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Analysis

From participation to commitment in silvopastoral programmes: Insights from Chiapas, Mexico

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ABSTRACT

Sustainable farming near tropical forests can buffer ecosystems at risk of biodiversity loss. In mountainous forest frontiers however, many smallholders raise cattle using practices that degrade land, also endangering future livelihoods. Silvopasture, a type of agroforestry, enables cattle farming, biodiversity conservation and can have climate benefits. But its adoption is slow, and ambiguity remains regarding the most relevant predictors for the adoption of agroforestry more broadly. In the context of a pilot silvopastoral project in La Sepultura Biosphere Reserve, we model livelihood diversity as a predictor of both farmers' participation in the project and their adoption of silvopasture (trees grown after a year). We use data collected with a novel token-based approach ($n = 104$) and account for selection bias. The findings show that livelihood diversity is significantly associated with the two outcomes, but with opposite directions: higher participation and lower adoption levels. Our results provide insight to design and target policies to encourage innovative and sustainable agriculture, especially in contexts of multiple interventions and policy mixes. For example, programmes including economic incentives may consider helping participants overcome different barriers at each stage of the adoption process: in the initial decision to try and during implementation.

1. Introduction

Biodiversity-rich, mountainous tropical forests are threatened by land degradation caused by diffuse, small-scale and poorly managed cattle farming in their frontiers. This livelihood activity can drive soil erosion, whereby deforested soils in steep areas degrade under strong rainfall and compact under grazing (Valdivieso-Pérez et al., 2012). Livestock roaming uncontrolled at the forest margins diminishes tree replacement and regeneration. Poor management can lead to degraded soils in the medium term, threatening livelihoods of families in rural and low-income contexts (Barbier and Hochard, 2018). However, preferences for cattle farming as a secure livelihood emerge strong among farmers across the tropics. This preference is due to the income provided and to being less susceptible than cash-crop agriculture to environmental and macroeconomic shocks.

Instead, sustainable farming practices can buffer ecosystems at the forest frontier. For example, combining farm or pastureland with trees in any of the several forms of agroforestry (see these forms, e.g. in Jose, 2019). Beyond ecological benefits (Jose, 2009), farmed trees can provide important contributions to people's life quality, such as food (e.g., fruits), shade to enhance other crops (agrisilviculture), and fodder for animals (silvopasture) in dry season too. The benefits of agroforestry systems are well documented (Broom, 2013; Cubbage et al., 2012), also in the context of climate-smart agriculture (Amadu et al., 2020).

Despite the multiple benefits of agroforestry and many projects to encourage its implementation in tropical regions, its adoption is slow (Zepeda Cancino et al., 2016). Numerous studies have explored what determines agroforestry adoption (e.g. Amare and Darr, 2020), how mixes of agroforestry types and other land covers can optimise smallholders' objectives, as well as how preferences differ from actual practices (e.g. Gosling et al., 2020). Empirical studies discuss, without much agreement, various key drivers that facilitate agroforestry practices, like external support (Powlen and Jones, 2019), or land tenure (Tschopp et al., 2020), among many other factors. Scholars have typically analysed adoption of agricultural innovation more generally as a function of microeconomic variables such as household income, wealth or

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education (see Amare and Darr, 2020). Qualitative and simulation studies, for example, provide valuable insight about the mechanisms and leverage points for adoption (e.g. Zabala et al., 2017; Gosling et al., 2020). Other studies focus on psychological variables, including individuals' attitudes or perceptions (e.g. Meijer et al., 2014; Segnon et al., 2015).

Overall, evidence about the main predictors of agroforestry adoption is largely inconclusive. This has practical implications because it precludes appropriate policy support to encourage it. This may be due partially to a methodological reason. Agroforestry adoption studies measure outcomes heterogeneously, i.e., what is adopted and at which stage of the adoption process is measured. Remarkably, it is common to operationalise the outcome as a binary measure of adoption versus non-adoption. This obviates the intuition that adoption of agricultural innovation more broadly is a sequential process in steps, including the initial decision to try the practice and later the extent to which it is continued (Darnhofer et al., 2005; Morris et al., 2000). Particularly, growing trees to reap their benefits usually takes longer than many other sustainable agricultural practices (such as new annual crops or changes in tillage). Trees need several years to grow in a process in which farmers or landowners must take care of them consistently.

Despite early and repeated recommendations that agroforestry adoption would best be modelled as a process involving various steps (Amare and Darr, 2020; Pattanayak et al., 2003), only few studies conceptualise it beyond a single event (with recent notable exceptions, e.g., Beyene et al., 2019; Jara-Rojas et al., 2020), arguably due to its empirical complexity (from data acquisition and monitoring to modelling). Our study contributes to clarify this ambiguity.

In this study we model the adoption of silvopastoral systems (SPS) using a two-step Heckman selection model of farmers' participation in an extension programme (initial agreement for trial), and of their adoption levels (tree-growing outcomes a year after participation). Our empirical study analyses a pilot project in the frontier area of a protected forest in Chiapas, Mexico. The project sought to encourage the growth of fodder trees in already-cleared land in the buffer area of La Sepultura Biosphere Reserve (REBISE, for its Spanish name) where cattle and other farming land uses are slowly degrading the landscape (García-Barrios et al., 2020a). Through current practices, when pasture is not available cattle is left to roam at the forest margins browsing wild plants (Dechnik-Vázquez et al., 2019). Uncontrolled, this can lead to further forest degradation. The project coached smallholders to grow trees in privately-owned plots, resulting in highly variable outcomes (Trujillo-Vázquez, 2009).

Our study asks why some farmers had better tree outcomes than others. We focus on the impact on participation and short-term adoption, of two key predictors rarely studied in the literature. *Livelihood diversity* is the number of productive activities that an individual carries out (growing maize, coffee, raising poultry, etc.). *Subsidy dependence* is the share of subsidies in annual household income.

The literature on agroforestry adoption pays scarce attention to the set of livelihood activities that an individual carries out already, as a factor influencing uptake of additional livelihood activities. We argue that livelihood strategies—their diversity and specialisation—are important and useful in both the trial and commitment to new activities. Livelihood activities can vary remarkably across individuals, they have a strong role in land-use decisions and can be easily observed for programme targeting. Small-farming communities that for external actors might appear homogeneous can indeed be a microcosm of inequality, polarisation, and strikingly heterogeneous livelihood strategies (Rivera-Núñez et al., 2020).

The findings contribute to understand motivations to adopt SPS in low-income rural areas surrounding tropical forests. This can inform further programmes to effectively encourage the uptake of sustainable land-use practices. In addition, indirectly, we explore the potential of policy instruments, including payments for ecosystem services (PES).

