

Understanding the adoption of sustainable silvopastoral practices in Northern Argentina: what is the role of land tenure?

Article

Accepted Version

Tschopp, M., Ceddia, G., Inguaccio, C., Bardsley, N. and Hernandez, H. (2020) Understanding the adoption of sustainable silvopastoral practices in Northern Argentina: what is the role of land tenure? *Land Use Policy*, 99. 105092. ISSN 0264-8377 doi:

<https://doi.org/10.1016/j.landusepol.2020.105092> Available at <http://centaur.reading.ac.uk/93098/>

It is advisable to refer to the publisher's version if you intend to cite from the work. See [Guidance on citing](#).

To link to this article DOI: <http://dx.doi.org/10.1016/j.landusepol.2020.105092>

Publisher: Elsevier

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other

copyright holders. Terms and conditions for use of this material are defined in the [End User Agreement](#).

www.reading.ac.uk/centaur

CentAUR

Central Archive at the University of Reading

Reading's research outputs online

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Understanding the adoption of sustainable silvopastoral practices in Northern Argentina: What is the role of land tenure?

Highlights

- We study the adoption of sustainable silvopastoral practices in the Dry Chaco
- Various Multivariate Probit (MVP) models are used to assess adoption decisions
- Socio-economic factors influence adoption of all practices
- Affiliation with a producer organization is an excellent predictor of adoption
- The limited influence of land tenure can be explained by local specificities

17 **Abstract:**

18 The Argentinian Dry Chaco has suffered from very high deforestation rates in the last decades, and forest
19 degradation remains an important issue. This study examines the adoption of sustainable silvopastoral
20 practices by smallholder households in the Chaco. Data for the study were collected from 393 families in
21 two municipalities of the Province of Salta. We used multivariate probit (MVP) models to assess land users'
22 decision to adopt three management practices. We show that socio-economic factors (household assets,
23 number of animals), human and social capital (literacy, affiliation with a producer organization), as well as
24 access to financial resources (credit) determine adoption. Secured land tenure also increases the likelihood
25 of adoption, but not as much as we initially hypothesized. We discuss how certain specificities of the area,
26 including difficulties accessing land titles and pressure from the agro-industry, as well as the characteristics
27 of the resource itself – forest grazing areas, some shared by multiple families – might explain this
28 unexpectedly low influence of land tenure on the adoption of sustainable silvopastoral practices.

29

30

31 Key Words:

32 Silvopastoral systems, adoption of sustainable practices, land tenure, Dry Chaco

33

34 **1 Introduction**

35 Deforestation, land use change, and agriculture account for 23% of global greenhouse gas emissions and
36 represent a significant share of the emissions of South American countries (Aide et al., 2013; Harris et al.,
37 2012; Shukla et al., 2019). The Dry Chaco – the second largest forest ecoregion in Latin America – has
38 experienced particularly rapid deforestation in recent years (Ceddia and Zepharovich, 2017; Grau et al., 2008;
39 le Polain de Waroux et al., 2017; Volante et al., 2016). This process has largely been driven by agricultural
40 expansion, with land use changing from forest to cropland or pastures (Fehlenberg et al., 2017; Piquer-
41 Rodríguez et al., 2018).

42 Deforestation in the Chaco negatively affects forest users, particularly indigenous people and *criollo*
43 smallholder farmers. Both groups use the forest’s resources either directly or through employment.
44 Indigenous people additionally rely on fishing and small-scale livestock ranching, while the main livelihood of
45 *criollo* smallholder farmers gravitates around cattle ranching and off-farm employment, including work in
46 construction or small shops and work migration to urban centres (Córdoba and Camardelli 2017).

47 *Criollo* smallholders and indigenous communities are particularly vulnerable to adverse effects of
48 deforestation and agricultural expansion for commodity production – processes that are occurring
49 throughout the Dry Chaco. Many smallholders and indigenous people have been displaced in recent years, or
50 have lost access to common resources because of deforestation (Carr et al., 2009). These trends of exclusion
51 not only heighten these groups’ vulnerability, but also increase the pressure on remaining forest ecosystems
52 by limiting the amount of land available to smallholders for grazing their herds, resulting in higher stocking
53 densities.

54 *Criollo* smallholders used to produce cattle in customary system known as *campo abierto* (“open field”). In
55 this system, cattle are left to roam in the forest, feeding from trees, bushes, shrubs, and natural pasture, with
56 limited supervision by the farmer (Camardelli, 2005). Almost half of all farms in our study region exclusively
57 use the *campo abierto* system. Scholars have shown that pressure from small-scale cattle farming in Chaco
58 forests can cause environmental degradation and alter the composition of landscapes and land covers in
59 these forest ecosystems. Pressure from cattle has already resulted in changed forest composition, with
60 bushes and shrubs encroaching on natural pastures (Grau et al. 2015). Finally, the Chaco forest, and in
61 particular its arid and semi-arid regions, have been noted as being particularly prone to erosion (Therburg et
62 al., 2019). This can be aggravated both by open-field grazing and by the advance of the agricultural frontier
63 and the related deforestation.

64 Increasing the use of more sustainable agricultural practices that reduce land and forest degradation is
65 therefore essential to preserving the Chaco. Forest restoration, including through sustainable agroforestry
66 practices, has the potential to increase carbon sequestration while providing stable livelihoods. More
67 specifically, sustainable silvopastoral practices can help to improve resilience as well as ecosystem services
68 for both users and non-users of the forest (Hänsela et al., 2009). Adoption of new management practices in
69 grazing systems has the potential to significantly lower the impact of smallholders’ livestock herding while
70 also reducing greenhouse gas emissions from this sector (Nieto et al., 2018). And, importantly, they could
71 help to secure smallholder livelihoods in one of Argentina’s poorest regions, which is prone to frequent
72 outmigration.

73 Argentina's National Forest Law (National Law Nº 26,331), passed in 2007, is aimed at addressing
74 deforestation of native forests throughout the country. It identifies three land use categories for native forest:
75 "red areas" are high-priority conservation zones, "green areas" may be used for productive purposes, and
76 "yellow areas" are of medium conservation value. Each province of Argentina adopted their own regulations
77 for the implementation of the forest law, with the province of Salta allowing a particularly high level of
78 discretion on the range of activities allowed in yellow areas (Fernández Milmanda and Garay, 2019). As a
79 result, deforestation rates remained high in the province over the period 2006-2016, even after the
80 implementation of the forest law.

81 To address some of these challenges and at the same time offer smallholders options for improving their
82 productivity and their resilience, the Argentinian State recently promoted a set of public policies for yellow
83 areas, under the label *Manejo de Bosque con Ganadería Integrada* ("Forest Management with Integrated
84 Cattle Ranching"), MBGI for short (Peri *et al.* 2018). This national plan echoes previous policy initiatives in that
85 it aims to reconcile conservation of native forests with smallholder production by allowing certain productive
86 uses, including silvopastoral cattle production, in a considerable share of the remaining native forest (Borrás
87 *et al.*, 2017). *Criollo* smallholders are one of the main target groups of this policy and this policy urges each
88 productive unit to issue a management plan following the following seven technical guidelines: 1) the
89 management plan has to comply with existing policies and plans for Sustainable Management of Native
90 Forests (forestry inventory, baseline, silviculture). 2) exclusive areas for biodiversity conservation have to be
91 determined (at least 10% of the farm areas), 3) Shrub management and pasture introduction to provide forage
92 to cattle; 4) implementing a monitoring system; 5) Livestock management and stocking rates control 6)
93 contingency plans for droughts and/or fire and 7) water management to reduce impact of livestock on the
94 forest (Alaggia *et al.*, 2019; Peri *et al.*, 2018). These seven guidelines are meant to be addressed through one
95 or several management plans developed by smallholders. At the time of the survey (2018) MBGI was only
96 implemented in a couple of pilot sites in the Province of Salta. Under this policy smallholders can therefore
97 improve up to 70% of their land, by using introduced exotic grass species, and by removing some shrubs
98 wither manually, or with a low-impact tractor roll. These improvements are however contingent on the
99 approval of their management plan. In order to fully comply with the policy, smallholders would therefore
100 have to adopt new management practices (e.g. enclosing some areas of their farm to avoid cattle intrusions
101 in high-priority conservation areas). Further, such practices include rotational grazing, introduction of exotic
102 grass species, and the removal of some types of thorny bushes and shrubs to create corridors for vegetation
103 development (guideline number 3). Shrubs are not completely removed but are uprooted and broken down
104 in smaller pieces in order to maintain soil cover. All of these methods are practised by some smallholders in
105 the region, but up to now their use is not widespread. Understanding the adoption patterns of these existing
106 practices is therefore crucial for a policy such as MBGI to be implemented successfully. Moreover, in spite of
107 these current policy developments, scant attention has been paid to the specific socio-economic groups of
108 *criollo* smallholders and indigenous people. The conditions for promotion of sustainable silvopastoral
109 practices have likewise received little attention. To our knowledge, an analysis of the adoption of sustainable
110 practices, including its drivers and adoption patterns, is currently lacking. Although there is a vast literature
111 on the adoption of agricultural practices (soil and water conservation, sustainable agricultural practices, etc.),
112 few articles examine what determines the adoption of silvopastoral practices. Our article addresses this
113 research gap using the case of the Province of Salta, Argentina. We focus on three practices and assess

114 different variables associated with their adoption. First, we summarize the existing literature on this topic.
115 Next, we present our data and the methods used for their collection and analysis. Then we discuss the results
116 obtained from our MVP statistical model. We conclude by summarizing our main insights.

