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Farmers' willingness to adopt silvopastoral systems: investigating cattle producers' compensation claims and attitudes using a contingent valuation approach

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Abstract Intensive cattle production systems are currently a major contributor to CO_2 emissions and biodiversity loss. Silvopastoral systems that combine foraging pastures and trees into an integrated system for raising livestock have been suggested a promising avenue to store carbon and preserve farmland biodiversity. However, investments and maintenance costs for these improvements are paid by producers, who reap few of the environmental benefits. The objective of the present study was to assess farmers' willingness to adopt silvopastoral systems by reforesting treeless pastures, their compensation claims related to adoption, and how both are affected by their attitudes towards silvopastoral systems. This study was based on a contingent valuation approach coupled with exploratory factor analysis to obtain measures of attitudinal constructs derived from the Theory of Planned Behavior. Results indicate that 52% of respondents were willing to adopt silvopastoral systems and the mean compensation claim per year per hectare is estimated at SEK 3107.17 (308€). Adoption decision is positively correlated with attitudes towards silvopastoral systems, suggesting that decision-making is not solely driven by profit maximization through concerns related to pecuniary factors.

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Introduction

The numerous environmental damages caused by livestock production, and notably, by intensive cattle production systems, are now well known (Steinfeld et al. 2006; Bilotta et al. 2007; Gill et al. 2010). In Sweden (the empirical focus area in this study), negative impacts of intensive cattle production on the environment are mainly characterized by carbon emissions and biodiversity loss. Today, around 13% of Sweden's total greenhouse gas (GHG) emissions emanate from livestock production, reflecting a release of more than 6.5 million tons of carbon dioxide each year (Swedish Board of Agriculture 2018). Simultaneously, the many plant and animal species linked to pastural landscapes which can traditionally be found in pastures and meadows have been crowded out in recent years, due to increasingly specialized and intensive livestock production systems (IPBES 2020). However, not all pasture systems contribute to the negative environmental impacts caused by livestock production. If managed sustainably, pastures have the potential to reduce such environmental degradations, and in some cases, even contribute positively to the mitigation of GHG emissions from livestock and to the preservation of farmland species and habitats (Raj et al. 2020, p.26). The agroforestry practice of silvopasture that combines foraging pastures and trees into a single integrated system for raising livestock has been suggested as a solution to both challenges, with prospects of remaining viable and competitive in the long term (Gold et al. 2000; Clason and Sharrow 2000; Raj et al. 2020, p.26; Bussoni et al. 2021; da Silveira Pontes et al. 2021). Silvopasture either describes systems where forage is deliberately introduced in timber productions, i.e., grazed woodlands, or systems where timber is deliberately introduced in forage productions (Klopfenstein et al. 1997). Consequently, by storing carbon in both soil and tree biomass, silvopastoral systems are estimated to have a carbon sequestration capacity that is five to ten times higher than treeless pastures (Lal et al. 2018) and are demonstrated to provide many resources and refuges to wildlife and native plant species (Alavalapati and Nair 2001; Jose et al. 2017). Additionally, farmers are considered better protected from income risks under silvopastoral systems, as those systems represent a strategy for income diversification and enhanced resilience (Kurtz et al. 2000; da Silveira Pontes et al. 2021), in particular by providing diversified sources of income on different time horizons (Hawken 2017). Furthermore, silvopastoral systems are appealing from an animal welfare perspective, as they provide shade and shelter (Broom et al. 2013; da Silva and Maia 2013).

Silvopastoral systems have received little attention in practical agriculture (den Herder et al., 2016) and lack visibility in both the Common Agricultural Policy (CAP) and in European member states' individual rural development programs (Mosquera-Losada et al. 2017). This lack of implementation is especially true in that silvopasture operates against farming norms and is not only slow to implement but also costly (Hawken 2017; Davis and Rausser 2020). While the environmental benefits of silvopasture are external to farmers, the investment and maintenance costs are often covered by the farmers (Shrestha and Alavalapati 2003), which can negatively affect their willingness to adopt silvopasture practices. Although a well-managed silvopasture can offset some of its costs in the long term, the benefits of silvopasture are unlikely to offer full and immediate compensation (Shrestha and Alavalapati 2003).

As the need for agroforestry systems in agriculture has grown more urgent in recent years, an increasing amount of literature has focused on farmers' perception of such systems, silvopasture included (e.g., Calle et al. 2009; Gregory et al. 2012; Jerneck and Olsson 2013; Meijer et al. 2015; Smith et al. 2022). These studies acknowledge the complexity of silvopasture implementation and try to assess what determinants influence adoption. However, this work has, so far, mostly focused on case studies in tropical climates. In Europe, literature about agroforestry systems, and silvopastoral systems in particular, has remained relatively scarce until García de Jalón et al. (2017) and Schaffer et al. (2019) demonstrated their usefulness within European agricultural systems. Both studies concluded that farmers might have poor interest in adopting silvopastoral systems unless monetary incentives are provided to overcome the high complexity of implementation and internalize the external benefits. Yet less than a handful of studies have tried to empirically assess such economic incentives (e.g., Davis and Rausser (2020) and Shrestha and Alavalapati (2003) for farmers in the USA; Buckley et al. (2012) for farmers in the UK). The results obtained in these papers, while confirming the choice of methods to investigate silvopasture adoption, are set in specific settings (e.g., in Texan ranches, the adoption of riparian buffer zones) and mainly misrepresent the process of pastoral reforestation. Furthermore, while behavioral characteristics have been primarily used in previous perception studies (e.g., Meijer et al. 2015), such psychological factors are equally relevant concerning farmers' willingness to adopt silvopastoral systems and their subsequent compensation claims, i.e., payments paid to the farmers to compensate the up-front costs of implementation, as supported by Buckley et al. (2012) and Davis and Rausser (2020).