2. Conceptual background: drivers of agroforestry adoption

Silvopasture is a type of agroforestry in which trees are grown at low to medium density in pastureland, to provide fodder and/or shade, among others. It can meet forest conservation goals and sustainable livelihoods in social-ecological systems where small-scale cattle farming predominates (Cubbage et al., 2012). It has multiple ecological benefits, such as protecting soil from degradation and sequestering carbon (Holderieath et al., 2012), and provides extra nutrition for cattle also in dry season. Trees need protection from livestock during the first years of growth and until they can withstand browsing (around 2–15, depending on the species).

When farmers decide whether to adopt sustainable practices, they consider how to allocate their effort, capital and land in trade-off with various other livelihood activities to which they often give preference. Prioritising the short- over the long-term benefit often inhibits adoption and continuance of sustainable agricultural practices. No perceived benefits and opposing macroeconomic factors interfere with farmers' motivation to try and adopt new practices with high environmental gains in the long term, economic gains in the medium term, but economic costs in the short term. This pattern commonly hinders adoption of environmentally-sound farming practices.

2.1. Outcomes of adoption of agroforestry

Although there is abundant experimental research about the ecological benefits of silvopasture, there is a paucity of social sciences' investigation about its adoption (Jera and Ajayi, 2008; Pagiola et al., 2008, 2007), albeit it should be a research priority (Dagang and Nair, 2003). In terms of key predictors of agroforestry adoption, the literature mostly focuses on explicitly measurable characteristics of the farm, household and individuals, which are amenable to statistical analysis (Pattanayak et al., 2003). Studies report high variability and sometimes contradictory directions of the effect of some predictors (Amare and Darr, 2020; Zabala, 2015). Reasons for this variability include the diversity of agroforestry practices studied and of socio-ecological contexts.

The empirical literature of agroforestry adoption generally measures it as a dichotomous dependent variable of adoption or non-adoption. Regression studies that consider adoption as a sequential process are scarce, also in the broader field of adoption of sustainable agricultural practices. Also, a richer measure of rate of adoption or level of outcomes is recommended, either in the form of continuous numerical or of ordered categorical variables, but it is less common in empirical analyses (Amare and Darr, 2020; Mercer, 2004). Further, whether the adopted activity is continued over time or abandoned is crucial to understand its sustainability, but the empirical demands to analyse these dynamics mean the study of continuation and dis-adoption is rare (Amare and Darr, 2020).

This predominance of a 'static' conceptualisation of adoption can be a major cause for the lack of consensus about what predicts uptake of agroforestry systems (and of SPS particularly). Among other reasons, cross-sectional studies might have measured outcomes at different stages of the adoption process. In the few studies that accounted for stages in the analysis (e.g., Beyene et al., 2019), some predictors were found to have distinct effects in each stage, including those of trial and commitment.

It has also been theorised that explanatory variables may be different or have distinct effects depending on the stage of the process at which the outcome variable is measured (Morris et al., 2000). Under the assumption of adoption as a sequential process, this additional heterogeneity in dependent variables can explain why many of the predictors used in the empirical literature appear to have inconsistent effects.

2.2. Drivers: livelihood diversity

The degree of livelihood diversity (as opposed to specialisation in a single activity) is a key definitional concept of livelihoods in developing countries (Ellis, 2000a; in developed countries, the literature focuses instead on crop diversity and farm diversification). Livelihood diversity is predominantly quantified as the portfolio of income sources (Perz, 2005; Vedeld et al., 2007). The literature on sustainable livelihoods and diversification, substantiated by the work by Ellis (2000a, 2000b, 1998), pivots around the role of diversification to alleviate poverty and reduce vulnerability (e.g. Fabusoro et al., 2010; Perz, 2005). However, almost no attention is given to the potential role of livelihood diversity as a predictor of adoption of sustainable agricultural innovation.

A diverse livelihood arguably adds complexity to decisions and behaviour. Already practised livelihood activities can influence adoption of new ones for several reasons. They generate trade-offs in the allocation of labour and other inputs among the innovation and other productive activities, and in the administration of the time available to acquire knowledge and experience about land-use practices. These are typical economic considerations. But also undertaking several activities can be a sign of an individual's innovative attitude (i.e. the tendency to try new things; Zabala et al., 2017).

The latter argument situates livelihood diversity closer to psychological or intrinsic variables. Experimenting with new livelihood activities does not necessarily require significant assets or financial investment. As in the case of growing trees, if farmers have small land plots available, the investment required might be limited to adequate labour and care. The willingness to experiment is also not necessarily restricted to those with highest levels of wealth. The literature about drivers of livelihood diversification finds it across wealth strata (Perz, 2005; Vedeld et al., 2007; see further details in Appendix).

2.3. Drivers: subsidy dependence

The contextual setting of external payments and subsidies for different purposes can also affect the effectiveness of further incentives for conservation. This effect has been scarcely investigated. We define external payments and subsidies as those designed and implemented by organisations outside of a community. Programmes with differing goals may generate counteracting stimulus, adding further complexity to livelihood decisions.

External payments for off-farm development and unrelated to conservation may promote more forested land, because they allow households to cover their expenses without needing to work on their lands (Isaac-Márquez et al., 2005). They may induce a reduction in land-use intensity or eliminate it altogether (Araujo et al., 2019), allowing secondary vegetation succession to take place. External payments that reduce the need for farming activities, such as some PES, can also elevate the rural out-migration threshold (Sánchez-Hernández, 2010). However, payments that reduce the need of farm activities would induce only passive reforestation. In that process individuals do not actively grow trees, hence such payments are of secondary importance for agroforestry implementation.

Substantial external payments can favour deforestation in two ways. First, if they encourage farming expansion and intensification. Promoting improvements of on-farm technical efficiency, including via labour saving technologies, can lead to clearing land even beyond farmers' self-interest or capacity in the absence of the incentive, if forest governance is not robust (Garrett et al., 2018). Second, if external payments diminish the relative importance of conservation that is either incentivised by PES or driven by the need for land conservation for future livelihoods. Our focus is on the latter: a plurality of unrelated external income sources can reduce the intrinsic importance small-scale farmers give to sustainable farming. So they engage less with it. This leads us to hypothesise that easy access to external income (via multiple external payment schemes) is likely to diminish the adoption of sustainable land practices, because land and ecosystem quality are not considered such an essential asset for their livelihood.

2.4. Hypotheses

Based on the considerations above, the empirical analysis is guided by three complementary hypotheses.

H1. The process of adoption is composed of distinct decisions: to participate in the programme (i.e., trial) and to perform afterwards (i.e., commitment). If this is the case, the set of predictors and the magnitude and sign of their effect on each of these decisions may differ between the stages.

