where d_i* is a latent variable that describes farmer decision to adopt, d_i is the observed farmer´s decision to adopt and takes a value of 1 if the farmer adopts at least one agroforestry practice and 0 otherwise. y* is a latent variable that describes the intensity of adoption, and yi is the observed response on the intensity of agroforestry practices, which is measured by the number of practices adopted. z and x are vectors of variables that explain the adoption and the intensity; α and β are vectors of parameters. ε_i and μ_i are error terms.

To determine whether the decisions about adoption and the intensity of adoption are made jointly or separately, a likelihood-ratio (*LR*) test was conducted. The test compares the maximum likelihood values of two models: a count data regression model (Poisson regression) and a truncated zero regression. The test allows for assessment of whether the models are significantly different from each other [51,52]. The *LR* test (value of λ) is identified by:

$$\lambda = -2(L_P - L_L - L_{ZT}), \tag{3}$$

where L_P, L_L and L_{ZT} are the log-likelihood values for the Poisson regression model, the Logit regression model, and the zero-truncated regression model, respectively. *LR* has a chi-square distribution and degrees of freedom equal to the number of the explanatory variables included in the model.

3.3. Practices Adopted and Variables Considered

The regression model was established based on previous research on the adoption of agroforestry and cattle farming practices. The response variable represents whether farmers adopted or not, and how many practices they adopted. Four complementary practices were considered in our analysis [39,53]:

- Scattered trees: trees are incorporated in pastureland with a density of at least of 20 trees per hectare.
- Forage from trees and shrubs: species are planted specifically to feed animals, using a cut and carry system or cattle browsing.
- Forestry plantations: trees are established by planting and/or seeding (sowing) or raised artificially, for commercial purposes or conservation.
- Forest: natural woody vegetation without human intervention or successional vegetation recovered after human intervention, used in household or commercial activities.

Table 2 presents summary statistics of the variables used in the regression models. The independent variables are characteristics of the farmer, biophysical and financial characteristics of the farm, and environmental factors selected following previous studies [12,54–58].

Table 2. Description and summary statistics of variables used in the study.

VARIABLE	DESCRIPTION	MEAN	STD DEV
Dependent Variables			
First decision (*Adopt*)	Dummy Variable = 1, if cattle farmer adopts at least one practice, 0 otherwise	0.68	0.46
Second decision (*Intensity*)	Number of practices adopted by cattle farmer	1.03	0.92
Independent Variables			
Age	Age of cattle farmer, in years	55.4	12.6
Education	Level of education: 1 = incomplete elementary; 2 = complete elementary; 3 = incomplete secondary; 4 = complete secondary; 5 = technical education; 6 = professional higher education	3.8	1.9
Flat	Dummy variable = 1 if more than 50% of farm is flat, 0 otherwise	0.44	0.49
Spring	Dummy variable = 1 if the farm has water spring, 0 otherwise	0.53	0.49
Herd Size	Number of cattle heads	65.8	119.2
Number of paddocks	Number of paddocks in the farm	12.5	20.4
Technical Assistance	Dummy variable = 1 if the farmer has technical assistance, 0 otherwise	0.39	0.48
Participation in Forestry project	Dummy variable = 1 if the farmer participates or has participated in forestry project, 0 otherwise	0.25	0.43
Association Member	Dummy variable = 1 if the farmer belongs to any association or group, 0 otherwise	0.33	0,47
Use of credit	Dummy variable = 1 if the farmer has asked for a loan in the last five years, 0 otherwise	0.69	0.46
Eco-region			
Cesar River Valley	Dummy variable = 1 if the farm is located in the departments of Cesar or La Guajira, 0 otherwise (omitted)	0.19	0.39
Lower Magdalena River Basin	Dummy variable = 1 if the farm is located in the departments of Bolivar or Magdalena, 0 otherwise	0.12	0.32
Dairy Farm Region	Dummy variable = 1 if farm is located in the departments of Boyacá and Santander, 0 otherwise	0.20	0.40
Coffee region and Cauca River Valley	Dummy variable = 1 if farm is located in the departments of Caldas, Quindío, Risaralda, Tolima or Valle del Cauca, 0 otherwise	0.34	0.47
Low Foothills of Eastern Cordillera	Dummy variable = 1 if farm is located in the department of Meta, 0 otherwise	0.13	0.34
Production systems			
Meat	Dummy variable = 1 if meat production systems is in place, 0 otherwise	0.23	0.42
Dual Purpose	Dummy variable = 1 if dual purpose production system is in place, 0 otherwise	0.64	0.47
Milk	Dummy variable = 1 if milk production system is in place, 0 otherwise (omitted)	0.11	0.31

Source: Own estimations.