117 **2 Adoption of agricultural technologies and silvopastoral practices: a** 118 **literature review**

119

120 A rapidly growing body of case studies of the adoption of agricultural practices in the global South and North
121 shapes our understanding of what enables effective transitions towards sustainability. Diffusion of
122 information through social networks plays a key role in explaining the spread of a given practice (Banerjee et
123 al., 2013; Rogers, 2003), along with the influence of state and non-state extension service actors (Garbach et
124 al., 2012; Kassie et al., 2013). An important share of the literature focuses on the characteristics and attributes
125 of households and individuals adopting different practices, comparing them with non-adopters.
126 Understanding these patterns is essential to effectively targeting the diffusion of new practices. This section
127 identifies key factors that are often used to assess the adoption of sustainable production practices.

128 There is a vast literature on the adoption of different practices by small-scale farmers in the global South.
129 Recently, researchers have focused on the adoption of soil and water conservation technologies (Amsalu and
130 de Graaff, 2007; de Graaff et al., 2008; Nkegbe et al., 2012; Tenge et al., 2004; Theriault et al., 2017; Zeweld
131 et al., 2019), conservation agriculture (Baudron et al., 2009; Bitttebier et al., 2018; Garbach et al., 2012; Shetto
132 and Owenya, 2007; Wauters et al., 2010), climate-smart agriculture (Kpadonou et al., 2017), and, more
133 generally, sustainable intensification or sustainable agricultural practices (Kassie et al., 2015; Ndiritu et al.,
134 2014; Nkomoki et al., 2018).

135 Many articles identify households' socio-economic characteristics as key determinants of the adoption of new
136 practices, including household size and available labour force (de Graaff et al., 2008; Tenge et al., 2004),
137 gender of the household head (Doss and Morris, 2001; Ndiritu et al., 2014; Theriault et al., 2017), and
138 education (Nkomoki et al., 2018), among others.

139 Socio-economic status and financial capabilities are considered an important factor, as new technologies
140 often require some level of capital investment in order to become effective. Accordingly, scholars have been
141 assessing the importance of having a bank account (Kleemann et al., 2014). Access to credit is also crucial,
142 and is often an important predictor of the adoption of a new practices(Kassie et al., 2015; Smith et al., 2017;
143 Zeweld et al., 2019), and a recent study showed that access to credit is a limiting factor for smallholders in
144 the Dry Chaco (Mastrangelo et al., 2019). Several studies emphasize the importance of networks in diffusion
145 and adoption patterns (Baumgart-Getz et al., 2012), although they rarely apply established social network
146 analysis methodologies; one exception is Banerjee et al. (2013). Furthermore, social capital and particularly
147 membership in a farmer association or cooperative is regularly stressed as a key factor in the adoption of new
148 practices (Ferreira Gonzaga et al., 2019; Hänsela et al., 2009; Shetto and Owenya, 2007). The role of State
149 extension services is likewise mentioned in several studies (Amsalu and de Graaff, 2007; Nkegbe et al., 2012).

150 However, the factor that almost every adoption study addresses is land endowment or the size of the
151 available land, and more specifically the issue of land tenure.

152 Since the early work of Hardin (2009), it has often been argued that granting land ownership to smallholders
153 or resource users could help to improve management while avoiding the freeriding behaviour associated with
154 common resources or disputed land. Although Hardin's original argument has met heavy criticism (Ostrom
155 2009), his hypotheses are still very present in the literature on adoption of new agricultural practices.

156 It is often assumed that private land titles and secured land tenure should automatically lead to greater
157 investments by smallholder farmers. For instance, Nkomoki et al. (2018) show that land tenure plays an
158 important and positive role in the adoption of multiple sustainable agricultural practices. Similarly, Knowler
159 and Bradshaw (2007) found in a meta-study on conservation agriculture that land tenure was one of the most
160 important factors explaining technology adoption. The security of tenure that accompanies private ownership
161 is generally seen as important for adoption of agricultural technology. One could however argue that security
162 of tenure, is separable from private ownership (Ostrom, 2009), something that Hardin's article did not
163 recognize. For example, Cuba's innovations in the "special period", involved assigning exclusive "usufruct
164 rights" to land held in common in state-owned cooperatives, thereby affording security of tenure without
165 privatization (Wright, 2009).

166 Only a small portion of the existing literature on technology adoption focuses on agroforestry practices, and
167 even less work exists on the adoption of silvopastoral practices. In this study, we understand agroforestry as
168 denoting a land management system that includes trees in intercropping or pasture production. A
169 silvopastoral system consists of livestock grazing in forest areas. Accordingly, we understand silvopastoral
170 systems to be a specific form of agroforestry. A study by Latawiec et al. (2017) is one of the few exceptions.
171 Their survey of 250 farmers in Matto Grosso revealed that labour availability plays a key role in the adoption
172 of sustainable practices. They also show that several obstacles hinder the adoption of new practices, and that
173 one of the main motivations for the adoption of such practices is the prospect of economic profitability and
174 higher yields.

175 **3 Methods**

176 **3.1 Survey data collected**

177 The data for this analysis were collected in a survey conducted in the Dry Chaco in the Province of Salta,
178 Argentina, in September 2018. Before administering the survey, we conducted qualitative interviews and
179 identified three selected sustainable silvopastoral management practices: (1) sowing of introduced pastures
180 on a small portion of the land for cattle grazing; (2) previous preparation of grazing land by manually removing
181 shrubs; (3) fencing and rotational grazing. These practices are often combined, and they involve different
182 labour and financial costs. Shrub removal is labour-intensive, but relatively cheap, while the other two
183 practices require more financial means. The focus of this paper is not on assessing in detail the impact that
184 these practices have on the ecosystem. Rather, our aim is to understand what drives the adoption of these
185 practices and to describe the socio-economic characteristics of farmers using them.

Understanding the adoption of sustainable silvopastoral practices

186 We conducted the survey in two municipalities of the departments of San Martín and Rivadavia. The survey
 187 focused on various socio-economic indicators (level of education, nutrition, household assets), land tenure
 188 and social capital indicators, as well as some additional information on agricultural production (number of
 189 animals, size of land, etc.) and agricultural practices. We interviewed 392 households in the two
 190 municipalities of Embarcación and Rivadavia Banda Norte. We chose these municipalities purposively
 191 because of the high level of conflicts recently experienced there, and because of their location near the
 192 “agricultural frontier”, which we hypothesized to be associated with increased pressure on social-ecological
 193 systems. We also chose these municipalities because they contain a relatively high density of smallholder
 194 families, whereas there are fewer smallholder families in areas that have high deforestation rates. We
 195 applied a stratified random sampling, in which each municipality was divided into different geographical
 196 zones, which were selected randomly for inclusion in the survey. All households within the selected zones
 197 were interviewed. Table 1 summarizes the characteristics of our sample. We use descriptive statistics (mean
 198 and SD) to indicate the distribution of the variables of this study.

199 To account for socio-economic status, we constructed an asset-index through a principal component
 200 analysis, as suggested by the Filmer Pritchett method (Filmer and Pritchett, 2001). Our index was
 201 constructed using a polychoric principle component analysis (PPCA), following the methodology developed
 202 by Kolenikov and Angeles (Kolenikov and Angeles, 2009, 2004). The index ranges from 0 to 3 and reflects a
 203 portfolio of different assets that are quite common in the region. The different variables that are included in
 204 the index model, are described in Annex A.

