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Climate change adaptation preferences of winemakers from the Rioja wine appellation

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A R T I C L E I N F O

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A B S T R A C T

This paper uses a discrete choice experiment to elicit winemakers' preferences towards climate change adaptation options in the Spanish Rioja region. The experiment includes different potential adaptation strategies such as relocation, the use of various grape clones, the installation of an irrigation system, the construction of vegetative or artificial structures to shade the vines, and oenological adaptations. The results show that the most widely accepted strategy is the installation of irrigation and shading structures. In contrast, the least accepted strategy is relocating, which is a costly and long-term solution. The monetary measures obtained are useful for policymakers because they show how much financial assistance will be required to adapt to climate change and maintain the high-quality wine production of the region. We also investigate the precision that can be expected from choice models with small samples through a simulation study, demonstrating the possibility of recovering true parameter values with small sample sizes using a specific experimental design tailored to the attributes and levels of the study.

1. Introduction

With climate change underway, adaptation is becoming a pressing issue for societies. One sector that might be particularly hard hit is agriculture, as its key production factor – land – is not easy to move. More specifically, winemakers might be significantly affected, as the taste of wine is highly dependent on the conditions under which it is produced. The literature on the impact of climate change on wine production consistently shows a clear trend towards drier and warmer conditions in most wine regions. Therefore, winemakers will have to make appropriate adjustments to these changes (Merloni et al., 2018).

To get a first insight into the evaluation of adaptation measures by winemakers, their preferences for different adaptation measures were investigated using a stated choice experiment. Adaptation to climate change in winegrowing has been addressed in other studies (Sacchelli et al., 2016), mainly discussing potential adaptation options. What is missing from the literature is how winemakers actually assess these options, and how their assessment varies across options. This information is essential for policymakers seeking to support

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what is often an important economic sector in wine-producing regions. Following the literature investigating, for example, farmers' preferences for adopting agricultural practices to reduce nutrient leaching and greenhouse gas emissions (Hasler et al., 2019; Niskanen et al., 2021), winemakers were asked to select the alternative that would be the best option for their business. Each alternative consisted of different adaptation measures and compensation paid by the public.

Rioja, the Spanish flagship region for still red wine, is no exception when it comes to the need to adapt to climate change. Rioja wine is made from grapes grown in an area that includes three autonomous regions in the northern part of Spain: La Rioja, Navarre, and the Basque province of Álava. There are seven traditional varieties authorised by the Regulatory Council of the wine appellation Rioja: four red varieties (Tempranillo, Garnacha, Mazuelo, and Graciano) and three white (Viura, Malvasía, and Garnacha Blanca), although this list was slightly extended in 2007. Located in the western sector of the Ebro Valley, Rioja wine production covers an area of 65,726 ha, with a production of 270.9 million litres of wine in 2019 (Rioja Appellation Regulation Council, 2019). From a geographical point of view, it has a particular combination of climatic, geomorphological, and topographical characteristics that determine the occupation of the agricultural area, which is predominantly of a wine-producing nature.

There is growing evidence that climate change has already affected the wine industry in the Rioja region. For example, Bellido et al. (2020) show that between 1950 and 2014, the average temperature in most of the Rioja region increased by between 0.9 and 1.2 degrees Celsius. This has led to a shift in the vineyard classification towards warmer classes. The authors conclude that the increase in temperature has resulted in climate conditions that are more similar to those of La Mancha, a region located further to the south with traditionally warmer conditions, than to the traditionally characteristic climate of Rioja.

One of the measures Bellido et al. (2020) proposed to adapt to these bioclimatic alterations is to relocate the vineyards towards higher and colder altitudes. However, this would require a significant investment on the part of winegrowers. Therefore, they also suggest using other grape varieties that are better adapted to the new climatic conditions. Other options discussed in the literature include different vineyard management practices, grape coverage based on pruning methods, the use of vegetative or artificial structures to shade the vines, or oenological adaptations such as reverse osmosis or the spinning cone, which are typically used to reduce excessive alcohol levels caused by higher temperatures.

The actions taken by the wine sector in Spain against climate change have also been recently analysed by Carroquino et al. (2020). One of their main conclusions is that, in general, and in line with previous research, understanding the risks of climate change has not been sufficient for winemakers to prompt action against them on their own, and additional policies are necessary. These policies could include, for example, subsidies, environmental regulations for wineries with little sustainability commitment, providing external information for small companies, addressing regional threats and adaptation possibilities, promoting carbon footprint calculation, and establishing a sustainability indicator that covers both mitigation and adaptation.