The objectives of the present study are to assess farmers' willingness to adopt silvopastoral systems, their compensation claims related to adoption, and how both are affected by their attitudes towards silvopastoral systems. Particularly, we focus on the psychological constructs described by the Theory of Planned Behavior (TPB; Ajzen 1991). TPB is one of the most widely used approaches for understanding determinants of behavior (Hansson et al. 2019), thereby suggesting that pecuniary concerns may not be the only concerns of relevance in farmers' economic decision-making (e.g., Hansson et al. 2012; Läpple and Kelley 2013; Borges et al. 2014; Meijer et al. 2015; Senger et al. 2017). Finally, we discuss scaling-up possibilities of silvopasture implementation. This study uses an open-ended contingent valuation method (CVM; Ciriacy-Wantrup 1947; Davis 1963) to elicit the value of farmers for the implementation of silvopastoral systems. CVM is a well-known method for estimating non-use values, especially for the valuation of ecosystems and environmental services (Carson et al. 2001). The method includes a survey to gather data from Swedish cattle producers and is followed by the Heckman two-step estimation method (Heckman 1979) to quantitatively analyze cattle producers' willingness to adopt silvopasture, their related compensation claims, and the impacts from TPB's psychological constructs.

This study contributes to scientific literature on silvopasture adoption in Europe in three specific ways. First, silvopastoral systems are defined here as treeless pastures that are reforested in cattle production systems that are most found in Europe. Whereas silvopasture is often referred to as a general term defining the combination of trees and foraging pastures, this study specifically adds knowledge to the process of pastoral reforestation and its economic implications. Second, this paper contributes to existing literature by bringing the psychological constructs of TPB (Ajzen 1991) to the study of farmers' adoption of silvopastoral systems. In doing so we can highlight how behavioral drivers affect adoption and show that not only pecuniary drivers may be relevant to explain adoption. Third, the present paper illustrates primary estimates in related compensation claims to silvopasture adoption in Sweden. As such, results can be used for policy recommendations and scaling-up possibilities in Sweden but may also be relevant for similar European cattle production systems by acting as an initial reference point.

Conceptual framework

CVM is rooted in welfare economics and more particularly, in the neoclassical concept of economic value under the framework of individual utility maximization (Hoyos & Mariel 2010). The indirect utility function of a producer is defined as the following:

$$V(I(l), Q(l), X) \tag{1}$$

where l is the farmer's land uses,[1] $I(l)$ captures the farmer's income, i.e., net-revenues from any kind of market activities, including monetary benefits from land uses, $Q(l)$ represents non-market land use factors such as environmental factors and X is a vector that accounts for other demographic, social and property characteristics that affect decisions on agricultural practices.

The value of the adoption of silvopasture relates to the impact that it has on the farmer's welfare, measured in monetary terms. Amongst the Hicksian welfare measures of economic value holding utility constant, the compensating surplus (CS) measures losses relative to initial utility levels (Hicks 1943). Thus, CS is the change in income that will decrease the farmers' initial welfare position after adopting silvopasture. This way, the farmer's indirect utility function after adoption can be rephrased in terms of willingness to accept (*WTA*) silvopasture as the CS measure:

$$V0(I(l0), Q(l0), X) = V1(I(l1) + WTA, Q(l1), X) \tag{2}$$

where *WTA* is the minimum compensation required by farmers to change from conventional grazing to silvopastoral systems. Here, silvopasture hectares are assumed to be perfect substitutes in utility terms for conventional grazing hectares, such that the producer does not have any interest in having both types of pastures simultaneously. Thus, the adoption of silvopasture implies a change in land uses from its current pasture $l0$ to silvopasture $l1$. Accordingly, a switch from conventional grazing to silvopasture leads to changes in income, from $I(l0)$ to $I(l1)$ where $\Delta \mathrm{I} = I(l0) - I(l1) \geq 0$ is the income loss from adopting silvopasture, and changes in non-market factors, from $Q(l0)$ to $\mathrm{Q}(l1)$ that, although beneficial e.g., to the environment, are external to the farmer.

The farmer is now faced with two options: (1) non-adoption of silvopasture and continuing to manage pastures according to current practices, holding utility at $V0$; (2) adoption of silvopasture practices conditional to compensation. In the latter case, the

[1] For simplicity, the farmer, being a cattle producer, is assumed to only manage grasslands. Land uses, therefore, relate to the management and productivity of pastoral systems.

selection of silvopasture over conventional grazing implies a sufficient compensation level so that the utility of adopting silvopasture is equal to or greater than the initial utility function:

$$V1(I(l1) + WTA, Q(l1), X) \geq V0(I(l0), Q(l0), X) \quad (3)$$

The farmer's utility is heterogeneous and determined by various factors. Socio-demographic factors like age, gender, education, income, etc., as well as farm characteristics such as size, biodiversity, access to the nearest city, etc., have been found to be important determinants in previous contingent valuations (e.g., Shrestha and Alavalapati 2003; Buckley et al. 2012; Lindhjem & Mitanib 2012; Mäntymaa et al. 2018; David and Rausser 2020). Yet these factors alone may not have sufficiently strong explanatory power in analyzing decision-making for agroforestry innovations (Meijer 2015). Focusing solely on explaining how factors relating to property and socio-demographic characteristics that influence decisions would, therefore, ignore other factors, such as the social and psychological influences on farmers' decision-making.

Hence, to represent farmer's behavior towards silvopasture adoption, we utilize underlying psychological constructs from the well-known Theory of Planned Behavior (Ajzen 1991). TPB establishes that adoption behavior emanates from the farmer's intention to adopt, which is consecutively determined by three psychological constructs: attitude, subjective norm, and perceived behavioral control (Ajzen 1991). Capturing both the level of understanding and appreciation of a behavior, 'attitude' refers to an individual's positive or negative evaluation of the behavior; the 'subjective norm' is the individual's perception of the social pressure put upon him/her to perform the behavior; and finally, 'perceived behavioral control' relates to the individual's perception of his/her own ability to successfully perform the behavior (Ajzen 1991). As argued by Hansson et al. (2012), studies based on the TPB framework provide useful insights into farmers' behavior. Indeed, previous applications of TPB have demonstrated its effective use in agriculture, from studies related to organic farming (Läpple and Kelley 2013) to diversification (Hansson et al. 2012; Senger et al. 2017). The use of the TPB has also been proven to successfully contribute to understanding farmers' intentions as to whether to adopt modern sustainable practices (e.g., Buckley et al. 2012; Borges et al. 2014), as well as demonstrating the decisive role of the attitudinal construct in tree planting by smallholder farmers (Meijer et al. 2015). TPB has not, however, been used to explore farmers' willingness to adopt silvopastoral systems. In the following paper, the behavioral intention that emanates from the psychological constructs will therefore contribute to understanding adoption drivers. Accordingly, the attitudes, subjective norms, and perceived behavioral controls, refer to the possibility of, respectively, describing farmers' evaluations of silvopasture adoption, measuring the importance of perceived social pressure put upon farmers to adopt silvopasture, and identifying the farmers' perceptions of their ability to adopt and implement silvopasture.