205

206 *Table 1: Description of variables used*

Variable name	Variable Codes	Description	Possible answers	Overall Mean (SD)
<i>Dependent variables</i>				
Pastures	P	1 if farmer sowed any pasture areas	binary	0.42 (0.49)
Manual shrub removal	M	1 if farmer engaged in manual uprooting of shrubs	binary	0.46 (0.50)
Fencing	F	1 if farm is delimited with fences	binary	0.42 (0.49)
<i>Independent variables</i>				
Household characteristics				
Municipality	MUNI1	Municipality (1 if Rivadavia Banda Norte, 0 if Embarcacion)	Binary	
Gender of respondent	GENDER	Gender of household head, 1 if male.	Binary	0.81 (0.41)
Distance to closest village	DIST	Distance to nearest village (in km)	integer (km)	29.29 (17.08)
Age of hh head	AGE	Age of household head	years	55.31 (15.43)
Year established	YEAR	Year the family established itself in the region	years	1955 (36.44)

Household size	SIZE	Number of people living in household	integer	4.17 (2.46)
Literacy	LIT	1 if every household head can read	binary	0.92 (0.27)
Socio-economic status	SES	Socio-economic status index (see Annex A)	continuous	1.04 (0.74)
Productive capital				
Access to credit	CRED	1 if household has access to credit or subsidies (public programmes e.g. rural development).	binary	0.07 (0.26)
Number of Cows	COW	Number of cows household has	numeric	43.41 (63)
Off-farm employment	OFF	1 if one or more household members are employed off-farm	binary	0.33 (0.47)
Land tenure & Social Capital				
Land tenure security	LANDT	1 if land tenure is secured (Property titles (individual or communitary), or in process.	binary	0.43 (0.49)
Conflicts	CONFL	1 if household reports conflict over land	binary	0.24 (0.43)
Membership in a producers' organisation	SOC	1 if household belongs to a civil society organisation (including cooperatives)	binary	0.44 (0.49)
Observations	n	Number of observations	n	392

207

208

209 3.2 Statistical model

210 3.2.1 Latent variable model

211 In this paper, we use a latent variable framework to model the decision of various households to adopt
 212 selected silvopastoral practices as a binary outcome. We can describe the potential decision of a farmer to
 213 adopt a specific practice as follows:

214

$$215 Y_{ik}^* = X_i \beta_k + \varepsilon_i \quad (1.a)$$

216

$$k = (P, M, F) \quad (1.b)$$

217 Where Y^* indicates the preference or perceived benefits of a farmer i to adopt a specific silvopastoral from
 218 the following list: P = introduction of introduced pastures, M = Manual removal of shrubs and bushes, and F
 219 = fencing (enclosure). In our model, the outcome is to be determined by observed household characteristics
 220 (X_i), as well as the error term. The unobserved preferences in Equation 1 translate into a binary outcome as
 221 follows:

222

$$Y_{ik} = \begin{cases} 1 & \text{if } Y_{ik}^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

223 Which means that a household will adopt a specific silvopastoral practice if their perceived preference or
224 benefits exceed 0.

225

226 3.2.2 Single versus multiple practices adoption: a multivariate probit model

227 Earlier studies on adoption, including the work by Feder (1982), focused on the challenges of accounting for
228 the adoption of multiple practices simultaneously. Single adoption models analyse the decision to adopt a
229 single technology using single binary dependent variables that include only one dependent variable
230 (technology adopted). The adoption of more than one practice was commonly assessed by calculating several
231 probit/logit models. However, in some cases the adoption of several agricultural technologies might be
232 interdependent, either because the technologies complement each other (positive correlation) or because
233 they act as substitutes for each other (negative correlation, see e.g. Kpadonou et al. 2017).

234 In order to estimate simultaneously the determinants of the three practices considered within this study, we
235 chose to apply a multivariate probit (MVP) model, following the suggestion of Cappellari and Jenkins (2003).
236 This type of model has recently gained in efficiency by incorporating maximum likelihood estimators derived
237 from simulations using Markov chain Monte Carlo methods. The procedure has been widely applied in the
238 field of agricultural practices adoption (Kassie et al., 2012; Ndiritu et al., 2014; Nigussie et al., 2017; Teklewold
239 et al., 2013b; Theriault et al., 2017; Ward et al., 2018).

240 MVP models address a key problem described by the adoption literature. Studying more than one practice
241 poses several challenges, because the dependent variables may be correlated. To address this issue, the MVP
242 model provides estimates of error terms of the different models simultaneously. The main advantage of MVP
243 models is that they do not require the formulation of assumptions of independence regarding the adoption
244 patterns of specific practices. It is therefore highly adequate for addressing situations in which households
245 might simultaneously adopt more than one practice, or might follow a differentiated or hybrid adoption
246 pattern.

247 3.2.3 Presentation of the model

248 We reviewed the literature in order to identify factors that have been found to influence the adoption of
249 different types of agricultural practices and technology (Barton et al., 2016; Hänsela et al., 2009; Kassie et
250 al., 2015; Nigussie et al., 2017). The variables are classified into a) socio-economic factors, b) Productive
251 capital and c) land tenure and social capital –or institutional characteristics. Figure 1 illustrates the basic
252 features of our model and shows how the various types of independent variable influence the realization of
253 the dependent variables.

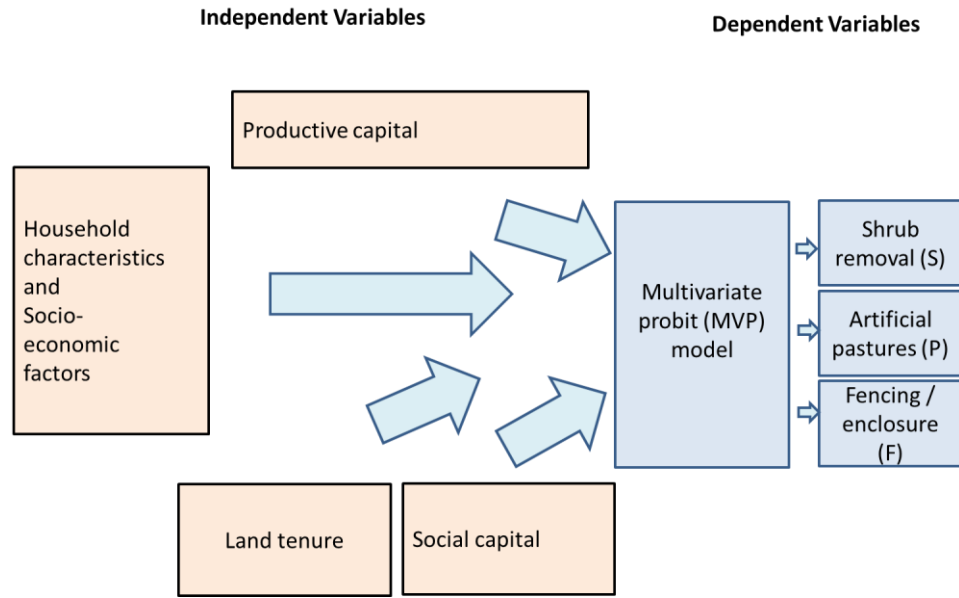
254

255 *Figure 1: Model used in the study, including independent and dependent variables and interaction effects*

256

257

Understanding the adoption of sustainable silvopastoral practices



258

259 Prior to conducting the analysis, we formulated different hypotheses regarding adoption of sustainable
260 silvopastoral practices, based on the existing literature:

261 (1) Age and distance to the nearest village are negatively associated with adoption of the practices.

262 (2) Socio-economic status, access to credit and subsidies, and affiliation with an organization are all
263 positively associated with adoption of the practices.

264 (3) Land tenure is positively associated with adoption of the practices.

265 Hypotheses 1 and 2 reflect some of the most important determinants found in the literatures. Household
266 characteristics such as age of household head and distance to the villages are associated with adoption.
267 Further, a higher socio-economic status, access to credit and membership to a producers association can
268 provide a household the necessary resources and knowledge required to invest in new agricultural practices.
269 This hypothesis further reflects recent findings from the Dry Chaco region (Mastrangelo et al., 2019). Finally,
270 our third hypothesis addresses the role of land tenure, which is often times found to have positive influence
271 on the adoption of new agricultural practices. In order to test the above hypothesis we initially specify a first
272 set of models (Model 1) in which the probability of adopting the various silvopastoral practices (namely, the
273 implantation of introduced pastures P, the manual removal of shrubs M and the introduction of fences F)
274 depends on the following variables: municipality (MUNI1), distance to the closest village (DIST), socio-
275 economic status (SES), land tenure security (LANDT), existence of conflicts (CONFL), access to credit (CRED),
276 number of cows (COW), year of establishment (YEAR), age of household head (AGE), gender of household
277 head (GENDER), membership in a producers' organization (SOC), off-farm employment (OFF), literacy (LIT),
278 household size (SIZE).

