Farmers' preferences for water-saving strategies in Brazilian eucalypt plantations

Gabriela Demarchi, Julie Subervie, Fernando Palha Leite, Jean-Paul Laclau

Farmers' Preferences for Water-Saving Strategies in Brazilian Eucalypt Plantations [*]

Gabriela Demarchi[†] Julie Subervie[‡] Fernando Palha Leite[§]
Jean-Paul Laclau[¶]

Abstract

In a climate change context, changing temperature and precipitation pattern are expected to have strong impacts on Brazilian eucalyptus plantations. Implementing adaptive water-efficient management practices is thus becoming necessary to maintain high levels of productivity while preserving the water resources. This paper investigates the ability of eucalyptus farmers to modify their current silvicultural practices in order to adapt to drought in the near future. We ran a choice experiment in the state of Minas Gerais, among 80 eucalyptus producers, who were asked to choose from several management options associated with various financial supports. The results show that adaptation by reducing the length of the eucalyptus rotation proves to be by far the preferred option, despite the associated costs. On the contrary, reducing density appears to be the least chosen option by the respondents, which may suggest that they underestimate the benefits of this strategy. We moreover find a clear and relevant segmentation of farmers' choice behavior, the general preference for reducing the length of the eucalyptus rotation being driven by the most vulnerable farmers of the sample.

Keywords: choice experiment, climate change, drought, water resources, adaptation, eucalyptus, Brazil.

[*]Funding for this research was provided by the French National Research Agency (ANR-13-AGRO-0005).
[†]French National Research Institute for Agriculture, Food and Environment (INRAE), Center for Environmental Economics of Montpellier (CEEM), gabriela.demarchidias@inrae.fr
[‡]French National Research Institute for Agriculture, Food and Environment (INRAE), Center for Environmental Economics of Montpellier (CEEM), julie.subervie@inrae.fr
[§]Empresa Celulose Nipo-Brasileira SA, Belo Oriente (Brazil), fernando.leite@cenibra.com.br
[¶]CIRAD, UMR Eco&Sols, F-34398 Montpellier, France

1 Introduction

The biophysical effects of climate change on natural and managed systems, agricultural productivity and food security are increasingly well-understood (IPCC, 2014; Moore et al., 2017). In many areas, management options for adaptation to climate change have already been developed. These adaptation measures include, for example, using scarce water resources more efficiently, developing drought-tolerant crops and choosing tree species and forestry practices that reduce vulnerability to storms and fires. Adaptation to climate change, however, requires the incorporation of this knowledge into management decisions (Keenan, 2015). Several management options for adaptation in agriculture exist, but farmers differ in their individual preferences for time and risk as well as in the constraints they face. Adaptation in agriculture may therefore vary significantly across regions, depending on climatic, social, economic and institutional factors (Khanal2018; Below et al., 2012; Deressa et al., 2009). How will farmers adapt to the effects of climate change in the near future thus remains hard to predict.

Several studies have explored the steps that farmers' can take in adapting to climate change(Chen, Wang, and Huang, 2014; Deressa et al., 2009; Seo and Mendelsohn, 2008; Alam, Alam, and Mushtaq, 2016; Alauddin and Sarker, 2014; Ngigi, Mueller, and Birner, 2017). Most have analysed the determinants of adaptation decisions by comparing the characteristics of adapters and non-adapters. For example, Deressa et al. (2009) found that household characteristics and access to agricultural extension and credit can influence farmers' adaptation decisions in the Ethiopian context. A number of studies have analysed the impact of adaptation on crop yields (Deressa and Hassan, 2009; Di Falco, Veronesi, and Yesuf, 2011; Di Falco et al., 2012; Huang, Wang, and Wang, 2015; Khanal et al., 2018). Although a growing number of studies employ choice experiments to estimate farmers' willingness to provide ecosystem services (see Kaczan, Swallow, and Adamowicz (2013) and references therein), there exist few ex-ante evaluations of the ability of farmers to adapt to climate change. Such evaluations would assess farmers' willingness to adopt new agricultural strategies that sometimes require drastic changes in forest or crop management. This study aims to fill this gap by conducting a choice experiment on a sample of Brazilian managers of eucalypt plantations who were asked to choose among several climate change adaptation strategies on eucalypt plantations.[1]

Eucalypt is a prime source of low-cost woody biomass, which explains its popularity among both industrial firms and smallholders. Like many plants, however, drought is a major risk for eucalypt plantations in a context of climate change. In the Brazilian state of Mi-

[1]Eucalypt plantations are not forests in the sense in which it is understood in temperate zones, since the average rotation is around 6-7 years. It should be seen as closer to the cultivation of permanent crops in tropical zones, like coffee for example.

nas Gerais, recent droughts have caused significant loss of yields and tree mortality in highly productive eucalypt plantations (Gonçalves et al., 2017). The sustainability of eucalypt plantations is now threatened by high water demand[2] and the absorptive capacity of the fast-growing genotypes that are increasingly used. In some areas, silvicultural practices also affect the availability of water, and consequently tree growth (Gonçalves et al., 2008; Gonçalves et al., 2017). In this study, we investigate what would be the adaptation strategies chosen by smallholder farmers who would have to deal with the consequences of climate change. Governments may intervene in this choice for at least two reasons. First, eucalypt plantations are intensive fast-wood plantations and the way they are managed may have negative effects on water resources. As in any standard negative externality problem, the social planner may want to subsidize the most water efficient strategies. For that reason, improving water use efficiency by adopting appropriate forest management practices has become a key challenge in ensuring ecologically sustainable levels of productivity (Booth, 2013). Second, eucalypt plantations have an important role in the Brazilian economy. Since climate change threatens the development of this sector, the government may want to support farmersâ adaptation to climate change by subsidizing the switch to the most profitable adaptation strategies. Our study aims at studying farmers' preferences for water-saving strategies in Brazilian eucalypt plantations to avoid mortality during prolonged droughts. We ran a choice experiment (CE) among 80 eucalypt growers who were asked to choose from several hypothetical adaptation strategies, defined as a combination of attributes. Each strategy was represented as a forest management option in which they received monetary compensation for implementing specific practices on their farm. We examined growers' preferences for five different options that have been identified in the literature as promising strategies for reducing the susceptibility of trees to drought while maintaining either the same or slightly diminished yields. These options include: reducing the cutting cycle, adopting new hybrid plants, reducing tree density, reducing the use of fertilizers, and coppicing. In our framework, a respondent who chooses to adapt to climate change opts for one of these forest management options, may also receive (in addition to a financial support) free technical assistance to help him implement the proposed system and a weather insurance subsidized at 50 percent.

The way in which farmers choose between several different adaptation strategies, each with varying levels of individual attributes, is used to quantify their preferences for these attributes, as well as to quantify overall willingness to accept (WTA) values, i.e. the amount of money an average grower would require in order to adapt to climate change. We analyze the data following the same approach as Gevrek and Uyduranoglu (2015); Lienhoop and

[2]Previous studies have shown that water use by eucalypt plantations depends on the particular territory, environmental conditions and land-use practices employed(Poore and Fries, 1985; Cornish, 1993; Calder, 1998; Almeida and Soares, 2003; Hubbard et al., 2010; Ferraz, de Paula Lima, and Rodrigues, 2013; de Barros Ferraz et al., 2019).

Brouwer (2015); Broch et al. (2013) and other recent studies. We use a mixed logit model, which allows for heterogeneity in growers' tastes. We moreover study the extent to which the socioeconomic and structural farm characteristics of the respondents may influence their answers using a latent class model.

Altogether, our results indicate that respondents tend to overvalue both free technical assistance and subsidized insurance. Moreover, the strategy based on the reduction of the cutting cycle appears to be by far the preferred option, while the reduction of plantation density is the least selected option. In between these two options, the respondents appear to equally value the reduction of fertilizer, the introduction of hybrid plants and coppicing. We also find that growers' preferences are highly heterogeneous and that the strongest preferences for reducing the cutting cycle are held by the most vulnerable farmers in the sample.

The remainder of this article is organized as follows. We first provide background information on the Brazilian eucalypt plantations and the possible management options for adaptation to climate change in Section 2. We present the methodology and the data used in Section 3. Thereafter we present the results of the analysis in Section 4 and discuss them in Section 5. Section 6 concludes.

2 Brazilian eucalypt plantations and climate change

2.1 Background

Cultivation of eucalypt trees began in the 19th century and spread throughout the next century as the most planted genus of broadleaf trees in the world. Today eucalypt plantations are spread over more than 20 million hectares around the world (Booth, 2013). Extensive cultivation of this genus beyond its natural range began in the early 20th century in Brazil (FAO, 2011). Over the past decades, it has expanded rapidly in Brazil, mainly replacing degraded pastures (Smethurst, Almeida, and Loos, 2015). Nowadays, eucalypt is the primary and most productive planted forest in Brazil, covering around 5.6 million hectares (IBA, 2016). Of all eucalypt plantations in Brazil, more than one-third belongs to companies in the pulp and paper sector. Independent farmers and farmers in outgrower schemes[3] hold the second largest share of planted forests in Brazil (IBA, 2016).