We test this empirically by modelling adoption as a sequential process (Morris et al., 2000), using a two-step Heckman selection approach. We selected independent variables based on the literature and further supported with an exploratory comparison of socio-economic variables between participants and non-participants in the project under study (see Methods).

The other two hypotheses refer to the potential influence of two variables on individuals' adoption of SPS practices, as discussed above: i) livelihood diversity (proxied by a livelihood diversity index), and ii) subsidy dependence (proxied by the share of subsidies in total household income; see Methods).

H2. Livelihood diversity is conducive to higher participation, because it can be an indicator of an agent's tendency towards experimentation (Zabala et al., 2017). Higher livelihood diversity can reflect an individual's positive attitude and values towards innovation, so they may be more prone to experiment with new practices. We pose that the role of diversity at a later stage (after deciding to participate) may be less clear: it can lead to lower adoption because of trade-offs with other activities (e.g., via competition for time and other resources), or to higher level of adoption if individuals are effective multitaskers (e.g., the activities they carry out in parallel are complementary).

H3. Subsidy dependence can negatively influence participation in programmes that create incentives to uptake new sustainable farming practices, but without providing direct payments as economic incentives. This third hypothesis is broadly based on the effect of crowding out intrinsic motivations for pro-social/environmental behaviour. This effect results from individuals getting used to receiving payments through external schemes (Rode et al., 2015). Households in the case study and other communities have received payments from several programmes in the past, often without conditionality and signing up the same assets (land) to receive funds from different programmes. Having received income in the past through relatively easy processes to sign up, individuals may shift their main interest and motivation to participate in new external projects: from experimenting with innovative practices to seeking the direct payments often offered (Heyman and Ariely, 2004). Further, reliance on external payments could also make individuals less intrinsically interested in conserving their local natural resources (as explained above) and/or encourage rent-seeking strategies.

3. Case study: La Sepultura Biosphere Reserve

The tropical regions in Latin America are a major locus of land-use change (Winkler et al., 2021). The state of Chiapas in Mexico has suffered some of the highest rates of deforestation and shows little evidence of a forest transition leading to forest recovery (García-Barrios et al., 2009). REBISE is a Biosphere Reserve in the Sierra Madre in the Pacific side of Chiapas, Mexico between 40 and 2550 m asl (see location in Fig. 1). It covers a wide range of ecosystems, including tropical montane cloud forest, which provides essential hydrological services and is considered the most threatened ecosystem in Mexico (CONABIO, 2010). In the buffer zone of the reserve, the lower areas and South oriented slopes are highly deforested. Human settlement surroundings are highly modified, and the landscape has been simplified or degraded due to farming, including cattle. Farmed land is at an increasing risk of soil erosion (Valdivieso-Pérez et al., 2012). Predominant livelihood

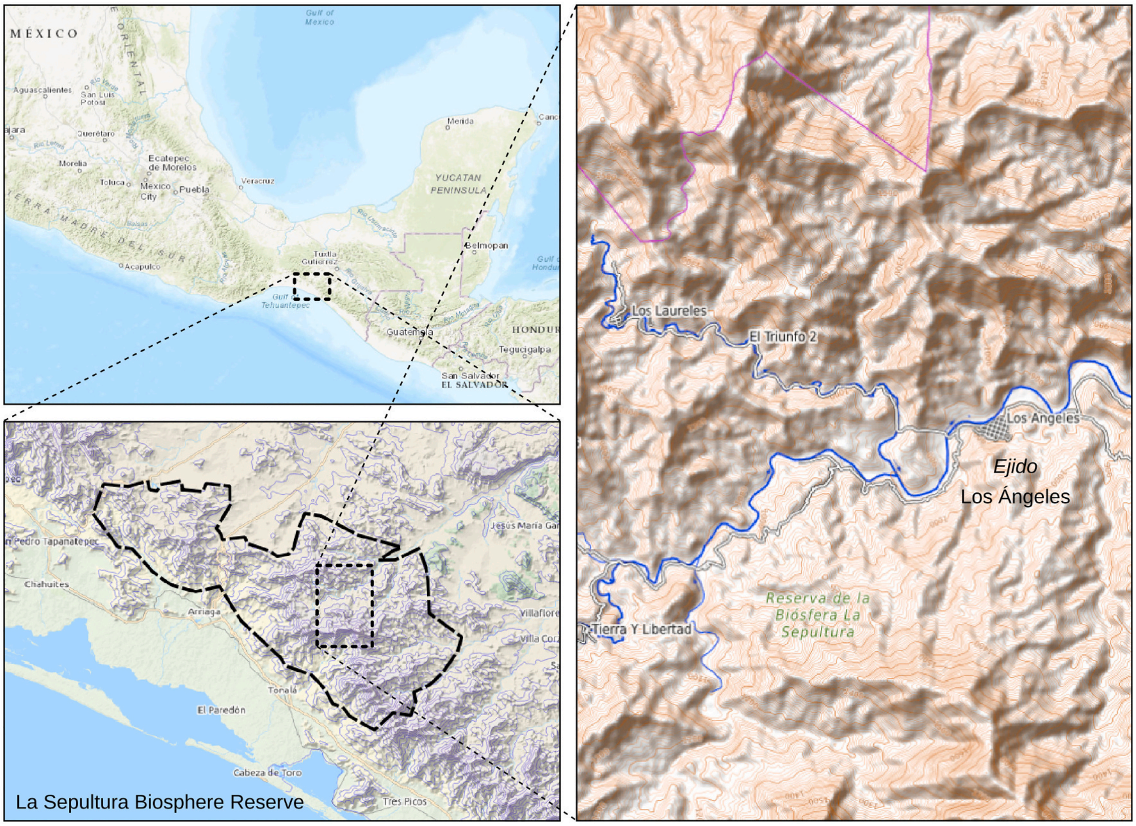

Fig. 1. Location of La Sepultura Biosphere Reserve and ejido of Los Ángeles. Data: OSM.

activities include growing maize and beans, cattle farming and shade coffee farming.

Among the various communities (*ejidos*) in the buffer area, Los Ángeles is representative with a population of 831 people (Trujillo-Vázquez, 2009) in approximately 200 households. The community has broadly reflected the agricultural history of Mexico of the last 40 years. Since the community settled down in the 1960s, the surrounding forest was progressively cleared to grow maize, and for cattle pasture afterwards (Sanfiorenzo-Barnhard et al., 2009). Maize specialisation drove most initial deforestation. Big fauna fled to what currently is the core of the protected area. The crisis of maize-based livelihoods (boosted by NAFTA in 1995) led farmers to diversify. With the protection of REBISE (also in 1995), farming expansion was restricted (Rivera-Núñez et al., 2020). Cattle farming became a preferred livelihood activity (García-Barrios et al., 2020a), hence intensifying the threat of landscape degradation (Aguilar-Martinez, 2007). Cattle is mostly limited by financial capital and land ownership and perceived as a less risky activity than cash-crop agriculture because the latter is highly dependent on rainfall and on the price of chemical inputs. Although international market prices heavily influence this preference (García-Barrios et al., 2009). Land property regime is a hybrid between the traditional *ejido* communal lands, and tacitly acknowledged private land ownership.