279 Subsequently, in order to test the robustness of the initial specification, we extend the model to account for
280 a number of interactions. In Model 2, we include interactions between the geographical variable and the land
281 tenure variable and the presence of conflicts over tenure respectively, namely $MUNI1 \times LANDT$ and

282 MUNI1×CONFL. The assumption is that the effects of tenure and land related conflicts impact differently on
 283 the adoption of silvopastoral practices, depending on the geographical location, because in one of the
 284 considered municipality (Embarcacion), there is currently much more pression from the large-scale
 285 agribusiness. In Model 3, we account for interactions CRED×SOC, CRED×LIT and LANDT×CONF. Here the
 286 assumption is that the effect of credit on adoption is conditional on being part of a producers' organization
 287 and on the degree of literacy. Additionally, we assume that the effect of land tenure is conditional on the
 288 existence of conflicts. Finally, in Model 4, we account for interactions between Gender and some key
 289 productive capitals which include GENDER×LANDT, GENDER×CRED and GENDER×CONF.

290 4 Results and discussion

291 4.1 Results from the MVP model

292 Table 2 presents the results obtained from the MVP model for the three silvopastoral practices considered
 293 in this study (introduced pastures, shrub removal, and fencing/enclosure). The impact of the different
 294 predictors on our model is discussed in the following subsection. We can see that only two variables are
 295 significantly associated with adoption of all three variables: socio-economic status and membership in a
 296 productive organisation. Further, Land tenure is significantly associated with two practices: introduced
 297 pastures and removing of shrubs. Gender of the household head is positively associated with the introduced
 298 pastures, while household size is associated with manual shrub removals (albeit with a negative coefficient).
 299 Finally, off-farm employment is associated with manual shrub removal while literacy is positively associated
 300 with fencing.

301 *Table 2: Results of the multivariate probit model analysis*

VARIABLES	P	M	F
MUNI1	0.294 (0.242)	0.334 (0.240)	0.434* (0.246)
GENDER	0.348** (0.167)	0.234 (0.157)	0.291* (0.176)
DIST	0.00370 (0.00447)	0.00804* (0.00446)	0.000135 (0.00449)
AGE	-0.00619 (0.00491)	-0.00161 (0.00478)	0.00202 (0.00493)
YEAR	-0.00215 (0.00188)	-0.00224 (0.00183)	2.16e-05 (0.00191)
SIZE	-0.0521* (0.0307)	-0.0778*** (0.0301)	-0.00273 (0.0306)
LIT	-0.0256 (0.278)	-0.0604 (0.256)	0.703** (0.285)
SES	1.070*** (0.403)	1.069*** (0.384)	1.077*** (0.398)
CRED	0.0716 (0.250)	0.198 (0.236)	0.566** (0.268)
COW	1.249 (0.836)	1.176 (0.815)	1.785* (1.053)
OFF	0.0962 (0.160)	0.319** (0.157)	0.298* (0.163)

Understanding the adoption of sustainable silvopastoral practices

LANDT	0.379** (0.164)	0.336** (0.162)	0.247 (0.166)
CONFL	0.472* (0.265)	0.377 (0.258)	-0.208 (0.252)
SOC	0.398*** (0.144)	0.344** (0.141)	0.335** (0.148)
Constant	3.314 (3.709)	3.284 (3.606)	-2.172 (3.772)
Observations	353	353	353
Log likelihood : -530.54804			
Wald Chi2: 88.14			
Prob > chi2: 0.0000			

302
303
304

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

305 The models accounting for interactions among the independent variables are presented in Table 3. The
306 discussion follows in the next subsection.

Understanding the adoption of sustainable silvopastoral practices

Table 3: Results of the multivariate probit model analysis with inclusion of interaction effects

VARIABLES	Model 2			Model 3			Model 4		
	P	M	F	P	M	F	P	M	F
	Wald chi2(48) = 102.22 Prob > chi2 = 0.0001			Wald chi2(51) = 99.15 Prob > chi2 = 0.0000			Wald chi2(51) = 103.86 Prob > chi2 = 0.0000		
	Log likelihood = -528.6229			Log likelihood = -533.01814			Log likelihood = -527.81991		
MUNI1	0.304 (0.246)	0.334 (0.234)	0.469* (0.248)	0.400 (0.296)	0.273 (0.282)	0.496* (0.297)	0.272 (0.241)	0.301 (0.230)	0.442* (0.245)
DIST	0.00470 (0.00458)	0.00771* (0.00458)	0.00140 (0.00455)	0.00381 (0.00452)	0.00760* (0.00451)	0.000902 (0.00451)	0.00480 (0.00454)	0.00850* (0.00459)	0.00188 (0.00453)
SES	1.096*** (0.401)	1.274*** (0.404)	1.110*** (0.407)	1.048*** (0.397)	1.180*** (0.393)	1.051*** (0.399)	1.086*** (0.403)	1.213*** (0.404)	1.130*** (0.402)
LANDT	0.527*** (0.172)	0.494*** (0.167)	0.374** (0.174)	0.765 (0.649)	0.00381 (0.539)	0.269 (0.630)	0.614* (0.336)	0.338 (0.314)	0.409 (0.344)
CONFL	1.036*** (0.376)	0.919** (0.364)	0.301 (0.329)	1.191* (0.697)	1.010 (0.694)	0.304 (0.613)	-0.623 (0.645)	-0.762 (0.624)	-2.001** (0.814)
CRED	-0.449 (1.112)	-0.105 (1.110)	-0.00643 (1.168)	0.128 (0.249)	0.294 (0.244)	0.618** (0.269)	0.0590 (0.472)	-0.0693 (0.468)	1.312** (0.612)
COW	1.349* (0.820)	1.225 (0.889)	1.854* (1.052)	1.281 (0.820)	1.260 (0.868)	1.873* (1.050)	1.315 (0.820)	1.302 (0.885)	1.876* (1.047)
YEAR	-0.00206 (0.00190)	-0.00241 (0.00185)	0.000162 (0.00193)	-0.00195 (0.00190)	-0.00270 (0.00183)	8.76e-05 (0.00192)	-0.00218 (0.00190)	-0.00265 (0.00185)	0.000421 (0.00194)
AGE	-0.00564 (0.00494)	-0.00160 (0.00484)	0.00217 (0.00497)	-0.00563 (0.00489)	-0.00147 (0.00475)	0.00196 (0.00493)	-0.00544 (0.00498)	-0.00118 (0.00485)	0.00148 (0.00503)
GENDER	0.326* (0.170)	0.150 (0.157)	0.226 (0.179)	0.330** (0.167)	0.167 (0.153)	0.239 (0.175)	0.334 (0.222)	-0.000213 (0.197)	0.239 (0.227)
SOC	0.372** (0.154)	0.366** (0.149)	0.313** (0.155)	0.395*** (0.146)	0.361** (0.141)	0.327** (0.148)	0.405*** (0.146)	0.383*** (0.142)	0.336** (0.148)
OFF	0.159 (0.165)	0.368** (0.165)	0.358** (0.167)	0.106 (0.161)	0.291* (0.158)	0.288* (0.163)	0.112 (0.163)	0.314* (0.162)	0.295* (0.164)
LIT	0.0241 (0.296)	-0.133 (0.292)	0.637** (0.300)	0.0779 (0.280)	-0.0253 (0.270)	0.695** (0.286)	0.0791 (0.280)	0.0328 (0.273)	0.695** (0.285)
SIZE	-0.0540* (0.0313)	-0.0839*** (0.0308)	-0.00445 (0.0313)	-0.0531* (0.0308)	-0.0838*** (0.0302)	-0.00496 (0.0310)	-0.0575* (0.0312)	-0.0943*** (0.0307)	-0.00759 (0.0311)
CRED*SOC	0.388 (0.513)	-0.153 (0.572)	0.240 (0.555)						
CRED*LIT	0.331 (1.043)	0.562 (1.010)	0.526 (1.098)						
LANDT*CONF	-1.433** (0.564)	-1.458*** (0.553)	-1.401*** (0.542)						
MUNI*LANDT				-0.375 (0.669)	0.415 (0.558)	-0.00741 (0.650)			
MUNI*CONFL				-0.858 (0.751)	-0.812 (0.743)	-0.623 (0.667)			
GENDER*LANDT							-0.230 (0.370)	0.102 (0.348)	-0.146 (0.382)
GENDER*CRED							0.104 (0.551)	0.637 (0.561)	-0.812 (0.680)
GENDER*CONFL							1.327* (0.712)	1.405** (0.688)	2.065** (0.858)
Constant	2.978 (3.740)	3.712 (3.655)	-2.444 (3.817)	2.716 (3.746)	4.298 (3.619)	-2.298 (3.805)	3.215 (3.749)	4.200 (3.644)	-2.936 (3.837)
Observations	353	353	353	353	353	353	353	353	353