In addition, winemaking is an essential economic activity for many of the regions concerned, directly generating a significant number of jobs, and, therefore incomes and taxes. Other benefits are that the vineyards and winemakers attract tourists and are thus indirectly support the regional economies (Winfree et al., 2018). Consequently, authorities generally have an interest in helping winegrowers to stay in the region and to maintain their businesses.

The present study aims to extend the literature on climate change adaptation by eliciting winemakers' preferences for different climate change adaptation options in the Spanish region of Rioja, using a discrete choice experiment (DCE). To the best of our knowledge, this is the first study that attempts to apply this valuation technique to the topic of climate change adaptation by winemakers, although it has often been used to elicit farmers' compensation needs for accepting agri-environmental measures (Buschmann and Röder 2019; Niedermayr et al., 2018; Schulz et al., 2014). The value estimates obtained from the DCE could guide policymakers in designing instruments to support adaptation efforts by winemakers, e.g., to develop subsidy schemes that would help the wine industry to adapt and maintain their business in the region.

The other aim of the study is to determine whether small samples can be used to recover valid parameter estimates. Conducting surveys with businesses, especially when the target population is already small, can result in rather small samples. For example, only 567 wineries could be identified in the Rioja region from a list compiled by the Regulatory Council responsible for the region. In addition, many of the wineries are family-run small to medium-sized businesses that often lack the capacity to take on additional tasks on a daily basis. Even if respondents were presented with a series of choice tasks, the total number of choice observations may be small. It is, therefore, important to investigate the degree of precision that can be expected from choice models with small samples is essential. To do this, we conduct a simulation study to test whether there is an experimental design capable of identifying the correct signs of the analysed preferences based on the procedures outlined by Bliemer and Collins (2016) and Mariel et al. (2021, Ch. 3.3). This is a novel approach that shows that we can recover the true parameter values given a specific experimental design even with small sample sizes, and it is specifically tailored to our attributes and levels.

The paper is organised as follows. Section 2 provides an overview of the existing literature on climate change related to the wine industry. Section 3 presents the methodology used in this study: first, a DCE designed to obtain the economic valuation of the different adaptation strategies to climate change in the Spanish region of Rioja; second, a simulation study to investigate whether the small sample size that we have in the DCE is sufficient to recover valid parameter estimates. Section 4 describes the main results. Section 5 concludes with a discussion of the results obtained, the limitations of the present study, and suggestions for future research.

2. The effects of climate change

Although the full impact of climate change is not yet known and will only become clearer as the process continues, there is no doubt that governments need to develop and implement strategies to support businesses in particularly vulnerable sectors. The agricultural sector is likely to be among them, as farmers and growers are already among the first to feel the effects of climate change. There is a broad consensus among wine industry agents that the effects of climate change are already being felt. The literature on climate change, as it relates to winemaking, shows that both the quality and the quantity of wine can be affected by changes in temperature (Ashenfelter and Storchmann, 2016; Jones et al., 2012) and variations in precipitation (Fraga et al., 2016; Jones and Davis, 2000) as well as by other factors such as different soil properties, UV radiation, and vineyard location (Moriondo et al., 2013).

The most direct effect of climate change on existing vineyards is the acceleration of the phenological stages due to the warmer temperatures. Earlier harvest dates and phenological stages have been reported worldwide. In France, Cook and Wolkovich (2016) find that since 1981, harvests have occurred about ten days earlier than the average for the last 400 years. Duchêne and Schneider (2005) find a similar result for north-eastern France between 1972 and 2002, as do Jones and Davis (2000) for the French Bordeaux region. Also in France, but in the Beaune region, Labbé et al. (2019) compile the longest homogeneous grape harvest dates and show that temperatures have increased to such an extent that the harvest happens, on average, 13 days earlier today than it did prior to 1988.

Elsewhere in Europe, Stock et al. (2004) conclude that in the Rheingau area of Germany, the first harvest date was, on average, two to three weeks earlier in the 2000s than a century earlier. Likewise, in California, Nemani et al. (2001) found that the beginning of the growing season shifted to between 18 and 24 days earlier in 1997 compared to 1951. Cahill et al. (2007) project that the harvest in California could be pushed one to two months earlier due to the increasing temperatures and, similarly, Webb et al. (2007) state that harvest dates will advance by two to three weeks in most of the Australian wine regions in 2050 compared to six decades earlier.