Households in Mexico have access to a diverse range of external payments for different purposes, including for sustainability. These payments influence livelihood strategies and therefore land use. In the case studied, many payment schemes exist such as for cattle and agricultural extension, carbon capture and hydrological ecosystem services (Aguilar-Martinez, 2007; Escobar-Avalos, 2007). Most projects are government-led nationwide programmes. Their conditionality and payment distribution form vary. It is suggested that, due to payments received and without associated guidance, people might be leaving aside traditional practices and conservation of local resources. Such context of external payments can affect the effectiveness of programmes for SPS by influencing household decisions to investment their human, natural and financial capital.

A research institute began a pilot programme in 2007 for farmers from the *ejido* of Los Ángeles to trial silvopasture (ECOSUR, details in Trujillo-Vázquez, 2009). The programme made an open call to the community, inviting farmers who were then supported to grow native fodder trees in small pasture plots of their own, with up to three farmers per plot (see illustration of silvopasture in Fig. 2 top). The programme provided incentives in the first year in the form of nursery and fencing material and training (Cruz-Morales et al., 2011; Trujillo-Vázquez, 2009). After a first group of 22 volunteers had planted saplings, in 2008 the local office of the National Commission of Protected Areas (CONANP) saw this as an appropriate model to incorporate in its strategy with cattle issues and provided budget for fencing material for further farmers who joined the group 2 months later. In 2009, a total of 68 farmers grouped in 44 plots participated. CONANP supported them with additional fencing material and payments in cash distributed at the farmer group's own criteria.

Farmers were required to plant the trees in order to receive incentives. But the reward received did not depend on whether the fodder-tree plot had established later, so there was no longer-term conditionality. The outcomes in terms of trees grown and care practices were measured. These were highly variable and not immediately explained by standard observable socio-economic variables such as wealth or land owned (Trujillo-Vázquez, 2009).

Livelihood strategies in the case study have two main classificatory dimensions (based on our descriptive analysis of data collected as explained in Methods). First is the gradient between livelihood diversity and specialisation (predominantly in cattle farming, agriculture, or off-farm activities). Second is a household's land and wealth. Land ownership increases access to subsidies, provides opportunities to escape poverty and mitigates vulnerability. The elite of the community can be described as individuals who are *ejidatarios* (rather than newer settlers),

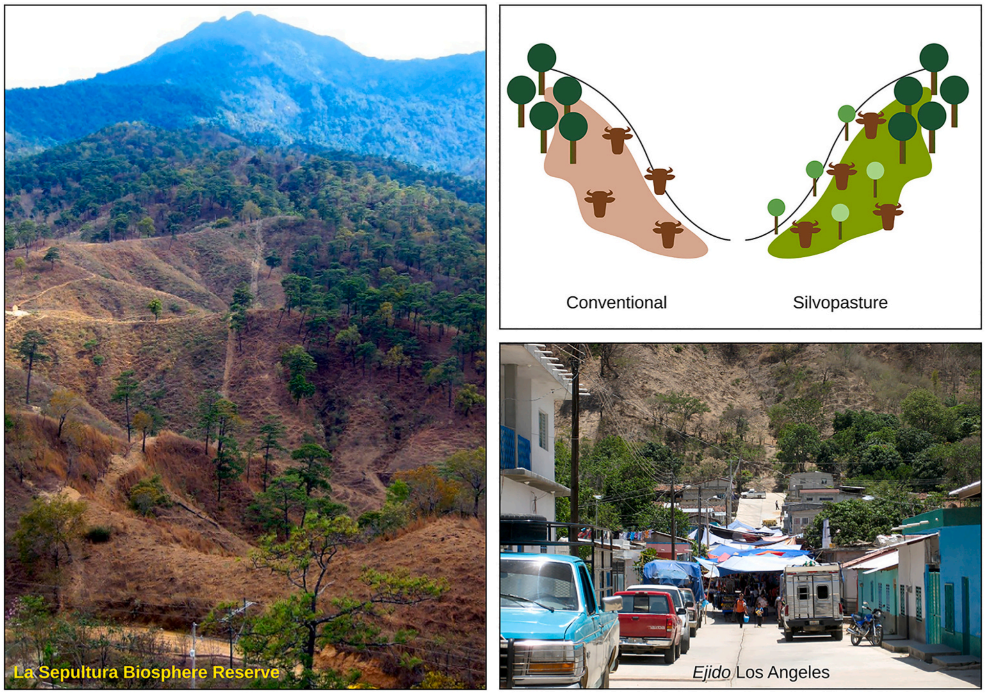

Fig. 2. Context of implementation of silvopastoral systems. Deforestation in steep slopes (left); comparison of conventional cattle farming and silvopastoral systems (top); and the ejido on market day, timed in coordination with the receipt of development subsidies (bottom).

have more land, more cattle, higher levels of income, and belong to the cattle-farming association. A fifth of a household's benefits on average are from subsidies, although this is highly variable and somewhat associated with land ownership. In the other extreme, the poorest individuals often specialise in the basic crops of maize and beans or work as paid labourers, and have higher proportion of expenditures on basic consumption. Their adoption of innovative or more prosperous activities is limited by physical and financial capital.

4. Methods

To understand farmers' decisions to participate and continue in the SPS adoption project, we model both outcomes using a Heckman selection model with primary and secondary data from both participants in the project and an equivalent sample of non-participants from the same community. The model specification and expected directions are explained below. All analyses are conducted in R (R Core Team, 2020; Toomet and Henningsen, 2008).

4.1. Data sources

We used secondary data of observed measures of plot-level outcomes of the SPS project (collected by Trujillo-Vázquez and García-Barrios in 2008) and we designed and administered a household survey to collect primary socio-economic and livelihoods data (See Table 1). The plot-level outcomes of the SPS project were measured only for programme participants, assuming that non-participants did not grow fodder trees. The programme monitored the following set of variables for each plot: i) farmers' actions to cultivate trees, including the number of saplings initially planted and caring activities to protect saplings against weeds, desiccation and cattle browsing, and ii) the number of trees 1 year after planting and their height and quality. These programme outcomes were monitored during and at the end of the first year after planting, thus within early phases of the adoption process.