We used age and education as human capital variables, which are individual farmer characteristics, inherited or acquired, that influence or motivate the decision to adopt. Natural capital is a set of resources and ecosystem services involved in the production process. In our study case, we used climatic conditions classified as eco-regions, flats, and water springs. Financial capital variables are financing mechanisms used to cover the cost of the adoption; we considered herd size and use of credit. Physical capital variables are goods generated by cattle farming (meat, dual purpose, and dairy farm), we used these goods to classify the production systems. Social capital and networks included the relationships among cattle farmers, agricultural extensionists, and professionals of the projects that promote knowledge exchange (technical assistance, participation in forestry project, and association membership).

4. Results

Among the observations included in the analysis, 32% of cattle farmers do not adopt any agroforestry practice, 41% adopt at least one practice, and the remaining 27% adopt two or more agroforestry practices. The mean and standard deviation of adoption intensity were 1.03 and 0.92, respectively. The Lower Magdalena River Basin and the Coffee region and the Cauca River Valley regions have the highest rates of adoption, while the highest rate of non-adoption corresponds to the Dairy Farm region and Low Foothills of Eastern Cordillera. Figure 1 shows the adoption of agroforestry practices by eco-region.

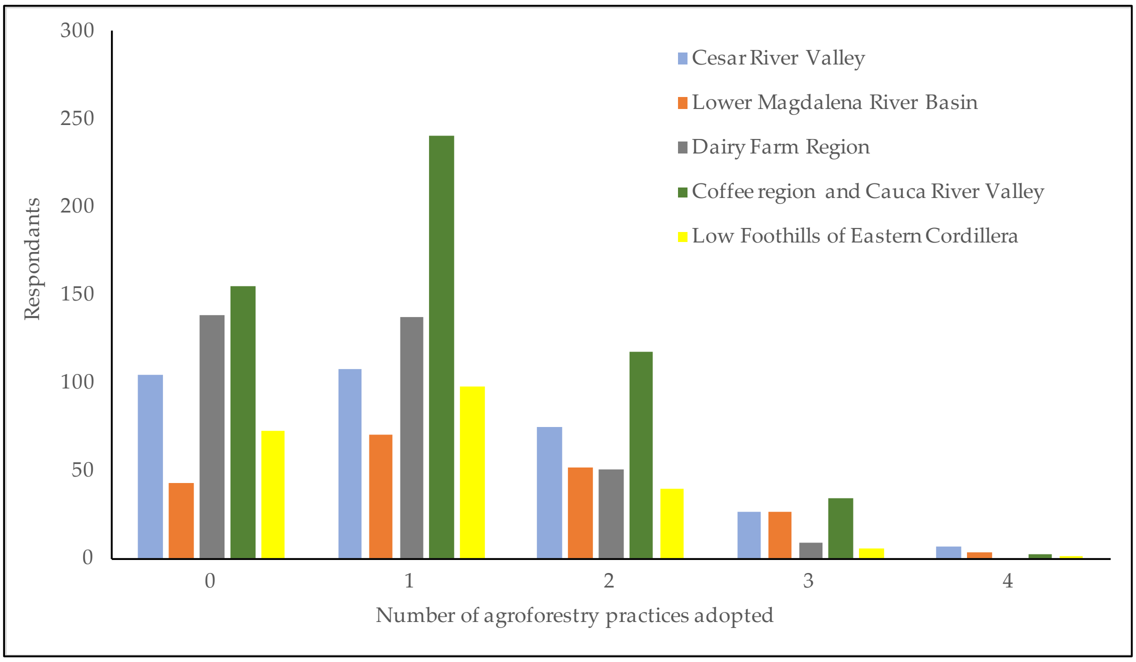

Figure 1. Number of practices adopted by eco-region.