Additionally, monetary characteristics of silvopasture like maintenance costs, alternative sources of income, etc., should be considered. Such factors remain significant in decision-making and contribute to a balanced representation of farmer's behavior surrounding adoption (Howley 2015). Finally, the farmer's utility depends on the compensation payment (*WTA*) received from adopting silvopasture. Therefore, by rearranging Eq. (3) depicting the decision whether to adopt silvopasture, we obtain the following equation:

$$WTA \geq V0(I(l0), Q(l0), X) - V1(I(l1), Q(l1), X) \quad (4)$$

illustrating the condition for the sufficient compensation payment level. Eq. (4) highlights that the factors that determine the adoption decision also determine the farmer's compensation payment. Although it is possible to use the same factors to explain both the decision to accept silvopasture and the compensation payment, it is more likely that some factors will have deeper impacts on either one of these (Mäntymaa et al. 2018). In fact, it is expected that the intention to adopt, i.e., the attitude, subjective norm, and perceived behavioral control, will have a stronger influence on the decision to adopt silvopasture than the level of compensation, as demonstrated by Borges et al. (2014), who found that the presence of various factors in each TPB construct facilitate adoption. Inversely, monetary factors (e.g., income, maintenance costs, etc.) will likely have a stronger influence on compensation payment, as suggested in Mäntymaa et al. (2018).

Materials and methods

Data

Data were collected through a survey which was designed in accordance with the open-ended contingent valuation method (Ciriacy-Wantrup 1947; Davis 1963). The survey consisted of four sections. The first section consisted of a brief introduction to the study, including a description of the questionnaire's objective and an explanation of silvopasture and the practice's potential benefits. The description was purposely short, since an extensive and detailed explanation of what silvopastoral systems entail and require from producers may have biased the results. The second section included questions related to farm and farmer characteristics. In the third section, respondents were asked to provide behavioral information concerning their intention of adopting silvopastoral systems. Finally, in addition to including questions related to monetary characteristics, the fourth section aimed to collect data on respondents' willingness to adopt silvopasture and the compensation payment the respondent would claim for converting their current pastures to silvopastoral systems.

Sample and procedure

The sample frame from which the sample was drawn was obtained from the agricultural register administered by Statistic Sweden and accessed from the LIFT[2]-project. The sample frame consisted of a list that included a total of 1500 livestock producers located within a geographical selection purposely made in the context of prior studies included in the LIFT-project. This geographical selection was made by randomly drawing 750 farmers in the North of Sweden and 750 farmers in the South. As a result, 14 out of the 21 counties of Sweden were included in the sample frame. Namely, the counties of Blekinge, Gävleborg, Halland, Jämtland, Norrbotten, Örebro, Skåne, Södermanland, Stockholm, Uppsala, Västerbotten, Västernorrland, Västmanland, and Västra Götaland. After removing all non-cattle producers from the list, our sample frame included a total of 1121 cattle producers. The sample then consisted of 663 cattle producers as all cattle producers within the sample frame were not reachable by email and could not be included in the survey. No selection was made concerning whether the producers only managed cattle or cattle mixed with other livestock productions and/or land uses, like crops. Furthermore, no selection was made regarding the producers' holdings, as silvopasture is considered feasible on all pasture sizes. Only grazing cattle is represented in the survey as the Swedish animal health and welfare legislation ensures that all cows are allowed outside during the grazing season. Accordingly, the holdings represented in the sample variated between 3 and 600 ha.

The survey was implemented through electronic questionnaires sent out via email. The use of online survey modes is convenient for data collection, and in contingent valuation studies as well. Previous literature has confirmed that this mode of data collection does not bias results compared with data collected from face-to-face interviews (Lindhjem and Navrud 2011). Furthermore, it has been estimated that as much as 98% of the Swedish population has access to internet in the household (Internetstiftelsen 2019). This confirms that the use of online survey modes is not likely to bias the sample due to poor internet access. The survey was implemented in March 2021 and active for 2 weeks. After two email reminders, the survey achieved a response rate of 17%. A total of 30 questionnaires contained significant numbers of missing values and were deleted from the final dataset. After eliminating unusable questionnaires, the survey achieved an overall adjusted response rate of 12%, resulting in a completed sample of 84 observations. This is somewhat low compared with other WTA surveys (e.g., Lindhjem & Mitanib 2012; Mäntymaa et al. 2018).

Elicitation method

An open-ended WTA question asking about the minimum compensation payment was chosen to elicit the respondents' compensation claims. The open-ended questions format consists of directly asking the respondents to state freely the minimum compensation value they would require for a hypothetical good or

[2] Low-Input Farming and Territories (LIFT) is a research project aiming to identify and understand how socio- economic and policy drivers affect the development of ecological approaches to farming and assess the performance and sustainability of such approaches. https://www.lift-h2020.eu

Table 1 Statements, scales, and descriptive statistics used to measure attitude (ATT), subjective norm (SN) and perceived behavioral control (PBC)