Short rotation eucalypt crops are a significant source of raw material for the pulp and paper industry in Brazil, and these plantations have been mostly established in areas where the climate favours high yields (Gonçalves et al., 2013). In addition to their private plantations, timber-based companies encourage the establishment of new plantations through outgrower programs. In these programs, companies typically provide seedlings, cuttings,

[3] Outgrower schemes, also known as contract farming, are broadly defined as binding arrangements through which a firm ensures its supply of agricultural products by individual or groups of farmers (FAO, 2001).

and other inputs in exchange for being given priority when purchasing wood after the harvest (Rode et al., 2014). These contracts encourage farmers to consider cultivation of eucalypt as a complement to their agricultural income.

2.2 Plantation management options for adaptation to drought

Eucalypt plantations are predominantly clonally propagated due to the ability of the plant to adapt to regions with low to moderate water scarcity and low fertility soils (Gonçalves et al., 2008). The largest Brazilian plantations are found in the Central-West and Southeastern regions of the country, particularly in the states of Minas Gerais (containing 24 percent of the total area of planted eucalypt), Sao Paulo (17 percent) and Mato Grosso do Sul (15 percent) (IBA, 2016). These clonal forests have been largely established on sites with water and nutrient restrictions, where they out-perform conventional seed-based silviculture. In a climate change scenario, however, the sustainability of these plantations is threatened. In this study, we focus on several potential management options, which are built based on results of a number of recent studies (Christina et al., 2017; Battie-Laclau et al., 2016; White et al., 2014; Matusick et al., 2013). We explored the agronomic literature in order to determine the most relevant adaptation strategies in the Brazilian context. We then inserted these strategies into an socio-economic framework allowing us to assess not only farmers' preferences for these strategies, but also the potential levers to guide these choices (monetary and non-monetary rewards), and the factors likely to explain the heterogeneity of these choices (the characteristics of the farmers themselves). In order to reduce the risks of tree susceptibility to drought resulting from climate change, several silvicultural systems for eucalypt production are currently under development. Management options to reduce the risk of tree mortality during exceptional droughts, however, have some disadvantages compared to current silvicultural practices. In particular, a loss of productivity may occur compared to the most productive clone, planted with a high stocking density and highly fertilized. Five silvicultural systems appear promising for reducing the risk of tree susceptibility to drought while either maintaining or slightly diminishing yields.

The Short Rotation (SR) option: This production system consists in reducing the length of the cutting cycle from 7 years (the current practice in our study area) to 4 years. Previous studies indeed show that an increase in the frequency of clearcutting would make it possible to store water in deeper soil layers over a greater proportion of the rotation (Christina et al., 2017). As Stape et al. (2010) showed, reducing the cutting cycle from 6 years to 4 years would not affect the mean annual increment (MAI). The main constraint to the farmers under this system is the higher frequency of harvesting operations, which implies increased total harvesting and replanting costs.

The New Hybrid (NH) option: This option consists in adopting new hybrid eucalypt trees that are more tolerant to drought, instead of the highly productive clones currently used. Although these hybrids are less productive, they have a greater water use efficiency rate that reduces water use and tree mortality (Booth, 2013). Therefore, the loss of MAI in this system compared to the most productive clones currently planted will depend on the expected risk of mortality during an exceptional drought period.

*The Reduced Density (RD) option:*This option consists in reducing the density of trees planted, switching from one tree per area of 3 meters by 3 meter to one tree per area of 3 meters by 4 meters. This would decrease tree stand evapotranspiration and competition for water resources (White et al., 2009, 2014). However, a decrease in leaf area is needed to reduce tree stand transpiration, which may slightly decrease the productivity.

The Reduced Fertilization (RF) option: This option consists in a reduction of fertilizer doses. Previous studies have pointed out that this strategy can diminish tree mortality risk in the event of extreme droughts, as a consequence of lower leaf areas (Battie-Laclau et al., 2016). Additionally, the water stored in the deep soil layers during the rainy season is withdrawn early in the dry season in fertilized plantations, leading to greater water deficit, while unfertilized stands use the water more slowly, making more water available during the rest of the season (Christina et al., 2018; White et al., 2014).

The Coppice Management (CM) option: This option consists in coppicing, which enables already-established roots to access to water at great depths (Laclau et al., 2013; Germon et al., 2019). Coppicing after the first rotation is a common option in Brazilian eucalypt plantations. An average loss of 5 percent on MAI is expected under this option (de Souza et al., 2016). In the field experiment presented below, these five management options are included in the strategies used for climate change adaptation.

3 Methodology and Materials

3.1 Statistical Models

We use the framework provided by Revelt and Train (1998), in which a sample of N respondents have the choice of J alternatives (strategies for climate change adaptation here) on T choice occasions. A farmer is assumed to choose an adaptation strategy if the utility from choosing that alternative is greater than choosing either no adaptation or any of the competing choices. The utility that farmer n gets from choosing alternative j is given by $U_{nj} = \beta'_n x_{nj} + \epsilon_{nj}$, where β_n is a vector of individual-specific coefficients, x_{nj} is a vector of observed attributes relating to individual n and alternative j, and ϵ_{nj} is a random term. The probability that farmer n chooses alternative k is:

$$P_{nk} = P(U_{nk} > U_{nj}) = P(\epsilon_{nk} - \epsilon_{nj} < \beta'_n x_{nk} - \beta'_n x_{nj}) \forall k \neq j$$

Different discrete choice models are obtained from different assumptions about the distribution of the random terms ϵ. We first use a mixed logit model.[4] We assume that all the parameters, except the monetary attribute, follow a normal distribution. Our models also include an alternative specific constant (ASC) taking the value of one if the *status quo* alternative describing the current situation is chosen and zero otherwise (Adamowicz et al., 1998; Scarpa, Ferrini, and Willis, 2005). As β_n is unknown, the unconditional probability for a sequence of choices d can be expressed by integrating over all values of β weighted by the density of its distribution, denoted $f(\beta|\theta)$, where θ are the parameters of the distribution:

$$S_n^{\text{MXL}} = \int \prod_{t=1}^{T} \prod_{j=1}^{J} \left[\frac{\exp(x'_{njt}\beta)}{\sum_{j=1}^{J} \exp(x'_{njt}\beta)} \right]^{y_{njt}} f(\beta|\theta)\, d\beta$$

where $y_{njt} = 1$ if the respondent chooses j in situation t and zero otherwise. The log likelihood for the model is given by $LL(\theta) = \sum_{n=1}^{N} \ln P_n(\theta)$. This expression cannot be solved analytically, and it is therefore approximated using simulation methods. We estimate this model by employing maximum simulated likelihood using 500 Halton draws (Hole, 2007). Since the monetary attribute is assumed to be a fixed parameter in our model, we have the convenient result that the willingness-to-accept (WTA) attribute k, i.e. the average value the respondents put on attribute k, all other things being equal, is:

$$E(\text{WTA}^k) = -\frac{E(\beta^k)}{\beta^{\text{money}}}$$

where β^{money} is the coefficient of the monetary attribute.

We then use a latent class model in order to provide some insights regarding the heterogeneity of farmers' preferences – if there is indeed any according to the results of the mixed logit model – and the importance of their characteristics in the decision-making process regarding climate adaptation practices. In this case, each respondent is assumed to belong to a class q, where preferences vary across, but not within classes. In this case, the probability of a particular sequence of choices is:

$$S_n^{\text{LC}} = \sum_{q=1}^{Q} H_{nq} \prod_{t=1}^{T} \prod_{j=1}^{J} \left[\frac{\exp(x'_{njt}\beta)}{\sum_{j=1}^{J} \exp(x'_{njt}\beta)} \right]^{y_{njt}}$$

where H_{nq} is the probability of belonging to class q. The log-likelihood for this model is $LL = \sum_{n=1}^{N} \ln S_n$. We maximise this expression using the expectation-maximization algorithm.

[4] The mixed logit model overcomes three drawbacks of the standard logit model by allowing for heterogeneity in tastes, correlation in unobserved factors over repeated choices made by each individual, and complete relaxation of the independence of irrelevant alternatives (IIA) assumption (Train, 1998; Greene and Hensher, 2003).

3.2 Design of the Choice Experiment

The selection of attributes for the study was based on a review of existing relevant literature on current agricultural and environmental policies and discussion groups involving scientists as well as Brazilian forest managers who participated in the project. The four attributes and their corresponding levels are presented in Table 1. The adaptation strategies are characterized by four attributes: a silvicultural management option, some level of monetary compensation, a weather insurance scheme that is 50 percent subsidized and the provision of free technical assistance to help the farmer implement the management option proposed. The silvicultural management attribute consists of five levels, namely the five management options designed to reduce the risks of tree susceptibility to drought in a context of climate change: reducing the cutting cycle, adopting new hybrid plants, reducing the tree density, reducing of the use of fertilizers, and coppicing the trees (see Section 2.2). In our model, reducing tree density is the reference level of the silvicultural management attribute.