Standard errors in parentheses
 *** p<0.01, ** p<0.05, * p<0.1

310 4.2 Discussion of the most important factors leading to adoption

311 4.2.1 Distance to the nearest village and age of the household head are associated with adoption

312 Distance to the nearest village has a positive but not statistically significant impact on the adoption of
313 pastures (P) and fencing (F). On the other hand, the manual removal of shrubs (M) is positively associated
314 with distance to the nearest village, albeit only at a 10% significance level, but consistently in all four
315 models presented. This result is to some extent surprising, as it contradicts our first hypothesis. This would
316 therefore mean, that households that are further away from villages are more likely to adopt those
317 practices. We explored this relationship further in the data, and have not found any cluster that could
318 explain those results, although we noted that the distribution of the distance to the closest village is
319 skewed to the right for households that also adopted removal of shrubs. However, this effect is very small,
320 and only significant with a 10% p value threshold. A possible explanation would be that such practice being
321 labour rather than capital intensive, it is more likely to occur in relatively remote areas, where labour is
322 more easily available than capital. Although most available studies do indeed find a negative coefficient
323 associated with distance from nearest village or market (Kassie et al., 2013, 2012; Khataza et al., 2019;
324 Mariano et al., 2012; Wollni et al., 2010), some studies have found a positive relationship between distance
325 to villages or market, in particular for practices that are not based on recent technologies or when there
326 is a cheaper alternative to other available technologies (Arslan et al., 2014; Ndiritu et al., 2014; Teklewold
327 et al., 2013b). The age of the household head was not significantly correlated with adoption, indicating
328 that age is not so important for the adoption of practices in the case examined in our study. However, the
329 results are nonetheless interesting: although non-significant, the negative effect of the household head's
330 age on the adoption of each of the three practices suggests that age might indeed play a certain role in
331 the adoption of agricultural practices, as is often pointed out in the literature (see similar findings in Ndiritu
332 et al. 2014). The lack of significance might be due to other factors determining adoption, such as access to
333 key resources or social capital.

334 4.2.2 Socio-economic status, access to credit and subsidies, and social capital are positively 335 associated with adoption

336 Our socio-economic index is a good predictor of the adoption of multiple agricultural practices. All three
337 practices were positively associated with the index, indicating that wealthier households are more likely
338 to adopt all three practices than poorer households. The number of animals kept by the household is
339 significant as well for some practices, though only at a 10% threshold. This suggests that wealthier
340 households who are particularly dedicated to cattle production are more likely to adopt all of the practices
341 examined. This result echoes findings from similar studies that were conducted recently on adoption of
342 sustainable practices (Nkegbe and Shankar, 2014; Theriault et al., 2017). A higher socio-economic status
343 can be associated with more available financial resources to be invested in new practices, and it can also
344 be associated with having access to a bank account -a variable not measured in this study, but which is
345 often found to being associated with adoption of new practices. Further some of the assets that compose
346 our index could also be use as collaterals for credit. Access to credit or subsidies is associated with fencing.
347 Ring-fencing a grazing area can be very costly and requires investments that are substantial considering
348 the income of most producers in the region. Access to credit or other financial resources is often
349 mentioned as a factor determining practices adoption in the literature as well (Teklewold et al., 2013a).

350 Finally, social capital and affiliation with a producer organization is positively associated with all practices.
351 Indeed, this factor is consistently one of the best predictors of adoption of a given practice in our model.
352 This is in line with the literature, where the importance of networks (Banerjee et al., 2013) and local
353 organizations (Kassie et al., 2015; Zeweld et al., 2019) for technology adoption is often emphasized.
354 However, the models that include interaction effects (Table 3) do not show any significant interactions or
355 additive effects between affiliation with an organization and other factors.

356 4.2.3 Land tenure is (slightly) positively associated with adoption

357 According to our model, secured land tenure is positively associated with two of the three practices
358 examined, namely introduced pastures (P) and manual shrub removal (M). However, having secured land
359 tenure is not associated with fencing. This is surprising, as the link between land tenure security and
360 investment in new technologies is strongly supported by previous studies (Amsalu and de Graaff, 2007;
361 Kpadonou et al., 2017; Nkomoki et al., 2018).

362 Usually, the causality behind this association is described as follows: households who have secured land
363 titles or are involved in a process of land tenure regularization might be more inclined to invest in their
364 land because they hope to increase its value, while the risk associated with the investment is low.
365 Economic theory sometimes assumes that land tenure security would result in increased investments in
366 land (see e.g. Hayes *et al.* 1997, Brasselle *et al.* 2002); it is sometimes described as having the potential to
367 reduce resource degradation (Landportal, 2019; Perz et al., 2014). However, our interview data as well as
368 preliminary discussions indicate that the direction of causality might not be so clear. Several development
369 projects in our study area require potential beneficiaries to possess official land tenure titles, although
370 some exceptions exist¹. However, silvopastoral systems in the Chaco can defy conventional wisdom on
371 land tenure security in agriculture. These systems tend to be more extensive than traditional farmland,
372 and often portions of the forest are shared among different producers. Sharing land might reduce the
373 incentives to invest in management practices or land improvement; but it could also incentivize producers
374 to invest in such practice, for example if labour availability is enhanced, thus incentivizing the investment.
375 These considerations might explain why land tenure is not necessarily associated with a significant
376 coefficient for all practices.

¹ One notable exception is the “Bosque nativos y Comunidad” project, which aims to strengthen sustainable management and community structures of local populations in the Chaco in the Province of Salta. However, smallholder communities that access the programme must be located on public land (*tierras fiscales*).

377 4.2.4 However, for two of the three practices considered, land tenure does seem important in
378 explaining their adoption. Securing smallholders' land tenure could thus create important
379 incentives for them to invest in more sustainable production practices. These results are in
380 line with recent research, which also indicates that securing land rights for *criollos* and
381 indigenous people could have an important effect on biodiversity preservation in the Dry
382 Chaco (Marinaro et al. 2015; Grau et al. 2014; Marinaro et al. 2017). This further highlights
383 potential beneficial effects of land tenure security on slowing down deforestation and
384 habitat loss in this particularly threatened ecoregion (Robinson et al., 2014). We therefore
385 believe that our results could be relevant in other regions of the Argentinian Chaco.

386 Discussion of interaction effects

387 The inclusion of interaction effects in the model enhances the model's quality. (see Table 3). While
388 including these interaction effects slightly increases the models' log likelihood, only few of the interactions
389 effects tested are significant. Interestingly, the interaction term between land tenure and conflict has a
390 negative coefficient. This suggests that conflicts over access to land tend to cancel out some potential
391 benefits of secured land tenure. This, in turn, would mean that land tenure can only be an important
392 determinant of the adoption of new, more sustainable practices if other conditions are given – including
393 a conflict-free environment. The interaction between gender and conflict is significant as well, which
394 indicates that women might be more affected by conflicts than men. This result is interesting; in Model 4,
395 conflict alone is either non-significant or has a negative effect on adoption of F. This negative effect is then
396 partially mitigated by the head of the household being a male. Other interactions, including the interaction
397 tested for municipality and land tenure proved to be non-significant. At the same time, the slight increase
398 in the log likelihood suggest that including these elements might slightly increase the goodness of fits of
399 our models.

400

401 5 Conclusion

402 This study investigated the adoption of selected sustainable silvopastoral practices in the Dry Chaco in the
403 Province of Salta, Argentina. We used a very innovative approach, namely a MVP model, to assess the
404 factors determining adoption of these practices. Our results indicate that adoption is associated with
405 several factors, with social capital, measured through affiliation with a producer organization, being the
406 best predictor of the adoption of multiple practices. Financial resources such as access to credit, as well as
407 the number of animals owned by the households, are also significant predictors of adoption of the selected
408 practices. The effect of securing land tenure is also in general positively associated with the adoption of
409 sustainable silvopastoral practices, although this can be conditional on the existence of conflicts. Because
410 of similar land systems in neighbouring provinces in Argentina and through the Dry Chaco, our results can
411 probably generalize to these areas, although more research could confirm those. These results have major
412 significance for policymaking in the region. They suggest that, securing land tenure for smallholders in the
413 Argentinian Dry Chaco, should be accompanied by a broader process of conflict resolution in order to be
414 fully effective. Our analysis further indicates that collaboration with and support of producer organizations
415 and cooperatives might facilitate the spread of such sustainable management practices.