The socio-economic questionnaire to collect demographic, economic and opinion data followed a standard approach. It included qualitative questions about livelihood strategies, including attitudes and constraints towards growing trees in their plots (see details about the data collected in the Appendix).

To collect data about livelihood strategies we used a novel game-like token approach, resembling the 'pebble' approach (e.g. Albizua et al., 2019). We elicited information about the proportion of inputs assigned to each livelihood activity and the returns obtained. Tokens represented land, effort, money for both consumption and investment, and benefits (50 tokens for each). Respondents distributed the tokens over a board with a diagram of the local households' economy, comprehending 36 activities (shown in Fig. S3 in Appendix) and referring to the previous 12 months.

This board was designed upon consultation with experts and key informants in the community. It was framed as a decision tree to understand household livelihood decisions and the proportional dedication to each livelihood activity. The illustrated board with tokens made the survey synoptic, clear and attractive for respondents. It elicited relative rather than absolute measures of assets, therefore feeling less compromising for respondents and arguably mitigating bias from reservations to disclose private information. Also, it is suggested that household models that consider consumption and production decisions jointly (i.e. distributing a single pool of money into both) are more accurate than models that assume separability, to explain decision-making dynamics in contexts of subsistence agriculture (Douglas, 2008). The board also made explicit the trade-offs and interactions of decisions about allocating limited inputs across activities.

We collected data from 104 heads of household. This sample accounts for about half of the community and includes most participants and a stratified random sample of non-participants. The sampling stratification was based on two sources: the community census of all heads of household and the list of members of the local cattle-farming association (see details in the Appendix). We collected data between April and June 2010. The sample was reduced during data validation due to survey incompleteness and the final model uses data from $n = 89$. The descriptive summary statistics of the main variables are shown in Table 2.

Table 1
Summary of primary and secondary data on livelihoods and adoption. * During data processing, all values of allocation of assets, effort, and benefits are standardised to a range of 0–1, making these values both fractional (bounded between 0 and 1) and compositional (sum up to 1).

Category	Variables
Adoption (Secondary data)	- Participation/non-participation (binary) In SPS project - Tree outcomes: numerical construct summing up total length of tree in a plot in single time. The variable was also transformed into ordered categories of tree outcome: *no participant*, *participant but no plants*, *few plants*, *many plants*. - Involvement in caring activities: categories of *planted/not-planted*, *fenced/-fenced*, *weeded/not-weeded*.
Demography (Primary data)	- Household size - Age and gender of respondent and of members of the household - Level of studies of household members - Position in the community of the head of the household (*ejidatario,* full rights; *poblador,* partial rights; *avecindado,* newcomer)
Economy (Primary data)	- Wealth proxies (characteristics of the house; categories) - Income level (ordered categories) - Land quantity (ordered categories) - Years of experience in cattle farming
Livelihood (Primary data; using board and tokens)*	- Allocation of hectares of land to each farming activity (L) - Allocation of effort to each livelihood activity (W) - Allocation of expenses into consumption and investment (I) - Share of benefits from each activity in the previous year (O, including subsidies) - Share of benefits from each activity (B)
Opinion questions (Primary data)	- Reported self-performance in the fodder-tree project - Limiting factor(s) for planting fodder trees - Level of difficulty found in planting the trees - Perceived benefit - Perceived time lapse until trees mature

4.2. Participation in the programme, adoption of silvopasture, and livelihood diversity

We constructed three variables from the data. Participation is defined as the formal involvement of individuals in the SPS adoption project. Silvopasture adoption and livelihood diversity are indices based on observed variables, and their computation is derived from a review of the literature on indicators of reforestation and on (livelihood) diversity respectively (see Appendix).

Adoption of SPS is defined here as the short-term success in growing fodder trees. Tree growth was monitored a year after planting, thus at an early stage of piloting the practice. This short-term success is reflective of activities such as planting and protecting saplings during the initial growth against weeds, desiccation and cattle browsing. We computed a standardised indicator summing up the total length of tree in a plot after 1 year, as a proxy for biomass. This is a continuous, observed variable that reduces caveats of stated and categorical or dichotomous dependent variables that are most common in the empirical literature on agroforestry adoption (see Appendix).

To select an appropriate livelihood diversity index, we comprehensively reviewed literature across disciplines about diversity indicators. Diversity can be measured in multiple ways, such as richness, Shannon, Simpson, Herfindahl and Gini. We selected an index of richness: the number of activities carried out, which excludes information about their proportions (included in Shannon and Simpson indicators). Our choice was based on theoretical considerations and for its simplicity (more details in Appendix).

4.3. Heckman model of participation and adoption

To explain participation and adoption we used a two-step Heckman selection model for two reasons: the dependent variable of interest (adoption) is only observed for those participating in the project, and we aim to explain adoption as a process with different steps, potentially with distinct main drivers on each. This model allows us to control for bias in the observed outcome due to an initial selection event (participation in the programme). It also enables empirical implementation of adoption theorised as a sequential process in two steps. Unlike other models (e.g. for censored or truncated data) a Heckman model allows the possibility that predictors affect differently at each step.

Following a theoretical model of behaviour as a process of subsequent decisions, the effect of predictors may vary at each stage (Morris et al., 2000): variables influencing decisions to participate may be different from (or have different effect to) those that influence posterior adoption. Consequently, the probability of participating can be assumed to be independent from the adoption function. In such case, the sample for which adoption is observed is biased; observed values of adoption are not randomly truncated, as would be the case if the data were truncated or censored (Greene, 2008). Because the sample selected is biased, the regression coefficients for the parameters influencing adoption may be biased in the direction of the factor that determines participation. A Heckman sample selection model can control for such bias (Giovanopoulou et al., 2011; Heckman, 1979). It is appropriate for cases in which the sample obtained is not random, but rather selected upon a previous event or decision (Greene, 2008). This event implies that the dependent variable of interest is observed only for a subset of the sample and that

Table 2
Descriptive statistics and comparison of participants and non-participants.