Statements		Scale (1–5)	Mean	Std. Dev
ATT1	For you, the adoption of silvopasture is:	Extremely bad – extremely good	2.93	0.833
ATT2	For you, the adoption of silvopasture is:	Not at all – extremely advantageous	2.76	0.97
ATT3	For you, the adoption of silvopasture is:	Not at all – extremely possible	3.06	1.004
ATT4	For you, the adoption of silvopasture is:	Not at all – extremely important	2.53	1.074
ATT5	For you, the adoption of silvopasture is:	Not at all – extremely necessary	2.23	0.992
SN1	Most people who are important to you think that you should adopt silvopasture	Strongly disagree – strongly agree	2.25	1.157
SN2	Most people whose opinion you value would approve that you adopt silvopasture	Strongly disagree – strongly agree	2.19	1.047
SN3	Most farmer like you will eventually adopt silvopasture	Strongly disagree – strongly agree	2.01	1.018
PBC1	If you want to adopt silvopasture, you have sufficient knowledge	Strongly disagree – strongly agree	2.28	1.179
PBC2	If you want to adopt silvopasture, you have sufficient resources	Strongly disagree – strongly agree	2.41	1.058
PBC3	How confident are you that you could overcome barriers that prevent you to adopt silvopasture?	Not at all – extremely confident	2.77	1.034
PBC4	The adoption of silvopasture depends only on you	Strongly disagree – strongly agree	3.79	1.269
PBC5	The decision to adopt silvopasture is totally under your control	Strongly disagree – strongly agree	3.57	1.327

service (Walker and Mondello 2007). The open-ended format was chosen over dichotomous choice or payment cards method to obtain better precision in compensation claims, especially given the small completed sample size. Accordingly, the open-ended elicitation format provides point estimates and does not restrict the respondents with defined intervals (Boyle et al. 1996). The open-ended method also minimizes the risk of vehicle biases like cognitive bias and strategic bias (Boyle et al. 1996). However, the main disadvantage of an open-ended format is often characterized by a significant amount of missing and zero responses due to the cognitively demanding task of responding with a specific amount (Bateman et al. 2002; Walker and Mondello 2007).

Additionally, to facilitate the respondents' elicitation task, they were asked to express an amount per hectare and per year. An annual payment, being the most common form of compensation in practice, was used over a one-time payment (Lindhjem & Mitanib 2012).

Scale development–theory of planned behavior constructs

TPB psychological constructs attitude, subjective norm, and perceived behavioral control can either be elicited from individual behavioral, normative and control beliefs, or by using statements to assess each construct (Läpple and Kelley 2013). The second approach was chosen and a total of 13 statements were developed and used as measurement indicators to measure attitudes (5), subjective norms (3) and perceived behavioral control (5) (See Table 1).

Statements were formulated based on the wording used in Borges et al. (2014) and Senger et al. (2017). A five-point Likert-like scale was used to assess respondents' level of agreement with the statements, with one being the most negative answer and five, the most positive. Five-point scales have been effectively used in other agricultural literature (Hansson et al. 2012; Senger et al. 2017).

Assessing type of measurement model

The use of measurement indicators implies a causal relationship between measures and the underlying latent psychological constructs (Götz et al. 2010). Depending on this causal link, the model can be considered either reflective or formative (Hansson and Lagerkvist 2014). Specifically, the reflective measurement model assumes causality proceeds from the latent constructs to indicators whereas the formative measurement model assumes the opposite; i.e., causality going from the indicators to the latent

Table 2 Significant factor loadings of theory of planned behavior statements

Statements		Factor 1 *Attitude*	Factor 2 *Subjective norm*	Factor 3 *Perceived behavioral control*
ATT1	For you, the adoption of silvopasture is good	**0.841**	0.229	−0.162
ATT2	For you, the adoption of silvopasture is advantageous	**0.863**	0.298	−0.006
ATT3	For you, the adoption of silvopasture is possible	**0.644**	0.34	−0.079
ATT4	For you, the adoption of silvopasture is important	**0.751**	0.527	−0.056
ATT5	For you, the adoption of silvopasture is necessary	**0.612**	0.581	−0.023
SN1	Most people who are important to you think that you should adopt silvopasture	0.384	**0.825**	−0.089
SN2	Most people whose opinion you value would approve that you adopt silvopasture	0.323	**0.877**	0.003
SN3	Most farmers like you will eventually adopt silvopasture	0.323	**0.704**	−0.05
PBC3	How confident are you that you could overcome barriers that prevent you to adopt silvopasture?	0.162	**0.552**	0.007
PBC4	The adoption of silvopasture depends only on you	−0.058	−0.061	**0.805**
PBC5	The decision to adopt silvopasture is totally under your control	−0.101	−0.01	**0.799**
	Range of item-to-total correlations	0.7964 – 0.9142	0.7249 – 0.9137	
	Range of item-to-item correlations	0.6829 – 0.8601	0.5239 – 0.8290	0.7255 (avg)
	Cronbach's alpha	0.9169	0.8633	0.8409

constructs (Rositter 2002; Podsakoff et al. 2003). Here, because latent constructs are causing measurement indicators, the model is considered reflective.

Exploratory factor analysis

Following the reflective measurement model, exploratory factor analysis was used to reduce TPB statements to underlying constructs. The results of the significant factor loadings can be found in Table 2. As in Hansson et al. (2012), three factors were kept, considering that TPB suggests three latent constructs, respectively: attitude, subjective norms and perceived behavioral control. Given the number of respondents, the criteria for determining significant factor loadings was set so that pattern coefficients ≥ 0.5 were considered statistically significant.

Statements that did not load significantly on any factor were removed from the analysis, one at a time, until significant pattern coefficients remained, as in Hansson et al. (2012). Consequently, two statements, i.e., PBC1 and PBC2, did not load significantly on any factor and were therefore excluded from the final analysis. PBC3, which covered respondents' confidence in overcoming barriers preventing silvopastoral system adoption, did not load significantly on the factor relating to perceived behavioral control, but rather factor 2, "subjective norm". Hypothetical explanations may be that barriers to adoption can be associated with producers' social networks or that their social network can help them in overcoming such barriers.

Bartlett's test of sphericity (Bartlett 1954) indicated that the correlation matrix was not random, with a Chi-square of 693.623, $p < 0.001$, and a KMO statistic of 0.8092, therefore determining that the correlation matrix was appropriate for factor analysis. Orthogonal Varimax rotation, being the most common rotational method used in factor analysis, was used to provide uncorrelated factors and easier interpretation of results (Williams et al., 2010). Item-to-total correlations, as well as item-to-item correlations, were all well above the cut-off values of 0.5 and 0.3 respectively, and all Cronbach's alpha (Cronbach 1951) values were above the cut-off value of 0.7 (Hair et al. 2010). Taken together, these indicators suggest that the measurement scales are reliable.