The level of monetary compensation, the attribute used to estimate the implicit values of the other attributes, was defined so as to be realistic for respondents. The starting point here was identifying a payment level that was in line with expected wood production losses when adopting one of the water-efficient management systems. We calculated that a loss in productivity of three cubic meters per hectare per year would cost about 100 Brazilian reais (BRL) The design moreover includes two non-cash reward attributes: the provision of a free technical assistance and a 50 percent subsidized weather insurance. It is generally assumed that the presence of a technical expert – also called agricultural extension in the literature – is likely to promote significant changes in farming practices and more effectively in the early stages of the process dissemination of the new technology, new practice or new system sought to be adopted (Anderson and Feder, 2007). This is the reason why a number of recent studies from the farmer choice experiment literature include technical assistance as an attribute of the options offered to respondents and generally show a marked preference of farmers for this type of non-cash rewards (Abebe et al. (2013); Andow et al. (2017); Minten, Randrianarison, and Swinnen (2009); Kuhfuss et al. (2016); Vignola, McDaniels, and Scholz (2012) to name just a few examples). Private climate insurance has also been seen as having the potential to reduce vulnerability of agricultural systems to climate-related risks to farm-level production, infrastructure and income (Smit and Skinner, 2002). This instrument seems less often offered than technical assistance as an attribute in the choice experiment literature, probably because it is not available in all contexts. However, a number of recent papers in the choice experiment literature have considered it as one of the more viable income smoothing strategies (Prasada (2020) and references herein).

We followed a D-efficient design approach to construct the choice sets, using prior information we had about the sign and relative values of the design attributes.[5] We used secondary data to construct prior values for the true parameters of the model. The value chosen for technical assistance was 600 BRL, which is the average price for hiring a specialist for one day in Minas Gerais region. The value chosen for weather insurance was 175 BRL for insuring one hectare of eucalypt plantation (after the 50 percent subsidy) and 35 BRL for the value of the equivalent of one meter cubic of wood.

The design was generated with the software package Ngene in order to produce 10 choice sets per respondent. In our study, a choice set consists of two alternative adaptation strategies and an option to decline both strategies (the *status quo* option). An example of a choice set is displayed in Figure 2.

3.3 Data

We collected original data from a total of 80 out-grower farmers[6] living in the state of Minas Gerais. In practice, we had access to the registry database of all the farmers enrolled in the contract-farming scheme of CENIBRA, an eucalypt pulp and paper company located in Ipatinga, on the eastern part of Rio Doce basin (Figure 1). There were several hundreds of farmers likely to participate in the experiment. Given the financial constraints of the research project, we targeted 200 of them, focusing on their geographic location so that we have respondents from all the different zones of the study area. After contacting them by phone, we ended up with 80 farmers who agreed to participate in the experiment.

In order to ensure that respondents would fully understand the questions and concepts used in the CE, the questionnaire was pre-tested with technical assistants from CENIBRA, who interacted frequently with the out-grower farmers.[7] The respondents had a 30-minute information session regarding the attributes and levels before beginning the survey. The monetary compensation levels were not mentioned, since it could result in anchoring at the highest offer.[8] A brief description of the choice task was provided to each respondent be-

[5]Efficient experimental designs can reduce confidence intervals for parameters of interest in choice models, or alternatively reduce required sample sizes. Informed priors can then be useful when trying to make strong inferences from small amounts of data, since these priors capture any assumptions the researcher makes about model parameters before observing the data (Kruschke and Liddell, 2017).

[6]According to the FAO, a contractual partnership between growers or landholders and a company for the production of commercial forest products. Out-grower schemes or partnerships vary considerably in the extent to which inputs, costs, risks and benefits are shared between growers/landholders and companies. Partnerships may be short or long-term (eg. 40 years), and may offer growers only financial benefits or a wider range of benefits. Also, growers may act individually or as a group in partnership with a company, and use private or communal land. Out-grower schemes are usually prescribed in formal contracts.

[7]CENIBRA did not participate in the design of the choice experiment. But they provided access to the pool of potential participants and guided the sampling so that it is representative in terms of geographic areas.

[8]The monetary compensation levels were not revealed during the 30-minute briefing that took place prior to the choice experiment, but of course they did appear explicitly on the choice cards. More precisely, the attribute of monetary compensation was presented during the information session through the following sentence: *The*

fore each choice set. We moreover provided plausible values for average annual incremental loss for each scenario, based on expert estimates.[9] The participants first answered survey questions about themselves, their farm and their environmental perceptions, and then participated in the CE. Data collection took place between March and April 2017 through face-to-face interviews.

Descriptive statistics of the farms owned or managed by the survey respondents as well as their main socioeconomic characteristics are shown in Table 2. The sample is mainly composed of male growers, who have on average three household members, a secondary education and less than 15 years' worth of experience growing eucalypt. The majority of farmers interviewed grew eucalypt as a complementary source of revenue (less than 30 percent of their income). Less than seven percent of the sample has a plantation insurance that covers for fire and other weather-related damages. The average farm size is around 200 ha and the mean area of eucalypt plantations is around 90 ha (the median is 65 ha).

We find, however, that these figures mask a high level of heterogeneity. The interviewed farmers are spatially distributed into four distinct geographic zones (see Table 3). The zone near the municipality of Belo Oriente is characterized by the greatest climatic constraints and can be considered the zone that is most vulnerable to climate-change in our study. The main constraints in this region are: higher water deficit, lower altitude and smaller precipitation volumes, compared to other zones.[10] These characteristics explain the lower MAI among the sample in this region. Since these plantations are located in the vicinity of CENIBRA's pulp mill, however, growing eucalypt in these areas remains economically viable for the time being. In contrast, plantations located in the area near the municipality of Cocais and Pecanha are characterized by the highest MAI rates, as a result of the greater annual precipitation levels, a higher altitude and soils with suitable properties to grow eucalypt trees. Despite the fact that Pecanha is one of the most distantly located plantations, eucalypt cultivation in this area remains viable. Caratinga is characterized by a moderate MAI due to its climatic and topographical conditions and is located on an intermediate distance from CENIBRA pulp mill. Although participants in the study were not randomly selected, our

third proposed compensation consists of the remuneration of an amount per hectare that takes into account losses in productivity without mentioning the values per hectare. The participants discovered the values only when starting the choice experiment.

[9]When presenting the choice experiment, we informed the participants various consequences of climate change, including loss of yields and tree mortality, through simple diagrams showing the relative advantages of the different adaptation strategies proposed. In particular, we ranked the proposed management options according to the likely loss in MAI: 1) SR option (no loss), 2) CM option, 3) RD and RF options, and 4) NH option (highest loss). We also clearly specified that the performance of these strategies was based solely on expert opinion and could not correspond to the reality that the farmer will face in the future.

[10]The precipitation pattern in the basin is characterized by two distinct periods. The rainy period extends from October to March and precipitation in this period varies from 800 to 1300 mm. The dry period extends from April to September, with the most severe droughts occurring from June to August. Precipitation during the dry period ranges between 150 and 250 mm (Agência Nacional de Águas, 2010).

sample is quite representative of CENIBRA out-growers' dispersion in the country.[11]

4 Results

In this section, we first provide the estimates of the mixed logit model parameters, along with the WTA estimates, and we discuss the apparent heterogeneity in farmers' preferences. We then turn to a latent class (LC) model in order to investigate to what extent heterogeneity in preferences is correlated with farmers' characteristics.

4.1 Mixed logit model

Our main results are displayed in Table 4. Consistent with economic theory, all reward-type attributes significantly increase the probability that farmers adapt to climate change. The coefficients of the cash payment variable, the free technical assistance variable and the subsidized insurance variable are statistically different from zero at the 1 percent level. From these coefficients, we calculate that 96 percent of farmers prefer adaptation strategies that provide free technical assistance and/or prefer subsidized insurance. These figures are given by $100 * \Phi(\beta_k / s_k)$ where Φ is the cumulative standard normal distribution, and β_k and s_k are the mean (Column 1) and standard deviation (Column 2), respectively, of the k^{th} coefficient of the model.

Following Sheremet et al. (2018), we moreover computed the simulated probabilities of adapting to climate change for the different management options (Figure 4). Although the levels shown in these graphs cannot be interpreted as such, especially because the adoption probabilities reported in choice experiments are generally overestimated (List and Gallet, 2001), it is nonetheless interesting to note that an adaptation strategy that would include both technical assistance and weather insurance was the most likely to be accepted for any management option and cash payment, while a strategy that would offer none of these two non-cash rewards has the lowest chances to be chosen.

Regarding preferences about management options, our results suggest that farmers prefer adopting coppice management or shortening the cutting cycle rather than diminishing the plantation density (which is the reference management option in our model). We calculate from the estimated coefficients that 75 percent of farmers prefer adaptation strate-

[11] We do not have quantitative data on those farmers who ultimately did not participate in the choice experiment. However, qualitative (informal) information collected from CENIBRA when the sample was drawn up suggests that the sample is representative in terms of zoning (the four geographical areas of CENIBRA farms are represented), but not in terms of farm size (participants in the survey are presumably larger on average than non-participants, according to CENIBRA staff). Moreover, as in any survey where respondents voluntarily choose to participate or not, we cannot exclude that participants differ from non-participants in terms of their allocation of leisure time or perhaps in terms of awareness of the likely impacts of climate change.

gies that involve a reduced cutting cycle and 69 percent prefer those that require coppice management (when confronting with diminishing the plantation density). Nevertheless, the WTA (Col 3) indicates that the farmers value reduced cutting cycles almost twice as much as coppicing: the average respondent is willing to receive 175 BRL to implement the density option instead of the cycle option, while he only requires 86 BRL to implement the density option instead of the coppice option. Finally, the results do not indicate any stronger (or lower) preference for the reduction of fertilizers or the adoption of drought-tolerant hybrids compared to the reference option.[12]

Column 2 of Table 4 moreover suggests that there is significant heterogeneity in respondents' preferences for nearly all attributes of the proposed adaptation strategies. This is particularly the case for the two preferred management options - coppice and reduced cutting cycles - and for the ASC (alternative specific constant). As for the reduction of fertilizers, which is not significant on average, we find on the contrary that the standard deviation is statistically significant, suggesting that at least some respondents have stronger or lower preference for this management option.[13].