The agroforestry practice most widely adopted is forest, by 50.9%. Among the reasons explaining the adoption of this practice were the benefits provided. Wood from the forest is used as a source of fuel, as input for the construction of house and livestock infrastructure, to produce revenues derived from selling timber, and for the preservation of watersheds and streams. Another factor that influences the wide adoption of forest is the low cost of establishment and handling associated with natural regeneration after human intervention [59]. This is consistent with the fact that the intensity of use of inputs (labour and capital) influences the adoption of technologies in farming systems [60,61]. The second-most adopted agroforestry practice is scattered trees (22.6%) established with different purposes, such as the production of fruit, rubber, or wood; as sources of forage; and protection of cattle from the sun and high temperatures, especially in warm areas, where cattle are more likely to suffer from heat stress [62]. The less-adopted agroforestry practices are forage from trees and shrubs and forestry plantations (18.4% and 12%, respectively), given that both require the use of certain species of plants, seeds, or plant material for the establishment, and they are associated with additional management, especially to protect plants from being ingested or trampled by cattle until they reach the proper size, which implies a higher level of complexity in the management of the practice, constraining adoption [44].

Table 3 shows the results of the econometric model and post-estimation statistics.

Table 3. Results of the Poisson and the Double Hurdle models.

VARIABLE	POISSON		DOUBLE HURDLE			
			LOGIT		ZERO TRUNCATED	
	Coef.	Marg. Eff.	Coef.	Marg. Eff.	Coef.	Marg. Eff.
	Rob. Std. Err.	Std. Err.	Rob. Std. Err.	Std. Err.	Rob. Std. Err.	Std. Err.
Age	**−0.001**	**−0.001**	**−0.009** **	**−0.002** **	**0.004**	**0.003**
	(0.002)	(0.002)	(0.005)	(0.001)	(0.003)	(0.002)
Education	**−0.007**	**−0.007**	**−0.036**	**−0.008**	**0.013**	**0.011**
	(.0012)	(0.012)	(0.032)	(0.007)	(0.020)	(0.017)
Flat	**−0.201** *	**−0.198** *	**−0.666** *	**−0.143** *	**0.014**	**0.012**
	(0.057)	(0.055)	(0.144)	(0.031)	(0.087)	(0.073)
Water shed	**0.184** *	**0.183** *	**0.222**	**0.047**	**0.267** *	**0.221** *
	(0.056)	(0.056)	(0.136)	(0.029)	(0.093)	(0.075)
Herd size	**0.001** *	**0.001**	**0.002** *	**0.001** *	**0.001** **	**0.001** **
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Number of plots	**−0.001**	**−0.001**	**−0.006** ***	**−0.001** **	**−0.001**	**−0.001**
	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)
Technical assistance	**−0.033**	**−0.033**	**0.082**	**0.017**	**−0.160** **	**−0.132** **
	(0.046)	(0.046)	(0.122)	(0.026)	(0.077)	(0.062)
Forestry project participation	**0.293** *	**0.316** *	**0.486** *	**0.098** *	**0.399** *	**0.368** *
	(0.049)	(0.057)	(0.142)	(0.027)	(0.077)	(0.076)
Association member	**0.086** ***	**0.087**	**0.142**	**0.030**	**0.104**	**0.089**
	(0.046)	(0.047)	(0.124)	(0.026)	(0.074)	(0.064)
Use of credit	**0.095** **	**0.093**	**0.239** **	**0.051** **	**0.072**	**0.059**
	(0.047)	(0.045)	(0.121)	(0.026)	(0.078)	(0.064)
Lower Magdalena River Basin	**0.157** **	**0.166**	**0.398** ***	**0.079** **	**0.162**	**0.144**
	(0.076)	(0.086)	(0.227)	(0.042)	(0.107)	(0.101)
Dairy farm region	**−0.629** *	**−0.528** *	**−0.842** *	**−0.192***	**−0.895** *	**−0.579** *
	(0.091)	(.064)	(0.225)	(0.053)	(0.166)	(0.079)
Coffee region and Cauca River Valley	**−0.310** *	**−0.295** *	**−0.231**	**−0.050**	**−0.526** *	**−0.415** *
	(0.075)	(0.068)	(0.202)	(0.044)	(0.117)	(0.086)
Low Foothills of Eastern Cordillera	**−0.298** *	**−0.268** *	**−0.075**	**−0.016**	**−0.668** *	**−0.446** *
	(0.083)	(0.067)	(0.208)	(0.045)	(0.142)	(0.074)
Meat	**0.136**	**0.141**	**0.466** **	**0.094** **	**−0.142**	**−0.115**
	(0.096)	(0.103)	(0.200)	(0.038)	(0.168)	(0.132)
Dual purpose	**0.120**	**0.118**	**0.476** **	**0.103** **	**−0.179**	**−0.155**
	(0.093)	(0.089)	(0.192)	(0.042)	(0.161)	(0.145)
Constant	**0.043**		**0.965** **		**−0.170**	
	(0.173)		(0.430)		(0.288)	
N	1605		1605		1095	
Wald Chi^2 (16)	199.7		104.2		128.8	
Pseudo R^2	0.033		0.057		0.131	
Log Pseudolikelihood	−1989.3		−945.9		−999.8	