	Variable	*N*	Description		m/c	(*SD*)	Partic. m/c	Partic. (*SD*)	Non-part. m/c	Non-part. (*SD*)	s
○	*Participation*	97	Partake in SPS adoption project				56		41		
○	*Adoption*	56	Performance in growing fodder trees; standardised length of trees in plot				8.28	(12.3)	–		
*	*Subsidies income*	97	Benefits from all subsidies (share)		0.21	(0.16)	0.21	(0.14)	0.20	(0.18)	
*	*Diversity*	97	Diversity index for effort: number of activities divided by the total possible activities		0.52	(0.21)	0.59	(0.21)	0.44	(0.18)	***
■	*Land total*	97	Total land owned (Ha)		29	(31)	32	(33)	26	(29)	
■	*Cattle income*	94	Benefits from cattle farming (share)		0.23	(0.19)	0.26	(0.17)	0.20	(0.20)	‘
■	*Income*	92	Level of income (MXN/year)	*Low (< 5)*	36		26		10		*
				Moderate (5–15)	39		23		16		
				High (> 15)	17		5		12		
■	*Age*	97	Age of adult respondent (yrs)		44	(15)	46	(14)	42	(17)	
■	*Youth*	97	Number of youth in the household (< 16 yrs)		1.4	(1.2)	1.3	(1.1)	1.4	(1.4)	

All variables are continuous except for participation and income (categorical). ‘m/c’: Mean value (continuous variables) or count (categorical variables). ‘s’: Significance codes for bivariate tests for differences between participants and non-participants (two-sample Wilcoxon tests for continuous variables, Fisher's exact test for categorical variables): 0 *** 0.001 ** 0.01 * 0.05 ‘. Variables included in the econometric model: ‘○’ dependent. ‘ * ’ independent in the hypotheses, ‘■’ control.

this subset is likely biased—tree outcomes observed only for those who participated in the programme. The model assumes two steps or decisions in the process: whether to participate (Eq. (1)), and how much to adopt (Eq. (2)). Therefore, this analytical model is particularly appropriate for the conceptual model of adoption as a sequential process.

Sample selection equation (Probit model; participation)

$$z_i = w_i \gamma + u_i \tag{1}$$

Outcome equation (regression model; adoption)

$$y_i = x_i \beta + \varepsilon_i \tag{2}$$

Where γ and β are the sets of coefficients for the vectors of explanatory variables w_i and x_i respectively. In the selection equation, y_i is observed only if $z_i > 0$. The error terms in both equations, u_i and ε_i, are assumed to have a bivariate normal distribution with mean 0, and a correlation ρ. The model assumes that $\rho \neq 0$ due to the sample selection bias. If u_i and ε_i were independent, then the data missing in y_i would be missing randomly, and a least squares regression would provide unbiased (though inefficient) estimates (Heckman, 1979). Because $\rho \neq 0$, an OLS estimation of the second equation would produce inconsistent estimates of the coefficients and heteroscedastic disturbance (Greene, 2008). This means that the non-random sample (with observed outcomes in the second equation) biases the estimated coefficients in the direction of ρ (Greene, 2008).

This sample selection bias is corrected in the Heckman approach via the Inverse Mills Ratio (IMR), i.e., *"the probability that an observation is selected into the sample"* (Heckman, 1979, p.156). By doing this, the model uses information from the full sample for the estimation, rather than from the selected sample only. The selection model is described as an omitted variable problem, where the IMR is the instrument that approximates the omitted variable (Heckman, 1979; Toomet and Henningsen, 2008).

Most commonly, this estimation uses a two-step analytical approach (Greene, 2008). First, the dependent variable in the selection equation is modelled using probit or logit analysis for the complete sample (participation; Eq. (1)). Then the IMR is calculated and included as a predictor in the model of the outcome of interest (adoption; Eq. (2)), using only the selected sample for which y_i is observed (Heckman, 1979). If the IMR is statistically significant, then the selection model is a better estimation of the outcome than a standard multivariate regression of only the selected sample.

We specify the model based on data exploration (variables indicated in Table 2) and assessed several specifications to determine the robustness of the final model. To select the set of control variables and to assess the suitability of the Heckman model, we evaluated alternative specifications and models, and made a final decision using three pieces of information: the Akaike Information Criterion, theoretically relevant variables and the information we obtained from descriptive statistics of the dataset. We also ran several tests for robustness and sensitivity of the results, including a test for endogeneity of the livelihood diversity variable and alternative specifications (see Appendix).

4.4. Expected directions

According to our null hypotheses, the expected directions of the effect of the key independent variables are as follows. A higher subsidy dependence may lower the likelihood of participation in a programme like this that did not provide payments initially (H3). Individuals with higher subsidy dependence might be used to getting paid when participating in external programmes, following an externally motivated or rent-seeking strategy. This covariate for this type of outcome is not found in previous literature and so the expectation is based on the reasoning explained earlier.

Individuals associated with higher livelihood diversity are more likely to participate more in the SPS programme (H2) because they arguably may have a stronger tendency to experiment. This contrasts with Bosselmann (2012) and Mukadasi et al. (2007), who found a negative effect, although not significant, of livelihood diversification (which they operationalised as number of income sources).

The expectation about the share of cattle farming in total income is ambiguous. From the few studies that include some form of measure of it, most found its effect significant, either positive (Läpple and van Rensburg, 2011; Marenya and Barrett, 2007), or negative (Amsalu and Degraaff, 2007).

There is no clear consensus in the broader literature on adoption of sustainable agricultural innovation, regarding the effect of common control variables, including total land acreage, age, number of young family members, household size and wealth/income levels (Zabala, 2015). We expect land owned to have a positive effect on adoption, but unlikely to be significant: land or farm size has been used in most regression studies and land size tends to have a positive effect, though not significant in most studies. Few studies have found a negative effect, and from those which found this negative effect to be significant (Amsalu and Degraaff, 2007; Cranford and Mourato, 2011; Mercer and Pattanayak, 2003) either it was small, or the studies reported two models corresponding to two aspects of the adoption, for which the effect is ambivalent. The effect of age is expected to be positive. Age has been used as a control variable in most regression studies on adoption and found significant in several of them. From those studies finding a significant effect, most have found a positive association (e.g. Läpple and van Rensburg, 2011; Mercer and Pattanayak, 2003; Sanginga et al., 2006), and only few a negative one (Faße and Grote, 2013; McGinty et al., 2008; Mukadasi et al., 2007).

Evidence from the literature about the role of demographic variables on agroforestry adoption is largely inconclusive. Family size is found to have a negative effect in over half the studies that include it but very few studies find it significant (Zabala, 2015), both positive (Läpple and van Rensburg, 2011) and negative (Arslan, 2011) (though the adoption reported by the latter is not of an innovation). Other similar measures are also inconclusive, such as children-to-adult ratio (Bosselmann, 2012) or adults in the house (Bosselmann, 2012; Marenya and Barrett, 2007). Based on studies using methods other than regression, a larger household appears to encourage participation and success: more workforce can take care of the trees, and more children increase the role of the '*successor factor*' (Wilson, 1997), whereby the head of the household is encouraged to conserve the land for their descendants.

The effect of income on adoption is found to be significant in less than half of the studies reviewed that include it. But again, the direction of the effect differs. Studies find higher income or wealth to have a significant negative (e.g. McGinty et al., 2008) and positive effect (e.g. Faße and Grote, 2013). Hynes and Garvey (2009) found that income had a significant (positive) effect in the decision to participate, but not in the continuation in a programme. A preliminary bivariate correlation analysis of the data suggests a strong relation between participation and income, but not between adoption and income. Such a covariate that explains substantially the selection but not the outcome is an appropriate exclusion restriction, as required for the Heckman selection model to be well identified. Thus, in the model, the selection equation for participation includes income level.