Table 3 Variables included in the model, definitions, and descriptive statistics

Variables	Definitions	Mean	Std. Dev
Dependent variables			
Adoption model			
Adoption	Dummy variable: intention to adopt silvopasture: 1 if yes; 0 if no	0.524	
Compensation model			
Claims	Compensation claims for the adoption of silvopasture (SEK/ha/year)	3107.17	2620.395
Independent variables			
Socio-demographic characteristics			
Gender	Dummy variable: gender of the producer: 1 if female; 0 if male	0.23	
Education	Ordinal variable: education level of the producer: 1 if primary school; 2 if high school; 3 if agricultural high school; 4 if university, 5 if agricultural university	3.02	1.219
Production	Dummy variable: type of cattle production; 1 if dairy; 0 if meat	0.32	
Income	Ordinal variable: income before tax of the producer	4.09	1.733
Farm characteristics			
Size	Total size of the pastures (ha)	51.77	98.748
Organic	Ordinal variable: organic production: 1 if yes; 2 if no, 3 if under transition	1.68	0.519
Vegetation zone	Categorical variable: Farm localization within Sweden's three principal vegetation zones: 1 if Boreal; 2 if Boreonemoral; 3 if Nemoral	1.51	0.722
TPB constructs			
Attitude	Solution factor of the attitude statements	−3.06	0.938
Subjective norm	Solution factor of the subjective norm statements	2.43	0.947
Perceived behavioral control	Solution factor of the perceived behavioral control statements	3.12	0.87
Monetary characteristics			
Maintenance costs	Categorical variable: expected increase of maintenance costs of silvopasture: 1 if strongly agree; 2 if agree; 3 if neutral; 4 if disagree; 5 if strongly disagree	2.32	0.925

Econometric approach

Based on the conceptual framework outlined above, the Heckman two-step estimation method (Heckman 1979) was used to quantitatively analyze cattle producers' willingness to adopt silvopasture and their respective compensation claims. The fact that only the respondents who were willing to adopt silvopasture revealed their compensation claims in the survey can lead to selection bias arising, as only the outcomes of treated observations are observable (Greene 2008). Therefore, to control for selection bias, the Heckman two-step estimation method (Heckman 1979) calls for the estimation of a correction term; i.e., the inverse Mills ratio, and later uses it as an additional explanatory variable (Heckman 1979). Accordingly, in the first step of the Heckman two-step estimation method (Heckman 1979), also called the selection model, the decision to adopt silvopastoral systems was analyzed with a probit model on independent variables. In the second step, named the "outcome model", the compensation claim was regressed using ordinary least squares (OLS) on independent variables and the inverse Mills ratio (Wolfolds and Siegel 2018). In the following, the selection model and outcome model will respectively be named the "adoption model" and the "compensation model". The Heckman two-step estimation method (Heckman 1979) has been previously proven successful in contingent valuations, especially in the context of voluntary forest landscape conservation (Mäntymaa et al. 2018).

Variables

The variables used in the two-step model, as well as their definitions and descriptive statistics regarding the two models are reported in Table 3. The dependent variable of the adoption model (*Adoption*) describes the cattle producer's intentions of adopting silvopasture. The dependent variable of the compensation model (*Claims*) is a continuous variable corresponding to the logarithm of the compensation levels claimed by producers for silvopasture adoption.The first set of explanatory variables described socio-demographic characteristics which may play a role in both the dependent determination of a farmer's adoption and compensation claims. Most variables included here such as *Gender*, *Education*, and *Income* are commonly used in standard contingent valuation studies (e.g., Lindhjem and Mitanib 2012). Additional dummy variables that specify whether the producer is specialized in dairy or meat products (*Production*) is included. The second set of variables are farm characteristics related to the logarithm of the total pasture area (*Size*), the farm's organic certification (*Organic*), and the farm's localization within Sweden's three main vegetation zones (*Vegetation zone*). The third set of variables represents the intention to adopt silvopastoral systems, captured by the psychological constructs of TPB, and consists of 13 statements, all summarized by the factor solution into three factors, each reflecting one underlying construct, i.e., *Attitude*, *Subjective norm*, and *Perceived behavioral control*. Finally, one monetary variable is added to depict the respondents' beliefs that silvopastoral systems will lead to economic loss due to high maintenance costs *(Maintenance costs*).

An important condition for the use of the Heckman two-step estimation method (Heckman 1979) is that variables of both models are only partially explained with the same independent variables. Previous literature suggests that the selection model must contain at least one variable unrelated to the dependent variable in the outcome model (e.g., Lalonde 1986; Greene 2008). If this condition was not respected, dependency between the sample of the two models and the dependent variables could cause problems of multicollinearity. Moreover, the addition of the correction term to the outcome equation may have led to estimation difficulties and unreliable coefficients (Briggs 2004). Accordingly, the compensation model is a reduced form of the adoption model where requested compensation is assumed to be a function of *Size, Maintenance costs, Production, Education and Income.* The adoption model is a function of *Organic, Vegetation zone, Attitude, Subjective norm, Perceived behavioral control,* and implicitly, compensation claims via the inclusion of their independent variables.

Results

Willingness to accept, compensation claims and respondents' demographics.

The survey achieved an adjusted response rate of 12%, corresponding to a completed sample size of 84 observations. Out of those, 52% of respondents were willing to adopt silvopastoral systems, conditional to some compensation claims. However, not all respondents provided their related compensation in the surveys. A total of 32% of claims accounted for missing responses, i.e., when respondents do not answer due to a lack of knowledge or the cognitively demanding task of the open-ended elicitation format (Bateman et al. 2002; Yu and Abler 2010). For instance, some respondents may know that they have a positive compensation claim but due to limited information about their own preferences, cannot give a specific amount (Yu and Abler 2010). Such missing responses, viewed as incomplete observations, are often dropped in the literature, and were accordingly removed from the analysis. Besides missing responses, only one zero answer was given by the respondents. A zero answer can either represent a protest zero, i.e., when a respondent does not accept some aspect of the hypothetical scenario described in the survey (Ready et al., 1996) or a valid zero, i.e., when a respondent is willing to accept the hypothetical scenario without compensation. As in Yu and Abler (2010), in which the authors showed that people with lower incomes are more likely to bid zero, the respondent asking for no compensation indicated earning less than SEK 100,000 (9,308€) annually from their agricultural activities. Given that all other responses were non-zero claims, this zero answer was categorized as a valid zero answer. Overall, 30 compensation claims were useable for the analysis, corresponding to 68% of total claims. This result is similar to Lindhjem and Mitanib (2012), in which the authors obtained 65% of non-protest and non-missing WTA values. Accordingly, the mean compensation payment claimed by respondents to adopt silvopastoral systems