Notes: Estimations obtained using STATA 10.1. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Coefficients are in bold and were obtained using robust standard errors. Robust standard errors in parenthesis. Chi tests were significant for all models ($p < 0.01$).

The *LR* test value yields $\lambda = 82$, which exceeds by far the critical value of 32 at the 1% significance, confirming the hypothesis that the decisions about adoption and the intensity of use of agroforestry practices are made separately. Consequently, the hurdle model is the most suitable to analyze how independent variables influence both decisions [51]. Another measure considered in selecting the model is the pseudo R^2 to compare the goodness of fit between the Poisson and the double hurdle model. The higher pseudo R^2 indicates which model better predicts adoption and the intensity of the adoption. The hurdle model predicts the outcome by 18%, compared to only 3% achieved with the Poisson regression model.

In the Logit regression, 10 out of 17 coefficients are statistically significant at least at 10%. The variables age, flat, number of paddocks, and dairy farm region have a negative effect on the likelihood of adoption of agroforestry practices, while herd size, participation in agroforestry projects, use of credit, the Lower Magdalena River Basin region, meat, and dual purpose production systems have a positive effect.

In the zero-truncated model, water springs, herd size, and participation in agroforestry projects have a positive effect. Conversely, technical assistance and Dairy Farm, Coffee region and Cauca River Valley and Low Foothills of the Eastern Cordillera regions have a negative effect.

5. Discussion

Age has a negative and significant effect on both decisions (adoption and intensity). Older cattle farmers are less likely to adopt because they do not have long-term plans and are less willing to engage in a new activity and to make an initial capital investment. As agroforestry is a long-run investment, they might not realize the outcome of adoption. The same effect has been reported by researchers about the adoption of cattle production practices and agroforestry practices [45,55,56,63].

In adoption assessment studies, education has had a significant positive effect, justified by the fact that the cattle farmers with a higher education level understand the knowledge underlying the technology and can make better-informed decisions [55,64]. Conversely, in this case, the results show that education does not influence the adoption of agroforestry practices. This may be explained by more highly educated cattle farmers having better off-farm employment opportunities and spending less time on on-farm managerial activities [65]. Additionally, the knowledge gained in formal education did not necessarily focus on livestock and agroforestry practices [17].

The variable flat, which refers to the biophysical characteristics of cattle farms, decreases the probability of agroforestry adoption by 14%. In Colombia, flat lands are devoted to agriculture activities that do not involve the planting of trees and make a more intensive use of land, incorporating machinery and irrigation systems, such as industrialized crops (sugar cane, flowers, and banana), annual crops (rice, corn, potatoes), or semi-intensive cattle farming [66]. Additionally, tree planting is more commonly used in sloping lands to deal with erosion problems, and farmers owning steeper farms are generally more likely to adopt agroforestry technologies [12].

