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

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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.

Key policy insights

- Eucalyptus growers who were asked to choose from several hypothetical adaptation strategies are very much in favor of free technical assistance and subsidized insurance to adapt to climate change.
- 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, while this option is often highlighted by researchers in ecophysiology and silviculture.
- Producers' preferences are highly heterogeneous and adaptation to climate change remains a major concern mainly for most vulnerable out-growers.

Keywords: choice experiment, drought, water resources, eucalyptus, Brazil.

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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 eucalyptus plantations who were asked to choose among several climate change adaptation strategies on eucalyptus plantations.

Eucalyptus is a prime source of low-cost woody biomass, which explains its popularity among both industrial firms and smallholders. In a context of climate change, however, drought is a major risk for eucalyptus plantations. In the Brazilian state of Minas Gerais, recent droughts have caused significant loss of yields and tree mortality in highly productive eucalypt plantations (Gonçalves et al., 2017). The sustainability of eucalyptus plantations is now threatened by high water demand¹ and the absorptive capacity of the fast-growing

¹Previous studies have showed that water use by eucalyptus plantations depends on the particular territory,

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). Therefore, improving water use efficiency by adopting appropriate forest management practices has become a key challenge in ensuring ecologically sustainable levels of productivity (Booth, 2013). 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 eucalyptus 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 of 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 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 producers' 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 Eucalyptus plantations and the possible management options for environmental conditions and land-use practices employed (Poore and Fries, 1985; Cornish, 1993; Calder, 1998; Almeida et al., 2007; Hubbard et al., 2010).

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 eucalyptus plantations and climate change

2.1 Background

Cultivation of eucalyptus trees began in the 19th century and spread throughout the next century as the most planted genus of broadleaf trees in the world. Today eucalyptus 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, eucalyptus is the primary and most productive planted forest in Brazil, covering around 5.6 million hectares (IBA, 2016). Of all eucalyptus plantations in Brazil, more than one-third belongs to companies in the pulp and paper sector. Independent farmers and farmers in outgrower schemes² hold the second largest share of planted forests in Brazil (IBA, 2016).

Short rotation eucalyptus 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 cuttings 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 reforestation as a complement to their agricultural crops. The cultivation of eucalyptus sometimes represents a significant part of their income.

2.2 Plantation management options for adaptation to drought

Eucalyptus 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 eucalyptus), 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

²Outgrower 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).

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).

In order to reduce the risks of tree susceptibility to drought resulting from climate change, several silvicultural systems for eucalyptus production are currently under development. Management options to reduce the risk of tree mortality during exceptional droughts, however, have some drawbacks 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 eucalyptus 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 consumption 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 (the current practice in our study area) 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). 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 net utility from choosing that alternative is greater than choosing either no adaptation or any of the competing choices. The utility that farmer n derives 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.³ 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 Halton draws (Hole, 2007). Since the monetary attribute is assumed to be a fixed parameter in our model, we have the con-

³The 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).

venient 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.

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)

We followed a D-efficient design approach to construct the choice sets, using prior in-

formation we had about the sign and relative values of the design attributes.⁴ 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 eucalyptus 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 living in the state of Minas Gerais. These farmers are part of a forestation incentive program run by Celulose Nipo-Brasileira S.A. (CENIBRA), a privately-held company controlled by Japan Brazil Paper and Pulp Resources Development (JBP), located in Ipatinga, on the eastern part of Rio Doce basin (Figure 1). CENIBRA ships 98 percent of its production to foreign markets, mainly in Asia, Europe, and North America. The industrial plant is supplied with wood from the company's own farms and leased land, as well as from small farmers that plant eucalyptus under a forestation incentive arrangement. The out-grower program is implemented in 87 cities in the state of Minas Gerais.

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. 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. A brief description of the choice task was provided to each respondent before each choice set. We moreover provided plausible values for average annual incremental loss for each scenario, based on expert estimates.⁵ 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.

⁴Efficient 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).

⁵In particular, we ranked the proposed management options according to the likely loss in MAI. Without providing precise estimates, we did however inform the respondents that the loss in MAI associated with the adoption of option SR were theoretically insignificant while those associated with option NH were not, and that the other options (CM, RD and RF) were probably between these two bounds.

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 eucalyptus. The majority of farmers interviewed grew eucalyptus 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. Coppicing, which consists in repeatedly cutting down young tree stems to near ground level to stimulate growth, is by far the most common silvicultural practice in the sample. The average farm size is around 200 ha and the mean area of eucalyptus 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.⁶ 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 eucalyptus 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 eucalyptus trees. Despite the fact that Pecanha is one of the most distantly located plantations, eucalyptus 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 sample is quite representative of CENIBRA out-growers' dispersion in the country.

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.

⁶The 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).

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.

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 strategies 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 R\$175 to implement the density option instead of the cycle option, while he only requires R\$86 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 drought-tolerant hybrids compared to the reference option.

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). 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). 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 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; Vanslebrouck, 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 eucalyptus 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. Such an effect does not appear in Class 2.