In order to present this result about heterogeneity graphically, we estimate the individual-level coefficients for each attribute using the approach suggested by Revelt and Train (2001) and using Stata software. The distribution of the individual-level coefficients associated with each management option for which β_k and/or s_k appear significant in Table 4 is displayed in Figure 3. In some cases, as for reduced cutting cycles and coppicing, the shape of the distribution of the coefficients suggests that we might have two different classes of farmers in our sample, which we investigate using a latent class model.

4.2 Latent Class model

The LC model provides an alternative approach to describing our data, in which farmers are expected to have different motivations and purposes for their respective choices regarding adaptation to climate change. To explore this possibility, the model assigns farmers to groups based on their preferences and other (latent) individual-specific variables. The LC model combines characteristics of the individual, such as socioeconomic characteristics with the

[12]For the present study we opted for the practical solution to simply maximize the sample size given the research budget at hand, i.e., trying to overpower the study as much as possible (de Bekker-Grob et al., 2015). However, a limited sample size, like the one in our study, prevents detection of small effects. This is possibly the reason why we were not able to detect any effect for two adaptation options using the mixed logit model (the New Hybrid strategy and the Reduced Fertilization strategy). A consequence of this is that no conclusions should be drawn from insignificant results.

[13]The fact that the standard errors are significant for most variables indicates that the Mixed logit model fits well with the presented data. As a robustness check we however ran the most standard Conditional logit model. Same results hold on the average estimates. They are displayed in supplementary material, as well as alternative mixed logit models, assuming the price to be a random parameter and using different probability density functions for the distribution of coefficients.

stated behavior in the choice sets (Beck, Rose, and Hensher, 2013). Preferences are presumed to be homogeneous within each latent class but different between classes (Colombo, Hanley, and Louviere, 2009). In this model, we focus on a selection of individual characteristics about the farmers and their farm (Wilson, 1997; Vanslembrouck, Huylenbroeck, and Verbeke, 2002; Horne et al., 2006; Ruto and Garrod, 2009), as well as geographical features (Espinosa-Goded, Barreiro-Hurle, and Ruto, 2010; Broch et al., 2013).

We select the optimal number of latent classes in a model using the Bayesian information criterion (BIC) and the Akaike information criterion (AIC), both of which pointing to a two-class model (Table 5). Our main results are displayed in Table 6. The smaller class (21 percent of the sample) is mainly comprised of male farmers who engage in cattle ranching activity as their main source of revenue and possess large eucalypt plantations. These farmers are heavily dependent on the income from these plantations and are located in a region considered to be more sensitive to climate change (Table 3).

Results displayed in the upper part of Table 6 call for four comments. First, while both groups exhibit a strong (and comparable in magnitude) preference for the technical assistance attribute, insurance does not seem to play a decisive role anywhere other than in Class 1 (though this result lacks precision). Second, although preferences for the coppice option appears significant in both groups, they are stronger in Class 1. Third, the reduced cutting cycle option now appears to be the preferred option for Class 1 only and not Class 2. Finally, the significant ASC in Class 1 suggests that a *status quo* effect occurs, the positive sign of the coefficient indicating that moving away from the current situation may have a negative effect on respondents' decisions to opt for adaptation in Class 1.[14] Such an effect does not appear in Class 2.[15]

5 Discussion

Although the results of this study cannot be generalized, our findings enable us to identify three main takeaways.

5.1 Farmers' valuation of reward attributes

First, we found that farmers particularly value adaptation strategies based on free technical assistance and/or subsidized weather insurance. This result is consistent with results provided in previous studies conducted in other contexts (Abebe et al., 2013; Andow et al.,

[14]None of the 80 farmers who agreed to participate in the experiment opted for the status quo option in all cards.

[15]These results can be found also using a mixed logit model that interacts farmersâ characteristics with attributes. Such a model is displayed in the supplementary material.

2017; Minten, Randrianarison, and Swinnen, 2009; Kuhfuss et al., 2016; Vignola, McDaniels, and Scholz, 2012; Prasada, 2020). When confronting the values that respondents place on technical assistance and subsidized weather insurance with market prices, we can conclude that farmers tend to overestimate the value of both of these attributes. Indeed, a subsidized weather insurance incentive has a market value of approximately 175 BRL per hectare per year, which is approximately 42 BRL lower than the WTA of the farmers who participated in this study (217 BRL). We also find that growers value technical assistance at nearly 149 BRL per hectare per year, while the average cost of technical assistance, considering the average 7 year cycle, is about 36 BRL per hectare per year (Rode et al., 2014). This result makes sense given that Brazilian eucalypt producers tend to be unaware of the existence of this sort of insurance; in our sample for example, less than seven percent of farmers had an insurance policy (Table 2). Note also that respondents are not irrational when they value technical assistance and insurance. The analysis of the choice experience simply indicates that they place a monetary value on these attributes that is higher than the real cost which would be incurred by the implementation of these instruments in reality.

5.2 Farmers' valuation of management options

Second, we found that farmers highly value adaptation strategies that bring them money today rather than in the future (shortening the cutting cycle, typically). This result is consistent with the standard hypothesis that economic agents value the present more than the future (Samuelson, 1937). It is also in line with findings from the behavioural economics literature, which suggests that individuals may have present-biased preferences (Laibson, 1997; Cohen et al., 2020). Moreover, if the rotation is shorter, then the exposure to the risk of drought is reduced. Moreover, if the rotation is shorter, then the exposure to the risk of drought is reduced. Such preferences, however, could have environmental as well as economic consequences. First, increasing the frequency of clearcuts could result in soil compaction and an increase in nutrient exports since nutrient remobilizations decrease the concentrations in stemwood throughout the rotation (Sette et al., 2013). Harvesting young trees could therefore increase soil nutrient depletion and the need for fertilizers to maintain high yields. Second, the quality of the wood obtained from young trees wood may not be optimal for cellulose production because wood density increases with tree aging (Sette et al., 2012). Additionally, increasing the frequency of harvesting operations could raise the final cost of a meter cubic of wood.

The marked preference for the coppice strategy (the second most preferred option of respondents) can be explained by the fact that a number of farmers already know this management practice and possibly employ it at least partially.[16] In such a case, adopting this

[16]Such information was collected in the field as part of the informal discussion with farmers.

strategy could be done without a significant decrease in income. Additionally, the possibility of multiple earnings from more rotations combined with the smaller cultivation costs can also make the eucalypt coppice system more economically attractive than alternative options (Ribeiro and Graca, 1996).

Another important finding of our study is the reluctance of farmers to decrease the plantation density to cope with prolonged drought periods, while this option is often highlighted by researchers in ecophysiology and silviculture (Booth, 2013; Gonçalves et al., 2017). One plausible reason for this is that switching from one tree per area of 3 meters by 3 meters to one tree per area of 3 meters by 4 meters would mean replacing the usual 1,111 trees per hectare by 833 trees per hectare – a loss that farmers would overestimate. Moreover, this option has some drawbacks, like the time needed to reach canopy closure, which would increase the need for weeding during the early growth stage.

5.3 Heterogeneity in farmers' preferences

Third, we found that farmersâ preferences for adaptation strategies are heterogenous. Our results from the mixed logit model indeed suggest that respondentsâ preferences are heterogeneous for a number of attributes, which include not only the rewards but also the adaptation strategies themselves. Our results from the latent class model moreover suggest that adaptation to climate change remains a major concern mainly for the most vulnerable out-growers (named Class 1), while other farmers who are less dependent on income from eucalypt plantations exhibit much less concern about it (named Class 2). These results are consistent with that highlighted by previous choice experiments involving farmers exposed to climate change in other regions of the world (Nthambi, Markova-Nenova, and Wätzold, 2021; Khanal et al., 2019; Schaafsma, Ferrini, and Turner, 2019) just to cite some recent ones). Our findings moreover suggest that adaptation policies should target the most vulnerable smallholders first (Donatti et al., 2018), whether with the objective of supporting the standard of living of households that depend on the cultivation of eucalypt or with the objective of preserving water resources. This is because our analysis shows that this category of the population displays more marked preferences for the proposed adaptation strategies.

6 Conclusion

This paper reports the results of a CE study that investigates how eucalypt farmers arbitrate between changes in silvicultural management practices and the monetary compensation offered in exchange for adopting these practices. Our approach compares several innovative silvicultural strategies, as well as a variety of "rewards" (or support) for undertaking these strategies.