5. Results: participation and adoption of silvopasture

The two steps of the model are shown on Table 3. The IMR value in the outcome equation is significant, suggesting that the estimates of the outcome equation would have been biased had we not controlled for selection bias. This and the robustness tests explained above provide support for the model presented here.

Income categories are significant for participation (selection equation) and lower income is related to higher likelihood of participation. The signs of coefficients for the explanatory variables in the participation and adoption equations are quite different. Livelihood diversity is significant in both equations, but with opposite direction. Land owned

Table 3
Participation and adoption in the fodder tree planting project.

	Probit selection: participation				Outcome equation: adoption			
	Estimate	*SE*	t-val.	Pr.	Estimate	*SE*	t-val.	Pr.
(Intercept)	−0.52	0.70	−0.75	0.46	23.73	11.90	2.00	0.05*
Subsidies	−0.49	1.11	−0.44	0.66	20.11	13.76	1.46	0.15
Diversity	2.14	0.83	2.60	0.01*	−27.96	11.00	−2.54	0.01*
Land	0.00	0.01	0.81	0.42	0.15	0.06	2.66	0.01**
Cattle farming	0.42	0.88	0.48	0.64	−10.97	10.84	−1.01	0.31
Income – medium	−0.64	0.36	−1.75	0.08				
Income – high	−1.56	0.48	−3.29	0.00**				
Age	0.01	0.01	0.49	0.63	−0.05	0.14	−0.37	0.72
Youth	−0.15	0.14	−1.07	0.29	3.50	1.65	2.12	0.04*
IMR					−12.42	6.19	−2.01	0.05*
N	89				51			
Log-likelihood (df = 9)	−48.51				−190.99			
AIC	115.03				399.97			
χ^2	24.44	**						
Correctly predicted %	75%							
Pseudo-R^2	0.32							
R^2					0.36			
Adjusted R^2					0.25			
F-statistic					3.48 [7, 43]	***		

Heckman two-step selection model results ($n = 38$ censored, 51 observed). Base level for income is 'low', the level with highest participation. ρ = −0.93. 'Pr.' t-statistic probability. Significance: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1.

and the number of youth are positive and significant only for adoption rates (outcome equation).

6. Discussion: livelihoods, participation and adoption

We hypothesised that adoption of silvopastoral practices is better explained through a multi-step process, that higher livelihood diversity leads to higher likelihood of participation, and that subsidy dependence influences the participation decision negatively. Our empirical analysis confirms the first two hypotheses to a large extent (on the sequential process and on livelihood diversity) and the other remains unclear (on subsidies).

The differences in the sign and coefficient of the explanatory variables in the two equations support the hypothesis that the two are separate and qualitatively distinct steps. Participation is decided in an initial, relatively straightforward decision, whereas involvement and actual performance occur in a second stage of the process. Importantly, the effect of livelihood diversity is significant in both participation and adoption, but with opposite effect. A higher level of livelihood diversity was associated with participation. But it was also related to lower adoption later. Once in the programme, individuals with more diverse livelihood perform worse. At this second stage, it is likely that the trade-offs with other livelihood activities emerge more vividly.

A plausible explanation is that signing up is easier than overcoming the later hurdles of adoption. People with diverse strategies are more eager to try new activities, driven by an innovative attitude that led them to diversify in the first instance. They already have a range of activities to which dedicate their effort, so once they join a new project, they might not have much time and effort left for the innovation, causing lower levels of adoption. The incentive structure of the programme was such that participants received rewards upon participation (in the form of saplings and material), but the posterior monitoring of the condition of planted trees did not alter the reward received. The lack of conditionality has been raised as a major shortcoming in PES schemes (Wunder et al., 2018), and a very small percentage of tree-growing initiatives in the tropics declare monitoring the establishment of trees (Martin et al., 2021).

Further discussion relates to demographic variables, for example, that more labour availability was expected to influence positively on participation and adoption. The model indicates that the number of young members in the household affects participation negatively, although not significantly, but affects adoption positively and significantly. While the evidence is inconclusive, this would be consistent with the expected impact of the successor factor (Wilson, 1997) that highlights the role of caring for the future of the younger generations. This is a longer-term motivation for parents and grandparents to conserve environmental assets, which can be relevant particularly for long-term investments, such as growing trees.

Aggregate benefits from subsidies had no effect according to the model and the null hypothesis cannot be rejected. One plausible explanation is that the model pools subsidies of very distinct nature, intended to either encourage productive activities, to alleviate poverty and development, or to conserve forest and hydrological services.

6.1. Policy and conceptual implications

The results shed light on how to design programmes with targeted incentives to encourage sustainable land-use practices. They highlight how participation in a programme does not guarantee adoption of the practice promoted. Individuals who are more likely to participate at the initial stage (whose livelihood is more diverse), may encounter more hindrances once they are in the programme. In contrast, among those who did not participate, the lack of land appeared to be a determinant hindrance.

A policy intervention that best fits with the specific barrier of the pro-environmental behaviour in question is suggested to be most effective (Steg and Vlek, 2009). For example, "low-engagement treatments are appropriate for low-effort behaviors" and vice-versa (Osbaldiston and Schott, 2012, p.280). Growing trees entails medium- to long-term commitment with moderate but consistent effort. So high-engagement interventions, such as goal setting (Osbaldiston and Schott, 2012) may be appropriate.

In communities with highly heterogeneous livelihoods, programmes to encourage silvopasture could anticipate important specific hindrances that participants will likely encounter at each stage, and include interventions to overcome them. We have found that individuals with more diverse livelihoods are more likely to participate. These could become pioneers who attract others to participate (Zabala et al., 2017), but they find harder to carry on and succeed. For some, it might be the lack of time and capacity. For others, the lack of genuine interest in the activity and of an immediate monetary incentive. If a programme cannot reduce these obstacles, then the emphasis might be to increase initial participation of individuals who are less likely to participate, but who would perform better if they entered the programme.

We do not interpret our results as implying that encouraging livelihood diversity is necessary to increase participation. Rather, the results suggest that heterogeneity among people (from less to more diverse in their livelihood strategies) entails also heterogeneity in what they need to participate. The results provide insight to identify specific interventions that can help each type of person, e.g., those who are more likely to participate and trial, and those who are more likely to commit over time.