Table 4 Descriptive statistics of compensation claims

	Sample	Mean	Median	Std. dev	Min	Max
Compensation claims	30	3,107.167	2,250.00	2620.395	0	15,000.00

Table 5 Regression results

	Compensation model					Adoption model
	Coef	*p*-value	95% CI	Coef	*p*-value	95% CI
Size	0.039	-0.695	(–0.155, 0.232)	–0.040	-0.815	(-0.380, 0.299)
Maintenance costs	-0.035	-0.739	(–0.244, 0.173)	–0.649	(0.010)*	(-1.141, -0.158)
Production	-0.246	-0.214	(–0.633, 0.141)	0.366	-0.439	(-0.562, 1.295)
Education	0.243	(0.003)**	(–0.081, 0.406)	0.439	(0.016)*	(0.082, 0.797)
Income				0.284	(0.027)*	(-0.032, -0.537)
Gender				–1.293	(0.041)*	(-2.535, -0.052)
Organic				0.708	-0.111	(-0.164, 1.579)
Vegetation zone				0.159	-0.606	(-0.443, 0.760)
Attitude				1.165	(0.000)***	(0.597, 1.733)
Subjective norms				0.257	-0.252	(-0.183, 0.698)
Perceived behavioral control				–0.296	-0.263	(-0.816, 0.223)
Constant	6.99	(0.000)***	(6.026, 7.953)	–2.884	-0.067	(-5.975, 0.207)
Mills (λ)	0.023	-0.92	(–0.417, 0.462)			
Rho	0.0516					
sigma	0.439					
Wald $\chi 2$ (5) = 13.91, $p = 0.0162$						

p-value s in parentheses, *$p<0.05$, **$p<0.01$, ***$p<0.001$

is SEK 3107.167 (308€) per year and per hectare (See Table 4).

By comparing the respondents' demographics and farm characteristics (Table 3) to those of the population of interest, i.e., all cattle producers within the geographical selection of the sample frame, we find that the sample resembles the population. Descriptive statistics in Table 3 and in the appendix report that the respondents' average pasture size is 51.5 ha which can be compared with 48.9 ha for all cattle producers within the geographical selection (Swedish board of agriculture 2018). Furthermore, the respondents are mostly located in the Boreal vegetation zone (62%, $n=52$), which is similar to the population of interest, among which cropping farms dominates the central and southern parts of Sweden (Swedish board of agriculture 2018). The cattle producers represented in the completed sample are predominantly male (77%; $n=64$), meat producers (68%, $n=57$), not organic (66%, $n=53$) and with an average age of 57, with 74% ($n=62$) of the respondents being older than 50. While the population shows similar patterns regarding farmers' average age, with also 74% being older than 50 years (Swedish board of agriculture 2020), the share of self-employed women entrepreneurs (29%), dairy producers (17%) and farms operating under organic certification (23%) differ slightly in the population although tendencies are similar (Swedish board of agriculture 2018).

Regression results

Regression results on (1) cattle producer's adoption model and (2) the related compensation model is presented in Table 5. The low Wald Chi-square test statistic (Wald $\chi 2$ (5) = 13.91, $p=0.0162$) illustrates that the model's explanatory variables are significant and that the model is consequently not overfitted, especially given the completed sample size.

The coefficient of inverse Mills ratio is reported as λ. Its insignificant test-statistic (z-score = 0.10; *p*-value = 0.920), suggests that selection bias is not a significant issue. No significant selection bias is also indicated by the correlation coefficient rho = 0.0516, which is close to zero.

Adoption model

Results first indicate that *Maintenance costs* is negative and significant. This suggests that if a cattle producer thinks that silvopastoral systems will lead to high maintenance costs, e.g., for fencing trees, he or she will be less inclined to adopt silvopastoral systems. The potential economic loss for converting and maintaining silvopastoral systems is therefore seen as a strong barrier to adoption, even with potential compensation. Furthermore, it can be interpreted that the economic weight of silvopasture impacts farmers' decision-making more greatly than potential economic benefits, e.g., from diversified sources of income. The socio-demographic variables *Gender*, *Education* and *Income* were found to be statistically significant. The negative sign of the *Gender* coefficient suggests that female cattle producers have a lower adoption probability, while the positive sign of the *Education* and *Income* estimates respectively suggest that the higher the level of education and income, the more positively they affect the decision to adopt. No farm-related characteristics emerged as statistically significant in the adoption model. Finally, results suggest that the use of TPB variables was sufficient to explain how underlying psychological constructs influence farmers in their decisions to adopt silvopastoral systems, with the attitudinal construct showing a positive and significant estimate. Accordingly, the more positively one values and perceives silvopastoral systems, the higher the intention to adopt.

Compensation model

Findings from the second stage of the model, i.e., the compensation model, only indicate a positive and significant relationship with the *Education* variable. *Education*, being significant in both models, suggests that higher education levels, in addition to increasing the intention to adopt silvopastoral systems, also increases related compensation claims. This highlights the importance of education, not only in increasing environmental consciousness, but perceptions of economic and labor requirements. As was the case in previous literature, the effects of the socio-demographic factors were found to be mixed across models, while the education level appeared to have a consistently positive influence (Tey and Brindal 2012; Lastra-Bravo et al., 2015; Mozzato et al. 2018; Liu et al. 2018).

Discussion and conclusions

This study contributes to the scientific literature on silvopasture adoption in Europe in three major ways. First, silvopastoral systems considered here are treeless pastures that are to be reforested. Even though grazed woodlands are essential, particularly in the process of establishing new pastures, the need for a transition towards sustainable animal production in Europe primarily requires that already existing grasslands are converted to silvopastoral systems (Hawken 2017). In fact, paired with growing trends in plant-based diets, the space dedicated to livestock production need not expand further (Erb et al. 2016) and reforestation of current treeless pastures should be a priority. Accordingly, this study specifically adds knowledge to the hypothetical process of pastoral reforestation and its economic implications. Second, this paper contributes to existing literature by bringing the psychological constructs of TPB (Ajzen 1991) to the study of farmers' adoption of silvopastoral systems. In doing so we can highlight how underlying psychological constructs affect adoption and that not only pecuniary drivers (such as concerns about revenues and costs) may be relevant to explain adoption. Third, this paper illustrates initial estimates of compensation claims related to silvopasture adoption in Sweden. As such, results can be used for policy recommendations and scaling up possibilities in Sweden, but may also be relevant for similar cattle production systems in Europe by acting as a beginning reference point.