416

417 **6 Reference**

- 418 Aide, T.M., Clark, M.L., Grau, H.R., López-Carr, D., Levy, M.A., Redo, D., Bonilla-Moheno, M., Riner, G.,
 419 Andrade-Núñez, M.J., Muñiz, M., 2013. Deforestation and Reforestation of Latin America and the
 420 Caribbean (2001-2010). *Biotropica* 45, 262–271. <https://doi.org/10.1111/j.1744-7429.2012.00908.x>
- 421 Alaggia, F., Cabello, M.J., Carranza, C.A., Cavallero, L., Daniele, G., Erro, M., Ledesma, M., López, D.R.,
 422 Mussat, E., Navall, M., Peri, P.L., Rusch, V., Sabatini, Á., Saravia, J.J., Echevarría, J.U., Volante, J.,
 423 2019. Manual de Indicadores para Monitoreo de Planes Prediales MBGI, INTA. ed. Buenos Aires.
- 424 Amsalu, A., de Graaff, J., 2007. Determinants of adoption and continued use of stone terraces for soil
 425 and water conservation in an Ethiopian highland watershed. *Ecol. Econ.* 61, 294–302.
 426 <https://doi.org/10.1016/j.ecolecon.2006.01.014>
- 427 Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., Cattaneo, A., 2014. Adoption and intensity of adoption of
 428 conservation farming practices in Zambia. *Agric. Ecosyst. Environ.* 187, 72–86.
 429 <https://doi.org/10.1016/j.agee.2013.08.017>
- 430 Banerjee, A., Chandrasekhar, A.G., Duflo, E., Jackson, M.O., 2013. The Diffusion of Microfinance. *Science*
 431 (80-.). 341, 363–372. <https://doi.org/10.1126/science.1236498>
- 432 Barton, D.N., Benjamin, T., Cerdán, C.R., DeClerck, F., Madsen, A.L., Rusch, G.M., Salazar, Á.G., Sanchez,
 433 D., Villanueva, C., 2016. Assessing ecosystem services from multifunctional trees in pastures using
 434 Bayesian belief networks. *Ecosyst. Serv.* 18, 165–174. <https://doi.org/10.1016/j.ecoser.2016.03.002>
- 435 Basurto, X., Ostrom, E., 2009. Beyond the Tragedy of the Commons. *Econ. delle fonti di Energ. e*
 436 *dell'ambiente* LII, 35–60.
- 437 Baudron, F., Corbeels, M., Monicat, F., Giller, K.E., 2009. Cotton expansion and biodiversity loss in African
 438 savannahs, opportunities and challenges for conservation agriculture: A review paper based on two
 439 case studies. *Biodivers. Conserv.* 18, 2625–2644. <https://doi.org/10.1007/s10531-009-9663-x>
- 440 Baumgart-Getz, A., Prokopy, L.S., Floress, K., 2012. Why farmers adopt best management practice in the
 441 United States: A meta-analysis of the adoption literature. *J. Environ. Manage.* 96, 17–25.
 442 <https://doi.org/10.1016/J.JENVMAN.2011.10.006>
- 443 Bijttebier, J., Ruyschaert, G., Hijbeek, R., Werner, M., Pronk, A.A., Zavattaro, L., Bechini, L., Grignani, C.,
 444 ten Berge, H., Marchand, F., Wauters, E., 2018. Adoption of non-inversion tillage across Europe:
 445 Use of a behavioural approach in understanding decision making of farmers. *Land use policy* 78,
 446 460–471. <https://doi.org/10.1016/j.landusepol.2018.05.044>
- 447 Borrás, M., Manghi, E., Miñarro, F., Monaco, M., Navall, M., Peri, P., Periago, M.E., Preliasco, P., 2017.
 448 Acercando el manejo de bosques con ganadería integrada al monte chaqueño. Una herramienta
 449 para lograr una producción compatible con la conservación del bosque. Buenas prácticas para una
 450 ganadería sustentable. Kit de extensión para el Gran Chaco. Buenos Aires.
- 451 Brasselle, A.-S., Gaspart, F., Platteau, J.-P., 2002. Land tenure security and investment incentives:
 452 puzzling evidence from Burkina Faso. *J. Dev. Econ.* 67, 373–418. [https://doi.org/10.1016/S0304-](https://doi.org/10.1016/S0304-3878(01)00190-0)
 453 [3878\(01\)00190-0](https://doi.org/10.1016/S0304-3878(01)00190-0)

Understanding the adoption of sustainable silvopastoral practices

- 454 Camardelli, M.C., 2005. Estrategias reproductivas y sustentabilidad de sistemas ganaderos criollos del
455 Chaco salteño: el caso de los puesteros criollos del lote fiscal n°20 en el departamento Rivadavia.
456 *Rev. Interdiscip. Estud. Agrar.* 57–93.
- 457 Cappellari, L., Jenkins, S.P., 2003. Multivariate Probit Regression using Simulated Maximum Likelihood.
458 *Stata J.* 3, 278–294. <https://doi.org/10.1177/1536867x0300300305>
- 459 Carr, D.L., Lopez, A.C., Bilborrow, R.E., 2009. The population, agriculture, and environment nexus in
460 Latin America: country-level evidence from the latter half of the twentieth century. *Popul. Environ.*
461 30, 222–246. <https://doi.org/10.1007/s11111-009-0090-4>
- 462 Ceddia, M.G., Zepharovich, E., 2017. Jevons paradox and the loss of natural habitat in the Argentinean
463 Chaco: The impact of the indigenous communities' land titling and the Forest Law in the province of
464 Salta. *Land use policy* 69, 608–617. <https://doi.org/10.1016/J.LANDUSEPOL.2017.09.044>
- 465 Córdoba, G.S., Camardelli, M.C., 2017. Características socioeconómicas del sitio piloto de degradación de
466 tierras y desertificación (ONDTYD). *Breves Contrib. del I.E.G* 28, 61–90.
- 467 de Graaff, J., Amsalu, A., Bodnár, F., Kessler, A., Posthumus, H., Tenge, A., 2008. Factors influencing
468 adoption and continued use of long-term soil and water conservation measures in five developing
469 countries. *Appl. Geogr.* 28, 271–280. <https://doi.org/10.1016/j.apgeog.2008.05.001>
- 470 Doss, C.R., Morris, M.L., 2001. How does gender affect the adoption of agricultural innovations?: The
471 case of improved maize technology in Ghana. *Agric. Econ.* 25, 27–39.
472 [https://doi.org/10.1016/S0169-5150\(00\)00096-7](https://doi.org/10.1016/S0169-5150(00)00096-7)
- 473 Feder, G., 1982. Adoption of Interrelated Agricultural Innovations: Complementarity and the Impacts of
474 Risk, Scale, and Credit. *Am. J. Agric. Econ.* 64, 94–101. <https://doi.org/10.2307/1241177>
- 475 Fehlenberg, V., Baumann, M., Gasparri, N.I., Piquer-Rodríguez, M., Gavier-Pizarro, G., Kuemmerle, T.,
476 2017. The role of soybean production as an underlying driver of deforestation in the South
477 American Chaco. *Glob. Environ. Chang.* 45, 24–34.
478 <https://doi.org/10.1016/j.gloenvcha.2017.05.001>
- 479 Fernández Milmanda, B., Garay, C., 2019. Subnational variation in forest protection in the Argentine
480 Chaco. *World Dev.* 118, 79–90. <https://doi.org/10.1016/j.worlddev.2019.02.002>
- 481 Ferreira Gonzaga, J., Vilpoux, O.F., Gomes Pereira, M.W., 2019. Factors influencing technological
482 practices in the Brazilian agrarian reform. *Land use policy* 80, 150–162.
483 <https://doi.org/10.1016/j.landusepol.2018.10.005>
- 484 Filmer L. Pritchett, D., 1998. The Effect of Household Wealth on Educational Attainment Around the
485 World: Demographic and Health Survey Evidence.
- 486 Filmer, D., Pritchett, L.H., 2001. Estimating Wealth Effects Without Expenditure Data—or Tears: an
487 Application to Educational Enrolments in States of India. *Demography* 38, 115–132.
- 488 Garbach, K., Lubell, M., DeClerck, F.A.J., 2012. Payment for Ecosystem Services: The roles of positive
489 incentives and information sharing in stimulating adoption of silvopastoral conservation practices.
490 *Agric. Ecosyst. Environ.* 156, 27–36. <https://doi.org/10.1016/j.agee.2012.04.017>
- 491 Grau, H.R., Gasparri, N.I., Aide, T.M., 2008. Balancing food production and nature conservation in the