Encouraging the two types of actors would require distinct instruments, also timed at different stages. For those who are more likely to participate but fail to adopt later, the programme should ease the most labour-intensive tasks or facilitate efficient team working. For those who did not participate in the first instance due to the lack of land, easing access to land can be effective, such as offering secure access to communal silvopastoral plots. This could motivate their participation, whereas a relatively small payment (as common in PES) would not help them purchase or rent land.

The findings also illustrate the importance of integrating policy instruments (including cash transfers depending on the case) in order to achieve both environmental and social goals (Rodríguez et al., 2011). A mix of instruments, such as informational strategies and cooperation (to reduce the effort needed), or reducing risk and uncertainty (e.g., over land use rights to encourage participation), can be effective and more appropriate in a context with heterogeneous needs and motivations.

Regarding the main conceptual implications of the study, the results provide two potential explanations to the high variability of findings in the empirical literature about what drives adoption of sustainable agricultural practices. Cumulative knowledge from empirical studies is largely inconclusive regarding the key drivers and the direction and magnitude of their effect—for example in the literature on PES. The first explanation for this variability is the heterogeneity of recipients' livelihoods. Responses to a blanket payment incentive may vary depending on an individual's other livelihood activities and/or land availability, among others, which are rarely captured in studies at sufficient granular level. Importantly, the second explanation regards how (when) adoption of a practice is measured; measuring it at different stages in the process reveals that drivers affect each stage distinctively. Arguably, across empirical studies there is limited consistency over the stage of the adoption process when the outcome is measured, and stages are rarely distinguished within the same quantitative analysis.

7. Conclusion

This study models what drives participation in a project to promote silvopasture, and its short-term adoption. It shows that the explanatory variables have a distinct effect in each of these two stages in the adoption process.

Our empirical contribution has four outstanding features. First, we demonstrate empirically the importance of livelihood diversity to understand adoption of sustainable land-use practices. Second, we analyse agroforestry adoption as a process where participation is the first of several decisions or sequential outcomes. Explicitly modelling different outcomes along the adoption process can help scholars clarify the highly variable results across agroforestry adoption studies. These two features (livelihood diversity as a predictor and agroforestry adoption in stages) are powerful to understand the issue but rarely seen in the empirical literature. Third, the adoption model accounts for selection bias in participation, by incorporating information about non-participants, and therefore obtaining more accurate estimates. The two model characteristics of considering agroforestry adoption in stages and accounting for selection bias (second and third outstanding features in this study), have long been recommended (Feder and Umali, 1993; Pattanayak et al., 2003), but rarely found in the agroforestry adoption literature (Amare and Darr, 2020). Finally, our observed continuous dependent variable of SPS adoption goes beyond a binary stated measure. Our contribution is complemented with an original and time-efficient approach to collect livelihoods data, based on board and tokens and inspired by natural resource management research employing role-playing games.

The two-step selection model reveals how different factors have contrasting effects on participation in the programme and SPS adoption. Separating stages in the analysis shows to what extent and in which ways these two key decisions are distinct. We suggest that heterogeneity in the empirical literature over how the outcome is measured, may be a major reason for inconsistent findings across studies regarding what drives agroforestry adoption. The potential consequences of this lack of consistency in empirical studies for building evidence should grant further attention among scholars.

A positive effect of livelihood diversity was expected for participation, but a negative one was not expected for short-term adoption. This is plausibly because participants with diverse livelihoods may be genuinely interested in trying a new activity, but once they take the easier decision (to participate) they may find that they actually do not have spare capacity to dedicate to it.

The results suggest the importance of previewing hurdles that individuals who are more likely to participate encounter once they have decided to experiment. Such knowledge can improve targeting incentives to increase both programme effectiveness and participants' self-efficacy and satisfaction, which may further promote continuance. Additionally, the results also suggest that those less likely to participate would be more successful once in the programme. Hence an intervention can instead focus on getting them to try in the first instance.

Current livelihood diversification is a result of pathway-dependent trajectories driven by local and global factors (García-Barrios et al., 2020b; Huber-Sannwald et al., 2012), such as changing international commodity markets, the introduction (and removal) of subsidies for farming expansion and changing local land-use regulations. These factors add uncertainty to livelihoods, which contribute to increase vulnerability of farmers with few resources and limited opportunities. This livelihood context is common elsewhere in Mexico and in other countries worldwide that combine high biodiversity and natural resources with low-income and vulnerable livelihoods. In such contexts, desirable characteristics of new livelihood activities are productivity, but also certainty. Diversifying livelihoods and increasing income from external programmes seem viable strategies to cope with vulnerability and uncertainty. These strategies heavily influence decisions about land-use practices.

These livelihood characteristics can also be objectively identified for targeting. Accordingly, programmes to impact on environment and development ought to heed the heterogeneity of livelihoods to identify challenges and opportunities for effectiveness.

We see several potentially fruitful research avenues to better understand how to encourage adoption of sustainable land-use practices. These derive from the new findings and the limitations of our study. Our results warrant further investigation of the impact of livelihood strategies (specialisation and diversity) on adoption of innovative practices, for example, using the same token/asset-allocation to collect data in other contexts. Analysing the impact of subsidies on adoption did not yield significant results, plausibly due to the distinct nature of the subsidies combined into our indicator. More research may be needed to understand the effect and interaction of a variety of contextual subsidies and test the hypothesis that the success of a payment scheme is conditioned by the set of other, non-environmental subsidies to which recipients have access. Another promising direction to understand the hurdles participants encounter beyond their initial decision to partake is to analyse, in longer programmes, what led disadopters to stop an activity. Further, by measuring adoption outcomes after a year, our study is a step forward beyond cross-sectional studies, as widely recommended in the literature for long-term sustainability efforts such as growing trees. Still, our timeframe does not reach the point when fodder trees start to give benefits, and so a longer-term ecological measurement, such as that made in few exceptional studies (e.g. Giudice Badari et al., 2020), would improve the evidence.

Major determinants to adopt new practices are the barriers found at each stage of the adoption process. Multiple factors motivate decisions for pro-environmental behaviour (Kollmuss and Agyeman, 2002), but motivated individuals need to overcome numerous hurdles. An individual may be moderately motivated, with favourable attitude, knowledge, or moral norms towards sustainable practices. But when attempting to overcome the attitude-behavioural gap, barriers are decisive. In such situations, incentives targeted to mitigate specific barriers are key. In turn, understanding the heterogeneity of recipients and of the obstacles they face, may be critical to envision whether the incentives will meet their target.

Declaration of interest

We have no conflicts of interest to declare.

CRediT authorship contribution statement

Aiora Zabala: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – original draft, Visualization, Funding acquisition. **Luis Enrique García Barrios:** Conceptualization, Methodology, Validation, Investigation, Writing – review & editing, Funding acquisition. **Unai Pascual:** Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2022.107544.

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