Findings reported here indicate that 52% of the surveyed producers are willing to adopt silvopastoral systems and that the related mean compensation claim is SEK 3107.167 (308€) per year and per hectare. As is the case of many WTA studies, only a few dependent variables are statistically significant (Lindhjem and Mitanib 2012). This is rooted in part in the cognitively demanding task of respondents in defining a compensation claim (Bateman et al. 2002). Additionally, it may also result from the completed sample size of 84 observations, in that only large true effects are detectable. Nevertheless, in the adoption model, several variables were significant in explaining cattle producer's decisions to adopt silvopastoral systems. In addition to socio-demographic and monetary characteristics—namely *Education*, *Gender, Income,* and *Maintenance costs*—the attitudinal construct from TPB was found to significantly affect respondents' adoption decisions. This result is in line with previous studies such as Meijer et al. (2015), in which the authors found that attitude had a significant positive influence on smallholder farmers' behavior surrounding tree planting. It is noteworthy that among TPB psychological constructs, only the attitudinal construct emerges as significant. The attitudinal construct is often found among TPB constructs to have the most significant influence in farmer decision making (e.g., Hansson and Lagerkvist 2014; Meijer et al. 2015). This is true because the attitudinal construct captures the individual's understanding of the value of silvopastoral systems and the individual's level of appreciation of said value. Still, the subjective norm and perceived behavioral control constructs, not being statistically significant, offer valuable information in that cattle producers do not consider their peers' pressure and their ability to adopt silvopastoral systems as decision drivers, thus confirming the results previously reported by Gregory et al. (2012). Consequently, we interpret these findings as highlighting that producers' decision-making regarding silvopasture adoption is not only driven by economic considerations (through concerns related to investment and maintenance costs of adoption), as it signals that farmers' understanding and appreciation levels (measured via the attitudinal construct) toward silvopastoral systems are of significant influence.

Regarding factors influencing related compensation claims, these results indicate that only the socio-demographic characteristic of *Education* is statistically significant. Overall, compensation claims seem less influential in the adoption decision, meaning that if respondents are not inclined toward adoption, the prospect of being compensated is of little importance, regardless of the amount. This is suggested by the high percentage (48%) of unwilling respondents.

As such, CVM successfully circumvented the absence of markets for valuation of the environmental benefits of silvopastoral systems. However, the use of CVM still faces some limitations. First, revealing compensation claims may be cognitively demanding for respondents and our results should be interpreted in light of this difficulty. Similarly, the potential presence of strategic biases implies that some respondents may have responded strategically, e.g., by inflating their compensation claims. Hence, future research has an important task in evaluating how compensation claims may be affected by the type of elicitation method, by comparing the open-ended format used here with other types of elicitation methods (such as the payment card method). The limited completed sample size in this study should also be acknowledged. This is notably caused by the common removal of questionnaires that include missing answers from the open-ended elicitation method. Nonetheless, it should be highlighted that the remaining completed sample size of 84 observations resembles the population of interest, when comparing based on demographics such as average producer age, farm localization and pasture size. While the shares of self-employed women entrepreneurs, dairy producers and farms operating under organic certification differ slightly in the completed sample compared with the population, tendencies remain similar (Swedish board of agriculture 2018). Furthermore, based on results from Austin and Steyerberg (2015), two subjects per variable tend to permit accurate estimation. Still, considering the limited completed sample size, it is important to highlight that results should be considered to depict an illustration of what silvopasture may mean in terms of WTA and compensation claims, rather than as proven values. Additionally, this study characterizes the adoption of silvopasture as a complete land conversion from conventional grazing to silvopasture. Yet, this differs in practice as Smith et al. (2022) found that 96% of the producers who implemented silvopasture in the USA reported using a combination of both open and reforested pastures. Perhaps the share of unwilling respondents towards silvopasture adoption and the compensation claims may have been found lower if farmers had the choice of the amount of land to convert. Future research has thus the important task of investigating changes in the results if that is the case. It should also be acknowledged that other variables not considered in this study may play a role in determining adoption, such as facilitating advice from advisors. As found in this research, economic incentives are but one of the many levers to impact producers' interest into adopting silvopasture and future studies will have an important task in furthering the understanding about determinants of silvopasture. Finally, given that not many people in Sweden have adopted silvopastoral systems, it is not possible to study actual behavior. Accordingly, this study represents respondents' intention to adopt silvopastoral systems, thus allowing for a prediction of future uptake. Nevertheless, the potential presence of hypothetical biases, so that actual behavior might differ from intentions, could be an interesting avenue for future research.