- 492 Neotropical dry forests of northern Argentina. *Glob. Chang. Biol.* 14, 985–997.
493 <https://doi.org/10.1111/j.1365-2486.2008.01554.x>
- 494 Grau, H.R., Torres, R., Gasparri, N.I., Blendinger, P.G., Marinero, S., Macchi, L., 2015. Natural grasslands in
495 the Chaco. A neglected ecosystem under threat by agriculture expansion and forest-oriented
496 conservation policies. *J. Arid Environ.* 123, 40–46. <https://doi.org/10.1016/j.JARIDENV.2014.12.006>
- 497 Hänsela, G., Ibrahim, M., Villanueva, C., Andrade, H.J., 2009. Exploiting synergies between
498 silvopastoral system components for carbon sequestration and an increase in cattle productivity :
499 experience from Costa Rica and Nicaragua. XIII World For. Congr. 11.
- 500 Hardin, G., 1968. The Tragedy of the Commons. *Science* (80-). 162, 1243–1248.
501 <https://doi.org/10.1126/science.162.3859.1243>
- 502 Harris, N.L., Brown, S., Hagen, S.C., Saatchi, S.S., Petrova, S., Salas, W., Hansen, M.C., Potapov, P. V,
503 Lotsch, A., 2012. Baseline map of carbon emissions from deforestation in tropical regions. *Science*
504 336, 1573–6. <https://doi.org/10.1126/science.1217962>
- 505 Hayes, J., Roth, M., Zepeda, L., 1997. Tenure Security, Investment and Productivity in Gambian
506 Agriculture: A Generalized Probit Analysis. *Am. J. Agric. Econ.* 79, 369–382.
507 <https://doi.org/10.2307/1244136>
- 508 Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., Mekuria, M., 2013. Adoption of interrelated
509 sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technol.*
510 *Forecast. Soc. Change* 80, 525–540. <https://doi.org/10.1016/j.techfore.2012.08.007>
- 511 Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., Mekuria, M., 2012. Interdependence of farmer
512 technology adoption decisions in smallholder systems: joint estimations of investments in
513 sustainable agricultural practices in rural Tanzania. *Foz do Iguaçu*, 254, 18–24.
514 <https://doi.org/10.5923/sgem2012/s1.169>
- 515 Kassie, M., Teklewold, H., Jaleta, M., Marenja, P., Erenstein, O., 2015. Understanding the adoption of a
516 portfolio of sustainable intensification practices in eastern and southern Africa. *Land use policy* 42,
517 400–411. <https://doi.org/10.1016/j.landusepol.2014.08.016>
- 518 Khataza, R.R.B., Hailu, A., Doole, G.J., Kragt, M.E., Alene, A.D., 2019. Examining the relationship between
519 farm size and productive efficiency: a Bayesian directional distance function approach. *Agric. Econ.*
520 (United Kingdom) 50, 237–246. <https://doi.org/10.1111/agec.12480>
- 521 Kleemann, L., Abdulai, A., Buss, M., 2014. Certification and access to export markets: Adoption and
522 return on investment of organic-certified pineapple farming in Ghana. *World Dev.* 64, 79–92.
523 <https://doi.org/10.1016/j.worlddev.2014.05.005>
- 524 Knowler, D., Bradshaw, B., 2007. Farmers' adoption of conservation agriculture: A review and synthesis
525 of recent research. *Food Policy* 32, 25–48. <https://doi.org/10.1016/j.foodpol.2006.01.003>
- 526 Kolenikov, S., Angeles, G., 2009. Socioeconomic Status Measurement With Discrete Proxy Variables: Is
527 Principal Component Analysis a Reliable Answer? *Rev. Income Wealth* 55, 128–165.
528 <https://doi.org/10.1111/j.1475-4991.2008.00309.x>
- 529 Kolenikov, S., Angeles, G., 2004. The Use of Discrete Data in PCA: Theory , Simulations , and Applications
530 to Socioeconomic Indices. Chapel Hill Carolina Popul. Center, Univ. North Carolina. 1–59.

Understanding the adoption of sustainable silvopastoral practices

- 531 Kpadonou, R.A.B., Owiyo, T., Barbier, B., Denton, F., Rutabingwa, F., Kiema, A., 2017. Advancing climate-
532 smart-agriculture in developing drylands: Joint analysis of the adoption of multiple on-farm soil and
533 water conservation technologies in West African Sahel. *Land use policy* 61, 196–207.
534 <https://doi.org/10.1016/j.landusepol.2016.10.050>
- 535 Landportal, 2019. 'Giving land tenure rights to commons can prevent degradation' | Land Portal |
536 Securing Land Rights Through Open Data [WWW Document]. Landportal news. URL
537 <https://landportal.org/news/2019/09/'giving-land-tenure-rights-commons-can-prevent->
538 [degradation'](https://landportal.org/news/2019/09/'giving-land-tenure-rights-commons-can-prevent-) (accessed 9.27.19).
- 539 Latawiec, A.E., Strassburg, B.B.N., Silva, D., Alves-pinto, H.N., Feltran-barbieri, R., Castro, A., Iribarrem, A.,
540 Cordeiro, M., Amin, K., Kalif, B., Gardner, T., Beduschi, F., 2017. Agriculture , Ecosystems and
541 Environment Improving land management in Brazil : A perspective from producers. "Agriculture,
542 *Ecosyst. Environ.* 240, 276–286. <https://doi.org/10.1016/j.agee.2017.01.043>
- 543 le Polain de Waroux, Y., Baumann, M., Gasparri, N.I., Gavier-Pizarro, G., Godar, J., Kuemmerle, T., Müller,
544 R., Vázquez, F., Volante, J.N., Meyfroidt, P., 2017. Rents, Actors, and the Expansion of Commodity
545 Frontiers in the Gran Chaco. *Ann. Am. Assoc. Geogr.* 108, 204–225.
546 <https://doi.org/10.1080/24694452.2017.1360761>
- 547 Mariano, M.J., Villano, R., Fleming, E., 2012. Factors influencing farmers' adoption of modern rice
548 technologies and good management practices in the Philippines. *Agric. Syst.* 110, 41–53.
549 <https://doi.org/10.1016/j.agsy.2012.03.010>
- 550 Marinaro, S., Grau, H.R., Gasparri, N.I., Kuemmerle, T., Baumann, M., 2017. Differences in production,
551 carbon stocks and biodiversity outcomes of land tenure regimes in the Argentine Dry Chaco.
552 *Environ. Res. Lett.* 12, 045003. <https://doi.org/10.1088/1748-9326/aa625c>
- 553 Marinaro, S., Grau, H.R., Macchi, L., Zelaya, P. V., 2015. Land tenure and biological communities in dry
554 Chaco forests of northern Argentina. *J. Arid Environ.* 123, 60–67.
555 <https://doi.org/10.1016/j.jaridenv.2014.06.005>
- 556 Marinaro, S., Grau, H.R., Macchi, L., Zelaya, P. V., 2014. Land tenure and biological communities in dry
557 Chaco forests of northern Land tenure and biological communities in dry Chaco forests of northern
558 Argentina. *J. Arid Environ.* 123, 60–67. <https://doi.org/10.1016/j.jaridenv.2014.06.005>
- 559 Mastrangelo, M.E., Sun, Z., Seghezzo, L., Müller, D., 2019. Survey-based modeling of land-use intensity in
560 agricultural frontiers of the Argentine dry Chaco. *Land use policy* 88, 104183.
561 <https://doi.org/10.1016/j.landusepol.2019.104183>
- 562 Ndiritu, S.W., Kassie, M., Shiferaw, B., 2014. Are there systematic gender differences in the adoption of
563 sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy* 49, 117–127.
564 <https://doi.org/10.1016/j.foodpol.2014.06.010>
- 565 Nieto, M.I., Barrantes, O., Privitello, L., Reiné, R., 2018. Effects of the management of extensive beef
566 grazing systems on the mitigation of greenhouse gas emissions in semi-arid rangelands of central.
567 *Sustainability* 10, 2–22. <https://doi.org/10.3390/su10114228>
- 568 Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Adgo, E., Nohmi, M., Tsubo, M., Aklog, D., Meshesha, D.T.,
569 Abele, S., 2017. Factors influencing small-scale farmers' adoption of sustainable land management
570 technologies in north-western Ethiopia. *Land use policy* 67, 57–64.