A mixed logit model and latent class model were used to analyse the CE data. When we analyse farmers' preferences as a whole, we find that adaptation to climate change is more likely to occur by reducing the eucalypt cutting cycle, since the majority of farmers have a predilection for this adaptation strategy. However, this practice could entail negative environmental and economic impacts. Furthermore, the farmers in our survey were shown to be extremely averse to reducing the density of eucalypt trees on their plantations. Since reducing tree density could be a more sustainable strategy than reducing the length of the cutting cycle, governmental, non-governmental or private bodies may want to consider supporting this practice. This, however, this can only be done at a high cost.

When we analyse heterogeneity in farmers' preferences for adaptation strategies, a two-class model explained the observed choices and provided a clear segmentation between farmer types. We detected that both groups are likely to adapt to the upcoming global changes, but not in the same way. In particular, a small group of the most vulnerable farmers appear to drive the result on the preference to adapt to climate change by reducing the cutting cycle. These results suggest that a customized approach to payments for ecosystem services[17] would make sense in this context.

Lastly, this study is only looking at one part of the problem (that of Eucalypt farmers) and not that of society as a whole (which would then include water consumers or other types of farmers). It gives us clues about farmers' willingness to adopt the proposed silvicultural changes and provides information regarding the order of magnitude, in monetary terms, with which farmers value each strategy. Overall, our results suggest that adaptation may not require complex or expensive changes. However, management should consider the maintenance and provision of environmental services across the landscape. One direction for further research is to better understand the divergence between private and social optima and define strategies for climate change adaptation that assure long-term sustainability for the planted forest sector.

[17] PES have been generally defined as transfers of resources between stakeholders in order to encourage the agreement between individual and/or collective land use with the public interest in the management of natural resources (Muradian et al., 2010).

References

Abebe, G.K., J. Bijman, R. Kemp, O. Omta, and A. Tsegaye. 2013. "Contract farming configuration: Smallholders' preferences for contract design attributes." *Food Policy* 40:14 – 24.

Adamowicz, W., P. Boxall, M. Williams, and J. Louviere. 1998. "Stated Preference Approaches for Measuring Passive Use Values: Choice Experiments and Contingent Valuation." *American Journal of Agricultural Economics* 80:64–75.

Agência Nacional de Águas. 2010. "Plano Integrado de Recursos Hídricos da Bacia Hidrográfica do Rio Doce." Working paper, Superintêndencia de Planejamento de Recursos Hídricos.

Alam, G.M., K. Alam, and S. Mushtaq. 2016. "Influence of institutional access and social capital on adaptation decision: Empirical evidence from hazard-prone rural households in Bangladesh." *Ecological Economics* 130:243 – 251.

Alauddin, M., and M.A.R. Sarker. 2014. "Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: an empirical investigation." *Ecological Economics* 106:204 – 213.

Almeida, A.C.d., and J.V. Soares. 2003. "Comparação entre uso de água em plantações de Eucalyptus grandis e floresta ombrófila densa (Mata Atlântica) na costa leste do Brasil.", pp. .

Anderson, J.R., and G. Feder. 2007. "Agricultural extension." *Handbook of agricultural economics* 3:2343–2378.

Andow, D., M. Resende Filho, R. Carneiro, D. Lorena, E. Sujii, and R. Alves. 2017. "Heterogeneity in intention to adopt organic strawberry production practices among producers in the Federal District, Brazil." *Ecological Economics* 140:177–189.

Battie-Laclau, P., J.S. Delgado-Rojas, M. Christina, Y. Nouvellon, J.P. Bouillet, M. de Cassia Piccolo, M.Z. Moreira, J.L. de Moraes Gonçalves, O. Roupsard, and J.P. Laclau. 2016. "Potassium fertilization increases water-use efficiency for stem biomass production without affecting intrinsic water-use efficiency in Eucalyptus grandis plantations." *Forest Ecology and Management* 364:77–89.

Beck, M.J., J.M. Rose, and D.A. Hensher. 2013. "Environmental attitudes and emissions charging: An example of policy implications for vehicle choice." *Transportation Research Part A: Policy and Practice* 50:171–182.

Booth, T.H. 2013. "Eucalypt plantations and climate change." *Forest Ecology and Management* 301:28–34.

Broch, S.W., N. Strange, J.B. Jacobsen, and K.A. Wilson. 2013. "Farmers' willingness to provide ecosystem services and effects of their spatial distribution." *Ecological Economics* 92:78 – 86, Land Use.

Calder, I.R. 1998. "Water use by forests, limits and controls." *Tree physiology* 18:625–631.

Chen, H., J. Wang, and J. Huang. 2014. "Policy support, social capital, and farmers' adaptation to drought in China." *Global Environmental Change* 24:193 – 202.

Christina, M., G. Le Maire, Y. Nouvellon, R. Vezy, B. Bordon, P. Battie-Laclau, J.L.d.M. Gonçalves, J.S. Delgado-Rojas, J.P. Bouillet, and J.P. Laclau. 2018. "Simulating the effects of different potassium and water supply regimes on soil water content and water table depth over a rotation of a tropical Eucalyptus grandis plantation." *Forest Ecology and Management* 418:4–14.

Christina, M., Y. Nouvellon, J.P. Laclau, J.L. Stape, J.P. Bouillet, G.R. Lambais, and G. Maire. 2017. "Importance of deep water uptake in tropical eucalypt forest." *Functional Ecology* 31:509–519.

Cohen, J., K.M. Ericson, D. Laibson, and J.M. White. 2020. "Measuring time preferences." *Journal of Economic Literature* 58:299–347.

Colombo, S., N. Hanley, and J. Louviere. 2009. "Modeling preference heterogeneity in stated choice data: an analysis for public goods generated by agriculture." *Agricultural Economics* 40:307–322.

Cornish, P. 1993. "The effects of logging and forest regeneration on water yields in a moist eucalypt forest in New South Wales, Australia." *Journal of Hydrology* 150:301 – 322.

de Barros Ferraz, S.F., C.B. Rodrigues, L.G. Garcia, C.A. Alvares, and W. de Paula Lima. 2019. "Effects of Eucalyptus plantations on streamflow in Brazil: Moving beyond the water use debate." *Forest Ecology and Management* 453:117571.

de Bekker-Grob, E.W., B. Donkers, M.F. Jonker, and E.A. Stolk. 2015. "Sample size requirements for discrete-choice experiments in healthcare: a practical guide." *The Patient-Patient-Centered Outcomes Research* 8:373–384.

de Souza, F.C., G.G. dos Reis, M.d.G.F. Reis, H.G. Leite, R.S. de Faria, J.P. Caliman, R.A. Barbosa, and C.H.R. de Oliveira. 2016. "Growth of intact plants and coppice in short rotation eucalypt plantations." *New Forests* 47:195–208.

Deressa, T.T., and R.M. Hassan. 2009. "Economic Impact of Climate Change on Crop Production in Ethiopia: Evidence from Cross-section Measures." *Journal of African Economies* 18:529–554.

Deressa, T.T., R.M. Hassan, C. Ringler, T. Alemu, and M. Yesuf. 2009. "Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia." *Global Environmental Change* 19:248 – 255, Traditional Peoples and Climate Change.

Di Falco, S., M. Veronesi, and M. Yesuf. 2011. "Does Adaptation to Climate Change Provide Food Security? A Micro-Perspective from Ethiopia." *American Journal of Agricultural Economics* 93:829–846.

Di Falco, S., M. Yesuf, G. Kohlin, and C. Ringler. 2012. "Estimating the Impact of Climate Change on Agriculture in Low-Income Countries: Household Level Evidence from the Nile Basin, Ethiopia." *Environmental and Resource Economics* 52:457–478.

Donatti, C.I., C.A. Harvey, M.R. Martinez-Rodriguez, R. Vignola, and C.M. Rodriguez. 2018. "Vulnerability of smallholder farmers to climate change in Central America and Mexico: current knowledge and research gaps." *Climate and Development* 0:1–23.

Espinosa-Goded, M., J. Barreiro-Hurle, and E. Ruto. 2010. "What Do Farmers Want From Agri-Environmental Scheme Design? A Choice Experiment Approach." *Journal of Agricultural Economics* 61:259–273.

FAO. 2011. "Eucalyptus in East Africa, Socio-economic and environmental issues." Working paper, FAO.

—. 2001. "Forestry out-grower schemes: A global overview." Working paper, Report based on the work of D. Race and H. Desmond. Forest Plantation Thematic Papers, Working Paper 11. Forest Resources Development Service, Forest Resources Division. FAO, Rome.

Ferraz, S.F., W. de Paula Lima, and C.B. Rodrigues. 2013. "Managing forest plantation landscapes for water conservation." *Forest Ecology and Management* 301:58–66.

Germon, A., C. Jourdan, B. Bordron, A. Robin, Y. Nouvellon, L. Chapuis-Lardy, J.L. de Moraes Gonçalves, C. Pradier, I.A. Guerrini, and J.P. Laclau. 2019. "Consequences of clear-cutting and drought on fine root dynamics down to 17m in coppice-managed eucalypt plantations." *Forest Ecology and Management* 445:48 – 59.

Gevrek, Z.E., and A. Uyduranoglu. 2015. "Public preferences for carbon tax attributes." *Ecological Economics* 118:186–197.