Wine-growing regions around the world are classified based on their climate using the Winkler Index (Winkler, 1974). This system divides viticultural areas into five climatic regions based on temperature, which is then converted into growing degree days (GGD). Knowing the number of GGDs is a critical factor in viticulture, as it helps determine what kind of grapes can be grown where (Boulton et al., 2013). Rioja is currently classified in Region III, along with other moderately warm regions such as the Northern Rhone or Margaret River. Climate change may cause Rioja's classification to shift to a warmer class (i.e., Region IV), where regions such as Napa Valley, Stellenbosch or Tuscany are currently found. These warmer regions allow for the ripening of later varieties such as Cabernet Sauvignon, Sangiovese and Syrah, but are less suitable for growing varieties such as Tempranillo, which is not resistant to drought and high temperatures (Lavado et al., 2023). Producers in Rioja would therefore have to try to relocate the vineyards where the current grape varieties are planted to higher altitudes, change the grape varieties they grow, or switch from viticulture to other agricultural productions. However, this has significant technical, legal, financial, cultural, and promotional implications for what Rioja is and does.

In general, adaptation strategies to combat climate change could focus on delaying grape ripening as much as possible. In this respect, Ollat et al. (2016), in a recent overview of the current challenges and strategies for adapting to climate change in the wine industry, agree with the effects of climate change mentioned, differentiating between short-term (viticultural and winemaking strategies) and mid-to long-term (i.e. grape modifications, locations, etc.), and state that adaptation measures are required to combat them. This distinction is also supported by Coupel-Ledru et al. (2014), Parker et al. (2014), and Tilloy et al. (2014).

Viguie et al. (2014) propose another way of categorising winemakers' adaptations to climate change. They distinguish between technical changes – such as changes in grape varieties, pruning methods, irrigation systems, and oenological practices – and organisational and location changes. When choosing between adaptation strategies, they also consider what they call no-regrets measures and flexible and reversible measures.

In another recent study, Wolkovich et al. (2018) focus on switching grape varieties in order to best adapt to climate change. They argue that there are more than a thousand grape varieties, many of which are better suited to hotter temperatures and drought: "The Old World has a huge diversity of wine grapes — there are more than 1,000 planted varieties — and some of them are better adapted to hotter climates and have higher drought tolerance than the 12 varieties now making up over 80 percent of the wine market in many countries" (Reuell, 2018, p. 1).

In summary, the effects of climate change on the wine industry are well documented in the literature and a wide range of adaptation strategies to combat them have been discussed. In the Rioja region of Spain, the development of appropriate adaptation strategies is particularly relevant due to the flagship red wine appellation. However, a specific issue with this particular region is that the adaptation has to consider the production code to obtain the Rioja appellation, which dictates the grape varieties that producers can use. Adaptation strategies must take into consideration the specificity of the region, as suggested by Mozell and Thach (2014).

Regarding the renowned Spanish wines, Duarte Alonso and O'Neill (2011) have already studied the potential effects of climate change and possible adaptation strategies in three prominent Spanish wine regions (La Mancha, La Rioja, and Penedès). In their survey on climate change and its effect on wineries in the mentioned areas, they find that, even though some of the respondents do not see climate change as a threat to their vineyards, or at least are not yet fully convinced that it will be an issue for them in the future, over 40% report that they have already seen the effects of climate change and some of them have even started to adapt. The study also suggests that not all wine producers have found the effects of climate change to be negative.

In another study focused on Spain, Resco et al. (2016) measure the sensitivity to climate change of the entire Spanish territory by region and provided information on what types of adaptation efforts could be adopted to continue the production of wines with a specific appellation such as Rioja. Surprisingly, they argue that in the case of Rioja, climate change might even have a positive impact since it would bring a reduction in frosts and that perhaps "only earlier varieties or warmer micro-climates may need adaptation responses" (Resco et al., 2016, p. 990). Finally, Naulleau et al. (2021) review 111 papers that evaluate adaptation strategies in major vineyards around the world. They conclude that a combination of adaptation strategies usually leads to better solutions, that multi-scale studies are better at considering local constraints and opportunities, and that there are only a few studies applying multi-scale and multi-level approaches to quantify the feasibility and effectiveness of adaptation strategies. Furthermore, the literature on adaptation strategies in the wine sector emphasises that this sector is extremely vulnerable to climate change and that the solution is not straightforward due to the complexity of winemaking and the interactions between socio-economic and environmental variables (Sacchelli et al. 2017).

We try to fill a gap in the literature on climate change adaptation by finding out how winemakers assess the potential effects of climate change on their businesses and what their preferences are concerning adaptation options for their vineyards. Following the literature on farmers' acceptance of agri-environmental measures (Bernués et al., 2019; Zasada, 2011), we use a DCE, a survey-based stated preference method, to determine winemakers' preferences for different adaptation options.

3. Material and methods

3.1. Stated preference survey

As it is generally difficult to persuade companies, which in this case are mainly family-run midsize firms, to give up their time and attention for interviews, we opted for a relatively short questionnaire that focused strongly on the core interest, i.e. the adaptation preferences of the companies. In this way, we aimed to ensure the highest possible quality and response rate. Accordingly, the questionnaire consisted of only two parts. The first part of the survey included a short introduction and five questions about the size of the vineyard, the percentage of land with an irrigation system already in place, the type of wine produced, the year the company was founded, and whether the respondent believes that climate change is real.