Agroforestry practices have been implemented to manage and protect water resources. The probability of adopting more than one agroforestry practice increased by 22% in farms with springs, considering that these give rise to watersheds and streams that are key source of water used for household, agricultural, and livestock activities [56,58,67].

Regional context influences the adoption of agroforestry practices differently. Cattle farms located in the dairy region are less likely to adopt agroforestry practices by 19% and to adopt more than one practice by 57% compared to those located in Cesar River Valley (location omitted variable). Those cattle farmers located in the coffee region and Cauca River Valley region have a lower likelihood of adopting intensive practices by 41%, in contrast to the omitted variable. In these regions, conventional ranching and farming practices, such as the tree cover removal for pasture establishment and the use of fertilizer to supply soil nutrients, are widespread, and the integration of agroforestry and cattle farming may contradict farmers' previous knowledge gained through years of experience [68]. Both regions are in higher altitudes, and lower temperature and sunlight intensity can be limiting factors in the adoption of agroforestry as a source of shade for cattle or to integrate trees into pastures [57,69]. Furthermore, the integration of agroforestry practices with cattle farming might not be suitable for all types of cattle farming systems, specifically for dairy and semi-intensive systems [46].

The regional context variable for the Lower Magdalena River Basin region has a significant positive effect on adoption, increasing the probability by 7%, given that trees and shrubs may have been planted to obtain multipurpose benefits, such as low-cost forage for improving animal performance, fulfillment of forage-demand in the dry season, and as source of shade for cattle [46,62].

The region of Low Foothills of the Eastern Cordillera has significant negative effect, by 44%, on the probability of adopting more than one agroforestry practice. This zone is characterized by acidic and low-fertility soils that restrict normal plant growth. The agriculture practices required to improve the soil conditions and provide the nutrients for seed survival and tree growth would constrain the adoption of agroforestry practices [57,70].

Herd size has a significant positive effect on adopting and intensity of adopting. The number of heads of cattle is an indicator of household wealth and resource availability. Wealthier farmers are more likely to invest capital in adopting agroforestry practices. A larger number of animals augments the demand for food and wood for livestock infrastructure (fences, cattle pens, stalls, and feeders), which might be supplied by the adoption of multipurpose shrubs and trees [16,17,45,46].

The number of paddocks has a negative effect on adoption. Rotational grazing is a pasture management practice that requires splitting up paddocks to move the cattle around the grasslands. Some agroforestry practices require non-use of pasture for trees and shrubs planting, diminishing the available grazing area and interfering with livestock production. Additionally, the cost related to agroforestry (seeds, materials for propagation, and the labor for planting and tending) might dissuade producers and constrain adoption [46,71].

As agroforestry can be considered a long-term investment, having financing sources may enhance its adoption. For cattle farmers who asked for a loan in the last five years, the probability of adoption of agroforestry practices increased by 5%. The use of credit is a mechanism to cover the cost of establishment of agroforestry and helps to overcome barriers to adoption, such as lack of savings or liquidity [12,46].

The variable participation in a project that involved tree planting has a significant and positive effect, increasing the probability of adopting agroforestry practices by 9.7% and the number of practices adopted by 36.7%. Project participation promotes interactions among stakeholders, giving the opportunity to build social networks, which are an essential source of technical information in rural areas. Extension projects may influence adoption in three ways: as a channel of information, as a vehicle for learning, and as a source of finance [72–74]. First, projects provide all information related to the technology to encourage the farmer´s adoption, explaining the potential benefits and giving specific recommendations for the establishment and maintenance of agroforestry practices [45,75]. Second, projects give spaces for learning by fostering horizontal (farmer-to-farmer) and vertical (organizations) connections [76]. The relationships between farmers contribute to exchange and spread information and help to develop trust with respect to the new technology and to overcome the barriers that arise from the adoption process [74]. The relationships with other organizations (governmental, national or international agencies and research centers) may provide technical, financial, and advisory support for adoption and extension [44,45]. Third, projects can provide sources of finance and incentives for adoption, such as seed, planting materials, and fertilizers, to participants, encouraging farmers to adopt by reducing the initial investment costs [19,74]. In some cases, projects have established a payment scheme to promote the adoption of agroforestry and to compensate farmers who decided to plant trees that generate environmental services, such as forest conservation, recovery of degraded soils, and water conservation. The payment is made provisionally for two or four years, according to the service provided by the farm, and seeks to alleviate financing constraints related to adoption [77].