Gonçalves, J.L., C.A. Alvares, A.R. Higa, L.D. Silva, A.C. Alfenas, J. Stahl, S.F. de Barros Ferraz, W. de Paula Lima, P.H.S. Brancalion, A. Hubner, J.P.D. Bouillet, J.P. Laclau, Y. Nouvellon, and D. Epron. 2013. "Integrating genetic and silvicultural strategies to minimize abiotic and biotic constraints in Brazilian eucalypt plantations." *Forest Ecology and Management* 301:6 – 27, Challenges and opportunities for sustainable management of eucalypt plantations.

Gonçalves, J.L., C.A. Alvares, J.H. Rocha, C.B. Brandani, and R. Hakamada. 2017. "Eucalypt plantation management in regions with water stress." *Southern Forests: a Journal of Forest Science* 79:169–183.

Gonçalves, J.d.M., J.L. Stape, J.P. Laclau, J.P. Bouillet, and J. Ranger. 2008. "Assessing the effects of early silvicultural management on long-term site productivity of fast-growing eucalypt plantations: the Brazilian experience." *Southern Forests: a Journal of Forest Science* 70:105–118.

Greene, W.H., and D.A. Hensher. 2003. "A latent class model for discrete choice analysis: contrasts with mixed logit." *Transportation Research Part B: Methodological* 37:681–698.

Hole, A.R. 2007. "Fitting mixed logit models by using maximum simulated likelihood." *The Stata Journal* 7:388–401.

Horne, P., et al. 2006. "Forest owners' acceptance of incentive based policy instruments in forest biodiversity conservation – A choice experiment based approach." *Silva Fennica* 40:169–178.

Huang, J., Y. Wang, and J. Wang. 2015. "Farmers' Adaptation to Extreme Weather Events through Farm Management and Its Impacts on the Mean and Risk of Rice Yield in China." *American Journal of Agricultural Economics* 97:602–617.

Hubbard, R.M., J. Stape, M.G. Ryan, A.C. Almeida, and J. Rojas. 2010. "Effects of irrigation on water use and water use efficiency in two fast growing Eucalyptus plantations." *Forest Ecology and Management* 259:1714–1721.

IBA. 2016. "Relatorio Anual IBA." Working paper, IBA.

IPCC. 2014. "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change." Working paper, [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Kaczan, D., B.M. Swallow, and W.V. Adamowicz. 2013. "Designing a payments for ecosystem services (PES) program to reduce deforestation in Tanzania: An assessment of payment approaches." *Ecological Economics* 95:20 – 30.

Keenan, R.J. 2015. "Climate change impacts and adaptation in forest management: a review." *Annals of Forest Science* 72:145–167.

Khanal, U., C. Wilson, V.N. Hoang, and B. Lee. 2018. "Farmers' Adaptation to Climate Change, Its Determinants and Impacts on Rice Yield in Nepal." *Ecological Economics* 144:139 – 147.

Khanal, U., C. Wilson, B.L. Lee, V.N. Hoang, and S. Managi. 2019. "Influence of payment modes on farmersâ contribution to climate change adaptation: understanding differences using a choice experiment in Nepal." *Sustainability Science* 14:1027–1040.

Kruschke, J.K., and T.M. Liddell. 2017. "Bayesian data analysis for newcomers." *Psychonomic Bulletin & Review*, pp. 1–23.

Kuhfuss, L., R. Préget, S. Thoyer, and N. Hanley. 2016. "Nudging farmers to enrol land into agri-environmental schemes: the role of a collective bonus." *European Review of Agricultural Economics* 43:609–636.

Laclau, J.P., E.A.d. Silva, G. Rodrigues Lambais, M. Bernoux, G. Le Maire, J.L. Stape, J.P. Bouillet, C. Jourdan, Y. Nouvellon, et al. 2013. "Dynamics of soil exploration by fine roots down to a depth of 10 m throughout the entire rotation in Eucalyptus grandis plantations." *Frontiers in plant science* 4:243.

Laibson, D. 1997. "Golden eggs and hyperbolic discounting." *The Quarterly Journal of Economics* 112:443–478.

Lienhoop, N., and R. Brouwer. 2015. "Agri-environmental policy valuation: Farmers' contract design preferences for afforestation schemes." *Land Use Policy* 42:568 – 577.

List, J.A., and C.A. Gallet. 2001. "What experimental protocol influence disparities between actual and hypothetical stated values?" *Environmental and resource economics* 20:241–254.

Matusick, G., K.X. Ruthrof, N.C. Brouwers, B. Dell, and G.S.J. Hardy. 2013. “Sudden forest canopy collapse corresponding with extreme drought and heat in a mediterranean-type eucalypt forest in southwestern Australia.” *European Journal of Forest Research* 132:497–510.

Minten, B., L. Randrianarison, and J.F. Swinnen. 2009. “Global retail chains and poor farmers: Evidence from Madagascar.” *World development* 37:1728–1741.

Moore, F.C., U. Baldos, T. Hertel, and D. Diaz. 2017. “New science of climate change impacts on agriculture implies higher social cost of carbon.” *Nature Communications* 8.

Muradian, R., E. Corbera, U. Pascual, N. Kosoy, and P.H. May. 2010. “Reconciling theory and practice: An alternative conceptual framework for understanding payments for environmental services.” *Ecological economics* 69:1202–1208.

Ngigi, M.W., U. Mueller, and R. Birner. 2017. “Gender Differences in Climate Change Adaptation Strategies and Participation in Group-based Approaches: An Intra-household Analysis From Rural Kenya.” *Ecological Economics* 138:99 – 108.

Nthambi, M., N. Markova-Nenova, and F. Wätzold. 2021. “Quantifying Loss of Benefits from Poor Governance of Climate Change Adaptation Projects: A Discrete Choice Experiment with Farmers in Kenya.” *Ecological Economics* 179:106831.

Poore, M., and C. Fries. 1985. “The ecological effects of eucalyptus.” Working paper, FAO Forestry Paper.

Prasada, D. 2020. “Climate-Indexed Insurance as a Climate Service to Drought-Prone Farmers: Evidence from a Discrete Choice Experiment in Sri Lanka.” In *Handbook of Climate Services*. Springer, pp. 423–445.

Revelt, D., and K. Train. 2001. “Customer-Specific Taste Parameters and Mixed Logit: Households’ Choice of Electricity Supplier.” Econometrics No. 0012001, EconWPA, Jan.

—. 1998. “Mixed Logit With Repeated Choices: Households’ Choices Of Appliance Efficiency Level.” *The Review of Economics and Statistics* 80:647–657.

Ribeiro, C.A.A.S., and L.R. Graca. 1996. “Manejo por talha dias: estabelecimento das idades otimas de corte.” *Revista Arvore* 20:29–36.

Rode, R., H.G. Leite, M.L. da Silva, C.A.Á.S. Ribeiro, and D.H.B. Binoti. 2014. “The economics and optimal management regimes of eucalyptus plantations: A case study of forestry outgrower schemes in Brazil.” *Forest Policy and Economics* 44:26–33.

Ruto, E., and G. Garrod. 2009. “Investigating farmers’ preferences for the design of agri-environment schemes: a choice experiment approach.” *Journal of Environmental Planning and Management* 52:631–647.

Samuelson, P.A. 1937. “A note on measurement of utility.” *The review of economic studies* 4:155–161.

Scarpa, R., S. Ferrini, and K. Willis. 2005. *Applications of Simulation Methods in Environmental and Resource Economics. The Economics of Non-Market Goods and Resources, vol 6.*, Springer, Dordrecht, chap. Performance of Error Component Models for Status-Quo Effects in Choice Experiments.

Schaafsma, M., S. Ferrini, and R.K. Turner. 2019. "Assessing smallholder preferences for incentivised climate-smart agriculture using a discrete choice experiment." *Land Use Policy* 88:104153.

Seo, S.N., and R. Mendelsohn. 2008. "Measuring impacts and adaptations to climate change: a structural Ricardian model of African livestock management." *Agricultural Economics* 38:151–165.

Sette, C., I.R. de Oliveira, M. Tomazello Filho, F. Minoru Yamaji, and J.P. Laclau. 2012. "Efeito da idade e posição de amostragem na densidade e características anatômicas da madeira de Eucalyptus grandis." *Revista Árvore* 36:1183–1190.

Sette, C.R., J.P. Laclau, M. Tomazello Filho, R.M. Moreira, J.P. Bouillet, J. Ranger, and J.C.R. Almeida. 2013. "Source-driven remobilizations of nutrients within stem wood in Eucalyptusgrandis plantations." *Trees* 27:827–839.

Sheremet, O., E. Ruokamo, A. Juutinen, R. Svento, and N. Hanley. 2018. "Incentivising participation and spatial coordination in payment for ecosystem service schemes: forest disease control programs in Finland." *Ecological Economics* 152:260–272.

Smethurst, P.J., A.C. Almeida, and R.A. Loos. 2015. "Stream flow unaffected by Eucalyptus plantation harvesting implicates water use by the native forest streamside reserve." *Journal of Hydrology: Regional Studies* 3:187–198.

Smit, B., and M.W. Skinner. 2002. "Adaptation options in agriculture to climate change: a typology." *Mitigation and adaptation strategies for global change* 7:85–114.