In conclusion, the findings reported in this study are useful for the purposes of policy design, in particular for discussing and illustrating scaling-up possibilities of silvopastoral systems. Hence, the survey analysis first suggests that half of the respondents are motivated to adopt silvopasture, despite the lack of knowledge surrounding the practice. This may imply that the potential of trees to mitigate emissions and protect and enhance biodiversity in pastural landscapes is consistent with the reasons they own and manage agricultural land (Kline et al. 2000). Silvopasture implementation of at least a portion of cattle producers could thus be feasible through advice and relatively low-cost training programs to provide technical assistance and education, as our results suggest. Similarly, García de Jalón et al. (2017) argue that education is necessary not only to promote novel agroforestry systems, but also to increase farmers' environmental awareness. Additionally, demonstration sites are equally important in introducing farmers to real life applications of agroforestry systems (García de Jalón et al., 2017). In turn, such programs can enhance farmers' levels of understanding and appreciation for silvopastoral systems and consequently improve farmers' attitudes towards the practice. Most importantly perhaps, is to increase advisors' leverage in supporting the uptake of agroforestry practices. Farmers generally have little extra time to invest. Having specialized and knowledgeable advisors who not only recommend agroforestry systems as direct solutions to farmers' concerns and problems, but also facilitate implementation, may therefore be needed. However, by placing producers' goals and needs first, economic incentives must also be considered if silvopasture implementation is to achieve greater acceptance and cooperation in the adoption process. In fact, because it is the non-market characteristic of the many environmental benefits of silvopastoral systems that has mainly led to the current sub-optimal situation in silvopasture and agroforestry adoption (Shrestha et Alavalapati 2003; García de Jalón et al. 2017), there is a clear necessity to compensate farmers' up-front costs of implementation for the environmental and social benefits that they provide. Accordingly, for silvopasture to become a more widespread approach, changes must be made at the regime level (Schaffer et al. 2019). These changes provide an opportunity for achieving targeted environmental objectives set by the Swedish Parliament, such as Sweden's long-term strategy for reducing greenhouse gas emissions as per the Paris Agreement, and the new FIT 55 package in the EU, especially concerning the regulations on Land Use, Forestry, and Agriculture to achieve an overall EU target for carbon removal by natural sinks of 310 million tons of CO_2 emissions by 2030 (European Commission 2021). Findings reported here provide an illustration of the initial compensation claims required to support silvopasture adoption in Sweden. Results may also be relevant for indicative compensation claims for similar production systems in Europe, by functioning as a reference point.

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Declarations

Conflict of interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

See Figs. (1, 2, 3, 4, 5, 6 and 7).

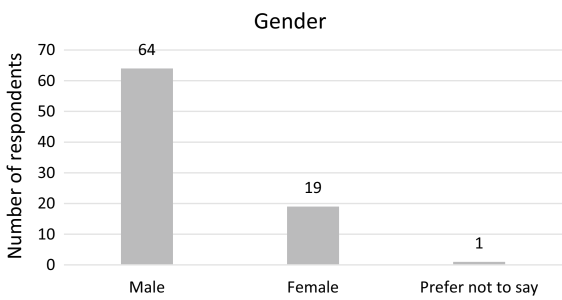

Fig. 1 Gender distribution of the respondents

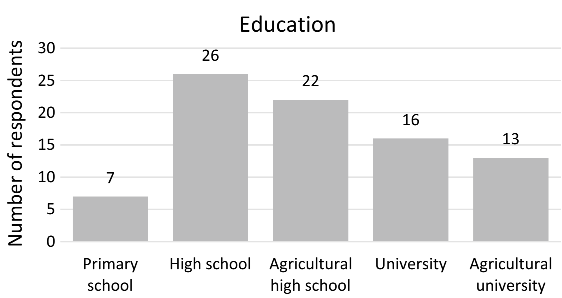

Fig. 2 Distribution of the respondents' level of education

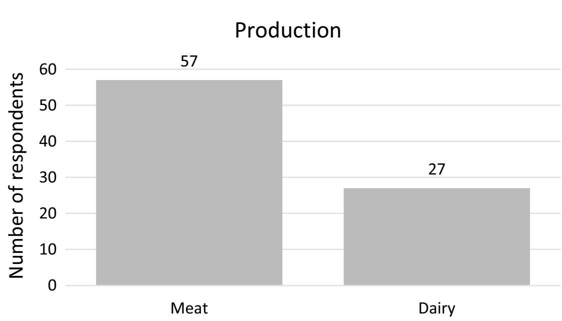

Fig. 3 Distribution of the respondents' type of production

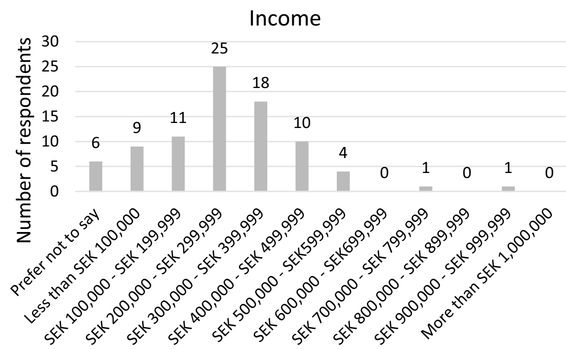

Fig. 4 Distribution of the respondents' level of income

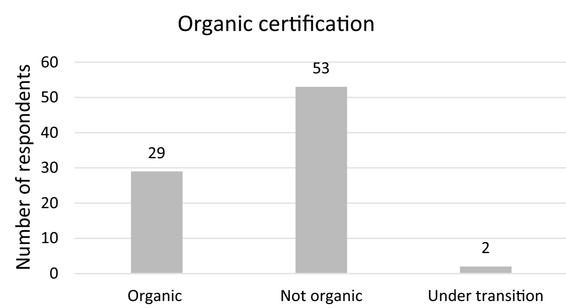

Fig. 5 Distribution of the respondents' organic certification

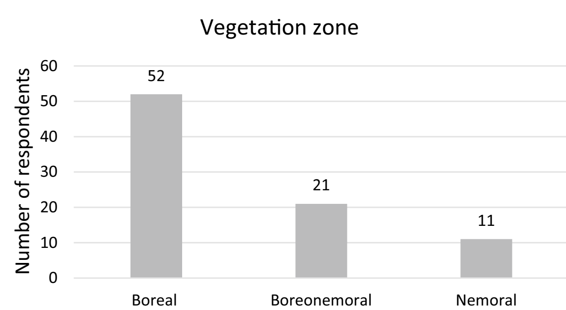

Fig. 6 Distribution of the respondents' localization within Sweden's three main vegetation zones

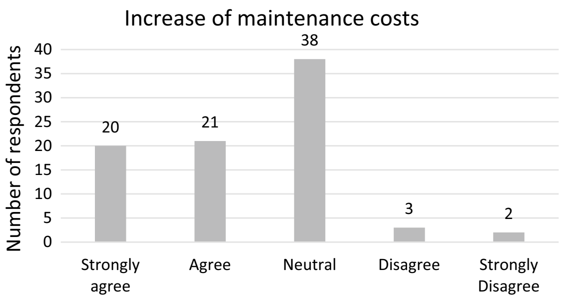

Fig. 7 Distribution of the respondents' level of agreement with the statement that silvopasture leads to higher maintenance costs

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