Contrary to expectations, the variable technical assistance was not significant for adoption, and cattle farmers who received it are 13% less likely to adopt intensive agroforestry practices. This may have been because the technical assistance received by cattle farmers was focused on traditional approaches to agricultural and livestock production and, therefore, unrelated to agroforestry, or because the staff with general training prevailed over specialists in forage production and livestock [46].

The association member variable encompasses all groups that farmers belong to, such as civil organizations (neighbor's associations, village communities, and water councils), breeding societies, and cooperatives for production and sale of agricultural products. This variable was included in the econometric model under the assumption that participation in these groups could provide information exchange, but it is not significant. Similar results have been reported in other agroforestry adoption research [12], and may be because the main purpose of these associations is not the diffusion of knowledge about agroforestry.

The agroecological conditions and the resource base available lead to establishing specific management practices and production methods and, consequently, the adoption of agroforestry practices [74,78]. Meat and dual-purpose systems influence the adoption of agroforestry practice by 9% and 10%, respectively. These systems are carried out on grazing-based practices. To improve animal performance and increase the production of biomass, animal feeding could be complemented using trees and shrubs as a source of forage.

An important point to consider is that in the last years, Colombia has experienced a dynamic change in land use resulting in a reduction of forests cover. The main causes of deforestation include the expansion of agriculture, wood extraction, extensive livestock, and urbanization [79]. In this line, according to Boron et al. [80], it is also key to advance and enforce good-quality land use planning to conserve remaining habitats, biodiversity and ecosystem services. As is recognized by Furumo and Lambin [81], a well-structured zero-deforestation governance landscape is taking shape in Colombia, but several barriers still impede public and private pledges in the country. In this scenario, agroforestry systems can help to improve ecosystem management to limit deforestation.

6. Conclusions

The aim of this article was to identify the variables that influenced the adoption of agroforestry practices on cattle farms prior to the establishment of silvopastoral systems in the framework of the MBSCR project. For this purpose, a hurdle model regression was proposed to assess adoption and the intensity of adoption for a sample of 1605 cattle farms in five agro-ecological regions in Colombia.

Decisions about adopting agroforestry and the intensity of adoption were influenced by various factors. Herd size, participation in projects that involve the tree planting, use of credit, Lower Magdalena River Basin region, and meat and dual-purpose production systems positively influenced the decision to adopt agroforestry; while water springs, herd size, and participation in projects that involve the tree planting influenced the intensity of agroforestry practices. This distinction is important because future intervention programs might aim to involve as many producers as possible or aim to have fewer producers who could acquire more in-depth knowledge of a specific practice. Depending on the goal, intervention programs could target producers based on the characteristics we describe above.

The strategies included in the MBSCR projects, such as the technical assistance, training, environmental service payment schemes, and credits management, favor overcoming the barriers that constrain the adoption.

To obtain the ecological and environmental benefits, agroforestry practices should be adopted by a significant proportion of cattle farmers, beyond simple participation in the project and the eco-regions where it was conducted. The diffusion of this technology might be increased among farmers who have adopted and who are potential adopters, and social networking could play an important role in spreading agroforestry as a sustainable practice. Silvopastoral systems may be included as a policy strategy for the mitigation of consequences of climatic change, such as burning and destruction of grasslands, decrease in milk production, and death of livestock. This might promote the integration of other governmental institutions and expand the scope of agroforestry.

Future research should consider the recent dynamics changes in land use of the country, applying analyses of datasets to improve the understanding of the processes and their interactions. The limitation of our study is the temporal gap between the origin of the dataset and the recent rapid changes experienced by the country and the region.

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