Stape, J.L., D. Binkley, M.G. Ryan, S. Fonseca, R.A. Loos, E.N. Takahashi, C.R. Silva, S.R. Silva, R.E. Hakamada, J.M.d.A. Ferreira, et al. 2010. "The Brazil Eucalyptus Potential Productivity Project: Influence of water, nutrients and stand uniformity on wood production." *Forest Ecology and Management* 259:1684–1694.

Train, K.E. 1998. "Recreation Demand Models with Taste Differences over People." *Land Economics* 74:230–239.

Vanslembrouck, I., G. Huylenbroeck, and W. Verbeke. 2002. "Determinants of the Willingness of Belgian Farmers to Participate in Agri-environmental Measures." *Journal of agricultural economics* 53:489–511.

Vignola, R., T.L. McDaniels, and R.W. Scholz. 2012. "Negotiation analysis for mechanisms to deliver ecosystem services: The case of soil conservation in Costa Rica." *Ecological Economics* 75:22–31.

White, D.A., D.S. Crombie, J. Kinal, M. Battaglia, J.F. McGrath, D.S. Mendham, and S.N. Walker. 2009. "Managing productivity and drought risk in Eucalyptus globulus plantations in south-western Australia." *Forest Ecology and Management* 259:33–44.

White, D.A., J.F. McGrath, M.G. Ryan, M. Battaglia, D.S. Mendham, J. Kinal, G.M. Downes, D.S. Crombie, and M.E. Hunt. 2014. "Managing for water-use efficient wood production in Eucalyptus globulus plantations." *Forest ecology and management* 331:272–280.

Wilson, G.A. 1997. "Factors influencing farmer participation in the environmentally sensitive areas scheme." *Journal of environmental management* 50:67–93.

7 Figures and Tables

Figure 1: Location of the study area

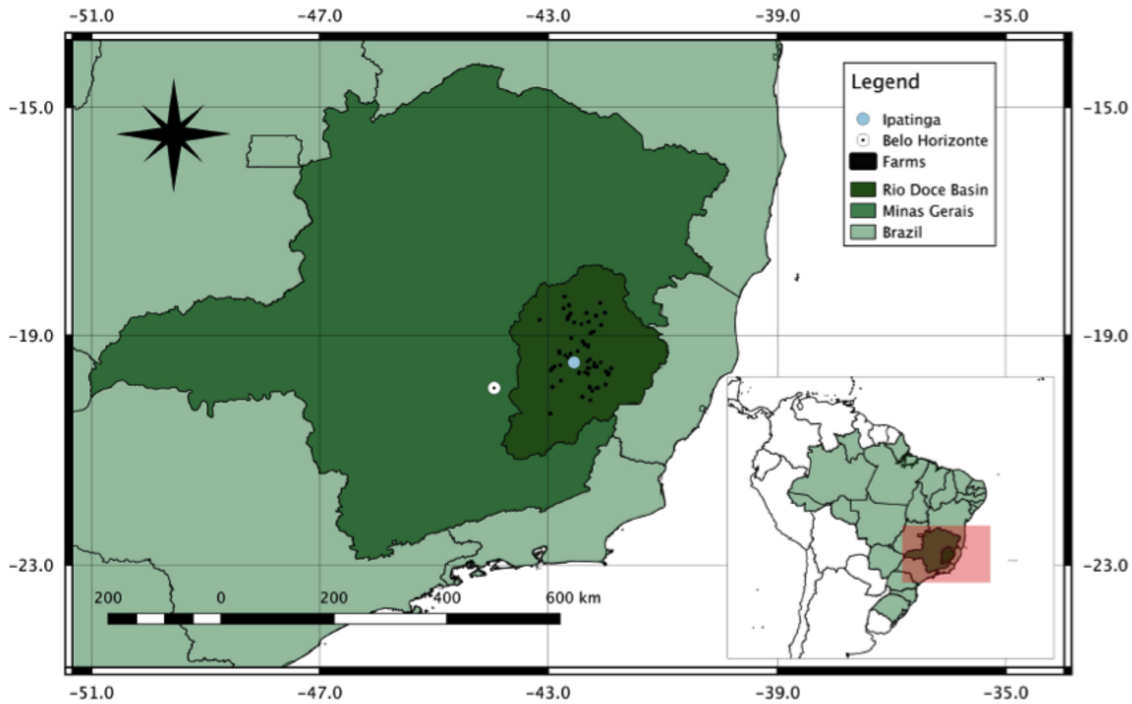
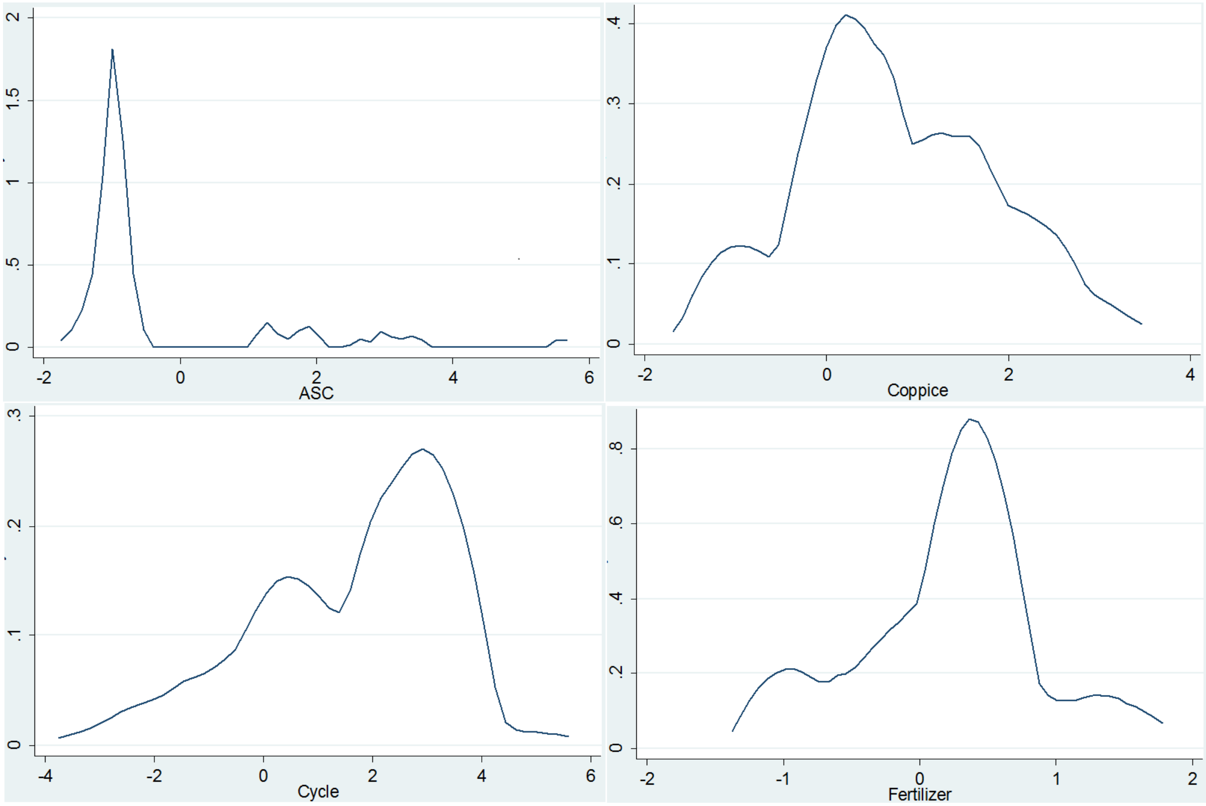