- 571 <https://doi.org/10.1016/j.landusepol.2017.05.024>
- 572 Nkegbe, P.K., Shankar, B., 2014. Adoption intensity of soil and water conservation practices by
573 smallholders: evidence from Northern Ghana. *Bio-based Appl. Econ.* 3, 159–174.
574 <https://doi.org/10.13128/bae-13246>
- 575 Nkegbe, P.K., Shankar, B., Ceddia, G., 2012. Smallholder adoption of soil and water conservation
576 techniques in Ghana. *J. Agric. Sci. Technol. B* 595–605. <https://doi.org/10.5897/AJAR2013.7952>
- 577 Nkomoki, W., Bavorová, M., Banout, J., 2018. Adoption of sustainable agricultural practices and food
578 security threats: Effects of land tenure in Zambia. *Land use policy* 78, 532–538.
579 <https://doi.org/10.1016/j.landusepol.2018.07.021>
- 580 Peri, P.L., Fermani, S., Mónaco, M., Rosales, V., Díaz, F., Collado, L., Torres, S.C., Ceballos, E., Soupet, J.,
581 Perdomo, M., Castelló, A.S., Antequera, S., 2018. Management of forests with integrated livestock
582 (MBGI) in Argentina, in: Rusch, V. (Ed.), *IV Congreso Nacional de Sistemas Silvopastoriles*. INTA
583 Ediciones, Neuquen, pp. 724–742.
- 584 Perz, S., Barnes, G., Shenkin, A., Rojas, D., Vaca, C., 2014. Private and communal lands? The ramifications
585 of ambiguous resource tenure and regional integration in Northern Bolivia. *Int. J. Commons* 8, 179–
586 206.
- 587 Piquer-Rodríguez, M., Butsic, V., Gärtner, P., Macchi, L., Baumann, M., Gavier Pizarro, G., Volante, J.N.,
588 Gasparri, I.N., Kuemmerle, T., 2018. Drivers of agricultural land-use change in the Argentine Pampas
589 and Chaco regions. *J. Appl. Geogr.* 91, 111–122. <https://doi.org/10.1016/j.apgeog.2018.01.004>
- 590 Robinson, B.E., Holland, M.B., Naughton-Treves, L., 2014. Does secure land tenure save forests? A meta-
591 analysis of the relationship between land tenure and tropical deforestation. *Glob. Environ. Chang.*
592 29, 281–293. <https://doi.org/10.1016/J.GLOENVCHA.2013.05.012>
- 593 Rogers, E.M., 2003. *Diffusion of innovations*, 5th ed. ed. Free Press, New York.
- 594 Shetto, R. ed., Owenya, M. ed., 2007. *Conservation agriculture as practised in Tanzania: three case
595 studies*. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche
596 Agronomique pour le Développement, Food and Agriculture Organization of the United Nations.,
597 Nairobi.
- 598 Shukla, P.R., Skea, J., Buendia, E.C., Masson-Delmotte, V., Pörtner, H.-O., Roberts, D.C., Zhai, P., Slade, R.,
599 Connors, S., Diemen, R. van, Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J.,
600 Portugal, J., Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., Malley, J., 2019. *Climate
601 Change and Land: an IPCC special report on climate change, desertification, land degradation,
602 sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*.
603 IPCC, Geneva.
- 604 Smith, A., Snapp, S., Chikowo, R., Thorne, P., Bekunda, M., Glover, J., 2017. Measuring sustainable
605 intensification in smallholder agroecosystems: A review. *Glob. Food Sec.* 12, 127–138.
606 <https://doi.org/10.1016/j.gfs.2016.11.002>
- 607 Teklewold, H., Kassie, M., Shiferaw, B., 2013a. Adoption of multiple sustainable agricultural practices in
608 rural Ethiopia. *J. Agric. Econ.* 64, 597–623. <https://doi.org/10.1111/1477-9552.12011>
- 609 Teklewold, H., Kassie, M., Shiferaw, B., Köhlin, G., 2013b. Cropping system diversification, conservation

Understanding the adoption of sustainable silvopastoral practices

- 610 tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and
611 demand for labor. *Ecol. Econ.* 93, 85–93. <https://doi.org/10.1016/j.ecolecon.2013.05.002>
- 612 Tenge, A., Graaff, J. De, Hella, J., 2004. Social and economic factors affecting the adoption of soil and
613 water conservation in West Usambara highlands, Tanzania. *L. Degrad.* 114, 177.
- 614 Therburg, A., Corso, M.L., Stamati, M., Bottero, C., Lizana, P., Pietragalla, V., 2019. Síntesis de Resultados
615 de la Evaluación de la Degradación de Tierras: 2012-2017. IADIZA, Mendoza.
- 616 Theriault, V., Smale, M., Haider, H., 2017. How Does Gender Affect Sustainable Intensification of Cereal
617 Production in the West African Sahel? Evidence from Burkina Faso. *World Dev.* 92, 177–191.
618 <https://doi.org/10.1016/j.worlddev.2016.12.003>
- 619 Volante, J.N., Mosciaro, M.J., Gavier-Pizarro, G.I., Paruelo, J.M., 2016. Agricultural expansion in the
620 Semiarid Chaco: Poorly selective contagious advance. *Land use policy* 55, 154–165.
621 <https://doi.org/10.1016/j.landusepol.2016.03.025>
- 622 Ward, P.S., Bell, A.R., Droppelmann, K., Benton, T.G., 2018. Early adoption of conservation agriculture
623 practices: Understanding partial compliance in programs with multiple adoption decisions. *Land use*
624 *policy* 70, 27–37. <https://doi.org/10.1016/j.landusepol.2017.10.001>
- 625 Wauters, E., Biolders, C., Poesen, J., Govers, G., Mathijs, E., 2010. Adoption of soil conservation practices
626 in Belgium: An examination of the theory of planned behaviour in the agri-environmental domain.
627 *Land use policy* 27, 86–94. <https://doi.org/10.1016/j.landusepol.2009.02.009>
- 628 Wollni, M., Lee, D.R., Thies, J.E., 2010. Conservation agriculture, organic marketing, and collective action
629 in the Honduran hillsides. *Agric. Econ.* 41, 373–384. [https://doi.org/10.1111/j.1574-](https://doi.org/10.1111/j.1574-0862.2010.00445.x)
630 [0862.2010.00445.x](https://doi.org/10.1111/j.1574-0862.2010.00445.x)
- 631 Wright, J., 2009. Sustainable agriculture and food security in an era of oil scarcity : lessons from Cuba.
632 Earthscan, London.
- 633 Zeweld, W., Van Huylenbroeck, G., Tesfay, G., Azadi, H., Speelman, S., 2019. Sustainable agricultural
634 practices, environmental risk mitigation and livelihood improvements: Empirical evidence from
635 Northern Ethiopia. *Land use policy* In Press. <https://doi.org/10.1016/j.landusepol.2019.01.002>
- 636
- 637

638 **Annex A: Variables included in the model and weights given by the Polychoric principle component**
 639 **analysis**

640 A socio-economic index was created by using a Polychoric Principal Component Analysis (PPCA) on a
 641 vector of socio-economic variables in our surveys, following a procedure first established by Filmer and
 642 Pritchett (Filmer and Pritchett, 1998). We used to conduct the Principle component analysis on a
 643 polychoric correlation matrix, in order to improve the model, as suggested by Kolenikov and Angeles
 644 (Kolenikov and Angeles, 2009). There were 10 variables considered for the index. The PPCA returns the
 645 weight given to each variable in our index, which correspond to the loadings of the first component.

Name of variable	Description	Type	Weight (loading PC1s)
HOUSE2	1 if household owns another house	binary	0.56 (0.50)
FLUSH	1 if household has toilets with a flush	binary	0.04 (0.19)
ENERGY	1 if household has electricity (or a generator)	binary	0.34 (0.48)
ROOF	1 if house has a roof made of solid material (clay tiles, wood, or metal)	binary	0.65 (0.48)
TV	1 if household has television	binary	0.09 (0.28)
FRIDGE	1 if household has a refrigerator	binary	0.36 (0.48)
WM	1 if household has a washing machine	binary	0.09 (0.29)
TRUCK	1 if household has a pickup truck	binary	0.18 (0.38)
MBIKE	1 if household has a motorcycle	binary	0.82 (0.39)
BIKE	1 if household has a bicycle	binary	0.44 (0.50)

646