5 Discussion

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

Farmers' valuation of reward attributes

First, 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 eucalyptus' 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).

Farmers' valuation of management options

Second, 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. This strong preference for shortening the cutting cycle may indicate that farmers highly value options that bring them money earlier. 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 most surveyed farmers already employ this management practice (see Table 2), meaning that adopting this strategy could be done without additional cost to them. Additionally, the possibility of multiple earnings from more rotations combined with the smaller cultivation costs can also make the eucalyptus 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.

Heterogeneity in farmers' preferences

Third, our results from the latent class model suggest that adaptation to climate change remains a major concern mainly for most vulnerable out-growers. Other farmers who are less dependent on income from eucalyptus plantations exhibit much less concern about it. This result is in line with the state of knowledge regarding smallholders' vulnerability to climate

change. It moreover suggests that adaptation policies should target the most vulnerable smallholders first (Donatti et al., 2018).

6 Conclusion

This paper reports the results of a CE study that investigates how eucalyptus 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 eucalyptus 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 eucalyptus 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. Adaptation by reducing the cutting cycle appears to be an option for a small group of the most vulnerable farmers only rather than the majority of surveyed farmers. These results suggest that a customized approach to payments for ecosystem services⁷ would make sense in this context.

Lastly, this study 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.

⁷PES 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).

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7 Figures and Tables

Figure 1: Location of the study area

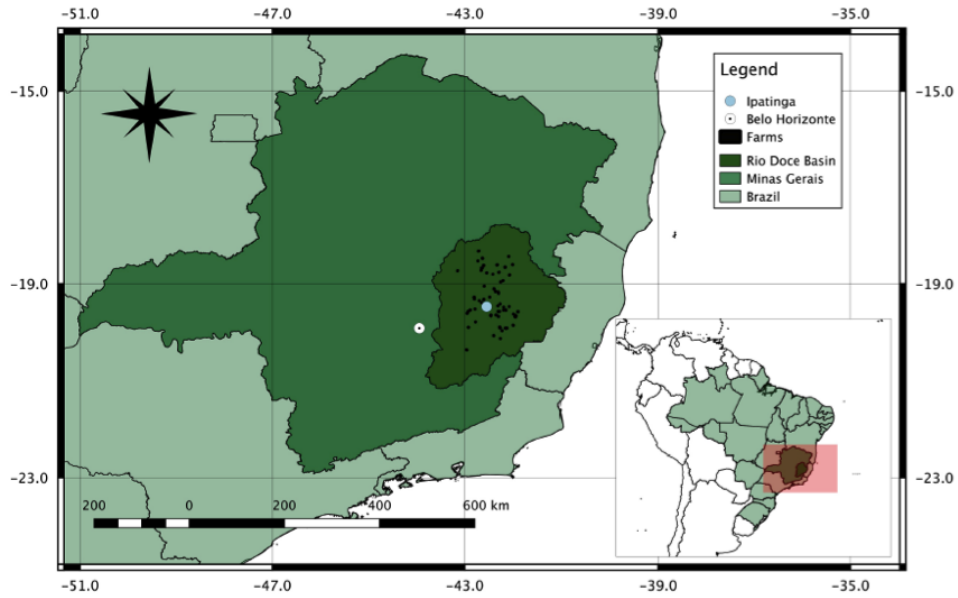
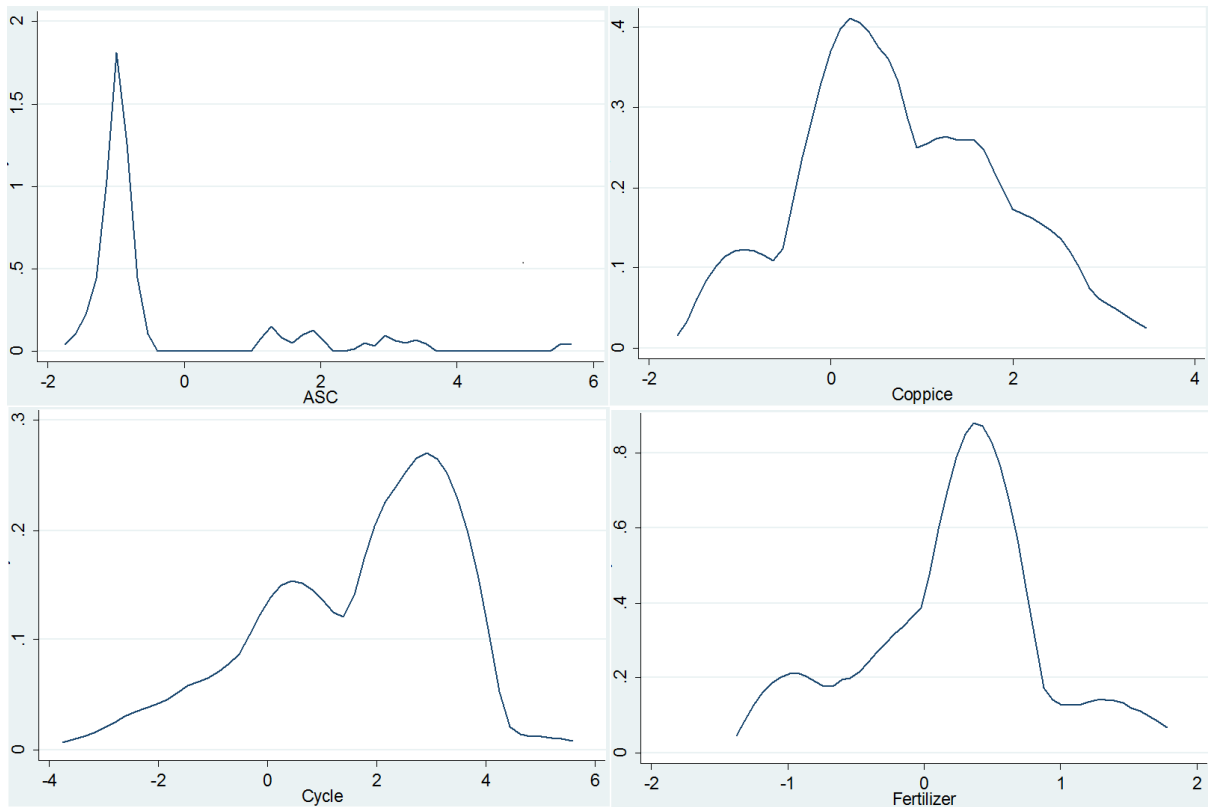