Figure 2: Example of choice card

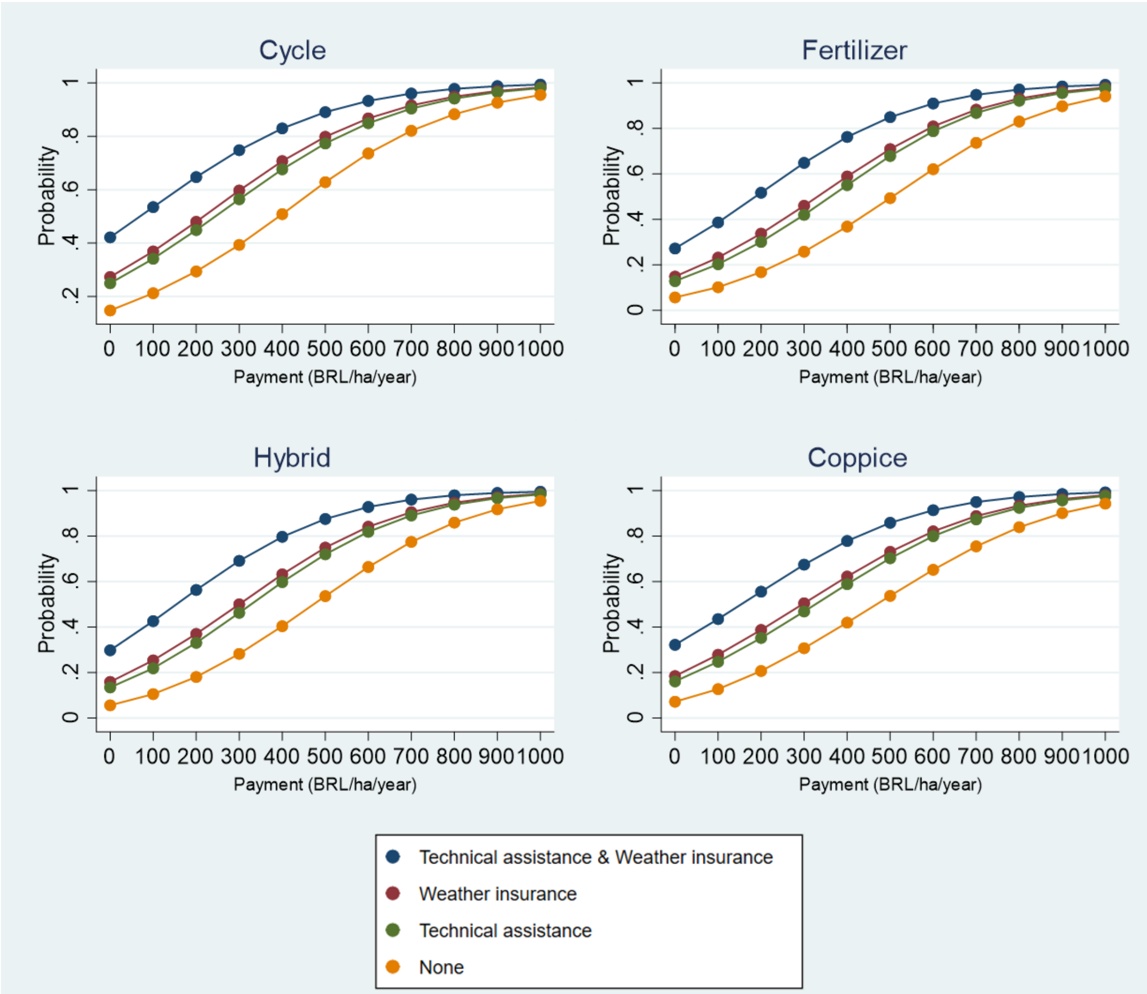
		Option A	Option B
Eucalypt management		4 years	4 m x 3 m
Compensation		**No** technical assistance	**With** technical assistance
		With weather insurance	**No** weather insurance
		R$ 200,00/ha/year	R$ 400,00/ha/year
Choice	☐ **Option A**	☐ **Option B**	☐ **None**

Figure 3: Distribution of the individual-level coefficients



Note: These graphs display the Epanechnikov kernel density estimates for the individual-level coefficients of the mixed logit model.

Figure 4: Simulated probabilities of adapting to climate change for different management options



Note: These diagrams show that an adaptation strategy that includes both technical assistance and weather insurance is the most likely to be accepted for any management option and cash payment, while a strategy that offers none of these two non-cash rewards has the lowest chances to be chosen.

Table 1: Description of attributes and levels

Attribute	Levels	Description
	Density (reference)	Reduction of plantation density (833 trees per hectare instead of 1,111)
	Fertilizer	Reduction of the dose of fertilizers (30% of the current dose)
Silvicultural management	Hybrid	Adoption of drought-tolerant hybrids
	Cycle	Reduction of the cutting cycle (4 years instead of 7 years)
	Coppice	Adoption of coppice management
Technical assistance	Yes; No	Free technical assistance for implementing the management option
Subsidized weather insurance	Yes; No	Subsidy of 50% for the insurance
Compensation (BRL)	100; 200; 300; 400; 500	Financial support to adapt to climate change

Table 2: Sample descriptive statistics

Variable		Unit	Mean	S.d.	Min	Max
Age		Year	52.34	14.16	23	86
Sex		1 = male; 0 = female	0.86	0.35	0	1
Education	Elementary	1 = yes; 0 = no	0.31	0.46	0	1
	Secondary	1 = yes; 0 = no	0.35	0.48	0	1
	Tertiary	1 = yes; 0 = no	0.34	0.47	0	1
Profession	Farmers	1 = yes; 0 = no	0.44	0.496	0	1
	Other profession	1 = yes; 0 = no	0.56	0.496	0	1
Household size		Number	3.42	1.37	1	7
Is eucalypt the main source of income?		1 = yes; 0 = no	0.24	0.43	0	1
Contribution of eucalypt on income	Less than 10%	1 = yes; 0 = no	0.37	0.48	0	1
	Between 10 - 30%	1 = yes; 0 = no	0.29	0.45	0	1
	Between 30 - 60%	1 = yes; 0 = no	0.24	0.43	0	1
	Between 60 - 90%	1 = yes; 0 = no	0.06	0.24	0	1
	More than 90%	1 = yes; 0 = no	0.04	0.19	0	1
Is livestock the main source of income?		1 = yes; 0 = no	0.19	0.39	0	1
Are there employees working all year long with the eucalypt crop?		1 = yes; 0 = no	0.42	0.49	0	1
Experience in eucalypt growing		1 = less than 15 yr; 0 = more than 15 yr	0.67	0.47	0	1
Do farmers have crop insurance?		1 = yes; 0 = no	0.062	0.24	0	1
Land area		Hectares	202.98	214.23	10	920
Eucalypt area		Hectares	89.28	84.9	7.5	400
Productivity (m3/ha/y)	Less than 35	1 = yes; 0 = no	0.15	0.36	0	1
	Between 35 and 40	1 = yes; 0 = no	0.34	0.47	0	1
	Between 40 and 45	1 = yes; 0 = no	0.3	0.46	0	1
	More than 45	1 = yes; 0 = no	0.46	0.5	0	1
	Not yet harvested	1 = yes; 0 = no	0.025	0.16	0	1
Zone	Belo Oriente	1 = yes; 0 = no	0.31	0.46	0	1
	Caratinga	1 = yes; 0 = no	0.29	0.45	0	1
	Cocais	1 = yes; 0 = no	0.2	0.4	0	1
	Pecanha	1 = yes; 0 = no	0.2	0.4	0	1
Cutting cycle		Years	7.02	0.81	5	9
Cost of implementation		BRL/hectare	2856.21	2357.52	800	10800

Table 3: Description of geographic zones in the study area

Zone	Precipitation	Water deficit	Altitude	Major agronomic crops
Belo Oriente	1094 mm	459 mm	220 m	Pasture (mostly overgrazed)
Cocais	1348 mm	137 mm	791 m	Eucalypt
Caratinga	1175 mm	324 mm	578 m	Coffee and Pasture
Pecanha	1171 mm	209 mm	780 m	Eucalypt and Pasture

Source: CENIBRA

Table 4: Mixed logit model estimates

Attribute	Mean		Std.Dev.		WTA
money	0.009	***			
	(0.001)				
assistance	1.298	***	0.758	**	-149
	(0.227)		(0.313)		(-95; -175)
insurance	1.890	***	1.053	**	-217
	(0.706)		(0.485)		(-25; -274)
fertilizer	0.187		1.050	***	
	(0.671)		(0.355)		
hybrid	0.460		-0.281		
	(0.649)		(0.934)		
cycle	1.529	***	2.306	***	-175
	(0.475)		(0.492)		(-51; -279)
coppice	0.750	***	1.482	***	-86
	(0.263)		(0.343)		(-30; -135)
ASC	-0.471		2.255	***	
	(0.796)		(0.519)		
Log-likelihood					-475.60
LR χ^2					81.95
P-value					0.00
Nb. of observations					2,400

Notes: ***, ** and * indicate that the estimated coefficients are statistically significant at the 1%, 5%, and 10% levels, respectively. Standard errors are given in parentheses. Last column gives the willingness-to-accept (WTA) estimates. Confidence intervals of WTA are given in parentheses.

Table 5: Criteria for determining the optimal number of classes

Classes	LLF	CAIC	BIC
2	-488.4	1,095.2	1,073.2
3	-460.8	1,115.4	1,079.4
4	-446.7	1,162.5	1,112.5
5	-434.2	1,212.9	1,148.9

Table 6: Latent class model estimates

Attribute	Class 1		Class 2	
money	0.005	***	0.007	***
	(0.002)		(0.001)	
assistance	0.876	**	1.002	***
	(0.432)		(0.181)	
insurance	0.951	◇	0.459	
	(0.619)		(0.813)	
fertilizer	1.308	◇	1.066	
	(0.884)		(0.840)	
hybrid	1.242	◇	1.282	◇
	(0.872)		(0.843)	
cycle	3.626	***	0.257	
	(0.833)		(0.254)	
coppice	2.162	***	0.430	**
	(0.670)		(0.189)	
ASC	2.826	***	-0.639	
	(0.965)		(0.541)	
Share	0.211		0.789	
Class membership				
gender	18.785		0.000	
(male=1)	(496.59)			
eucalypt as main income	7.128	**	0.000	
(1 if larger than 30 percent)	(3.32)			
eucalypt area	0.037	**	0.000	
(ha)	(0.017)			
location	9.382	**	0.000	
(1 if vulnerable zone)	(3.983)			
Livestock as main income	4.678	*	0.000	
(yes=1)	(2.472)			
constant	-32.707		0.000	
	(496.59)			

Notes: ***, **, * and ◇ indicate that the estimated coefficients are statistically significant at the 1%, 5%, 10% and 15% levels, respectively. Standard errors are given in parentheses.