Figure 2: Example of choice card

		Opção A	Opção B
Plano de manejo requerido		 4 anos	 4 m x 3 m
Compensação proposta		Com assistência técnica	Com assistência técnica
		Sem seguro florestal	Sem seguro florestal
		R\$ 400,00/ha/ano	R\$ 300,00/ha/ano
Opção escolhida	<input type="checkbox"/> Opção A	<input type="checkbox"/> Opção B	<input type="checkbox"/> Nenhuma

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.

Table 1: Description of attributes and levels

Attribute	Levels	Description
Silvicultural management	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)
	Hybrid	Adoption of drought-tolerant hybrids
	Cycle	Reduction of the cutting cycle (4 years instead of 7 years)
Technical assistance	Coppice	Adoption of coppice management
	Yes; No	Free technical assistance for implementing the management option
Subsidized weather insurance	Yes; No	Subsidy of 50% for the insurance
	100; 200; 300; 400; 500	Financial support to adapt to climate change
Compensation (BRL)		

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	0.31	0.46	0	1
	Secondary	0.35	0.48	0	1
	Tertiary	0.34	0.47	0	1
	Farmers	0.44	0.496	0	1
Profession	1 = yes; 0 = no	0.56	0.496	0	1
Household size	Number	3.42	1.37	1	7
Is eucalyptus the main source of income?	1 = yes; 0 = no	0.24	0.43	0	1
	Less than 10%	0.37	0.48	0	1
	Between 10 - 30%	0.29	0.45	0	1
	Between 30 - 60%	0.24	0.43	0	1
	Between 60 - 90%	0.06	0.24	0	1
Contribution of eucalyptus on income	1 = yes; 0 = no	0.04	0.19	0	1
	More than 90%	0.19	0.39	0	1
Is livestock the main source of income?	1 = yes; 0 = no	0.42	0.49	0	1
Are there employees working all year long with the eucalyptus crop?	1 = yes; 0 = no	0.67	0.47	0	1
Experience in eucalyptus growing	1 = less than 15 yr; 0 = more than 15 yr	0.062	0.24	0	1
Do farmers have crop insurance?	1 = yes; 0 = no	202.98	214.23	10	920
Land area	Hectares	89.28	84.9	7.5	400
Eucalyptus area	Hectares	0.15	0.36	0	1
	Less than 35	0.34	0.47	0	1
	Between 35 and 40	0.3	0.46	0	1
	Between 40 and 45	0.46	0.5	0	1
Productivity (m3/ha/y)	More than 45	0.025	0.16	0	1
	Not yet harvested	0.31	0.46	0	1
	Belo Oriente	0.29	0.45	0	1
	Caratinga	0.2	0.4	0	1
Zone	Cocais	0.2	0.4	0	1
	Pecanha	7.02	0.81	5	9
Cutting cycle	Years	0.9	0.3	0	1
Management	1 = coppice; 0 = coppice and reforming	2856.21	2357.52	800	10800
Cost of implementation	R\$/hectare				

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 *** (0.227)	0.758 ** (0.313)	149
insurance	1.890 *** (0.706)	1.053 ** (0.485)	217
fertilizer	0.187 (0.671)	1.050 *** (0.355)	
hybrid	0.460 (0.649)	-0.281 (0.934)	
cycle	1.529 *** (0.475)	2.306 *** (0.492)	175
coppice	0.750 *** (0.263)	1.482 *** (0.343)	86
ASC	-0.471 (0.796)	2.255 *** (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.

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.

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