The second part of the survey was the DCE. Each respondent was presented with five choice tasks offering three alternative strategies: a status quo alternative and two unlabelled hypothetical alternatives for addressing the effect of climate change on wine production. Each alternative was described by varying levels of the five attributes (Table 1). Each attribute represented a different adaptation option for winemakers. In addition, the two hypothetical alternatives presented a non-zero level of a specific subsidy that the local authorities would partially pay for if winemakers opted for one of those alternatives. Respondents were told that the purpose of the survey was to elicit their preferences regarding these adaptation strategies.

The attributes of the DCE and their levels were selected based on the literature review and the results of a focus group. The focus group was organised in November 2018 in an oenological station located in Haro, a town situated in the northwest of the Rioja province. This station provides analysis and technical support to public and private organisations in the oenological sector. It also carries out analyses to control the ripening of the grapes and the quality controls established by the Rioja Appellation Regulation Council for the classification of wines. The focus group was attended by five winemakers, two technicians and a manager from the oenological station.

Possible adaptations, as discussed in the literature and the focus group, can be classified into short-term and long-term. The short-term ones are mainly related to changes in vinicultural techniques and the wine-making process, while long-term adaptations include vineyard relocation and changes in plant material. The focus group revealed that winegrowers have already begun and are continuing to adapt to the changing climate through simple measures such as harvesting the grapes earlier due to the increase in temperature, leaving more leaves on the vines to protect them from the sun, or reforestation near the vineyards.

In the case of the Rioja region, not all available adaptation strategies can be implemented; for example, changing the grape variety to one that grows better in the new climate is not feasible. This is because the Regulatory Council of the wine appellation Rioja defines the authorised varieties and wine-making practices. Even though rising temperatures may force the Regulatory Council to change the close link between certain grape varieties and locations in the future, the strategies proposed in the DCE must be feasible under current regulatory norms.

Moreover, some of these adaptation strategies, such as relocating vineyards or changing plant material, are costly and difficult to implement because "vines are perennials with a productive life of more than 25 years, but full production is not achieved until 5 or 6 years after planting" (Ashenfelter and Storchmann 2016, p. 26). Nevertheless, our DCE includes both short-term and long-term adaptation strategies that may be feasible for wine producers if sufficient financial support is available from the local authority. Moreover, the proposed strategies are in line with the '2019 ProWein Business Report', which states that in order to avoid greater irregularity in production levels and prevent market volatility, the most urgent adaptations are changes in vineyard locations, grapevine varieties, and some cultivation practices (Santos et al. 2020).

The first attribute, *Grape*, represents different clones of authorised grape varieties that are presumed to be more resistant to the effects of climate change (Table 1) than those currently used by wineries. It was explicitly stated in the attribute description that this change refers to different clones of the same grape variety to avoid misunderstandings with the use of non-authorised grape varieties. The second attribute, *Relocation*, represents the relocation of existing vineyards to a higher altitude or a different orientation. The third attribute, *Irrigation*, involves the implementation of a full irrigation system in all of the winemaker's vineyards. The fourth attribute, *Grape Coverage*, can represent two different ways of covering the grapes. The first system of grape coverage is based on the implementation of specific pruning or driving, which leads to good growth and manipulation of the canopy (the leaf coverage of the grapevine). The second system of grape coverage represents the implementation of a specific vegetative or artificial structural cover. The fifth attribute, *Oenological Adaptations,* represents adaptations typically used to reduce excessive alcohol levels caused by higher temperatures through technologies such as reverse osmosis or the spinning cone. Finally, the last attribute is a hypothetical subsidy. It was specified as a one-off payment per hectare of vineyard. The winemakers would receive the indicated amount of money from the local authorities to implement the proposed adaptation strategies. The costs of the adaptation measures are likely to vary considerably, as some are more short-term, while others are long-term. Therefore, the subsidies would not cover the full cost of every adaptation measure offered. The fact that, in some cases, winemakers would also have to invest their own money should provide an incentive for them to be honest about their preferences and avoid possible windfall profits. As a benchmark for setting the range of cost levels, we used the information that planting a vineyard costs around 14,000 euros per hectare (Viveros Barber, 2018). The maximum amount of €9,000 would therefore cover about two-thirds of such an investment.

Table 1
Attributes and their levels.

Attribute	Levels
Grape	No change Different clones
Relocation	No change Relocation to higher altitude or different orientation
Irrigation	No change Implementation of a full irrigation system
Grape coverage	No change Implementation of specific pruning or driving Implementation of a structural cover (vegetal or artificial)
Oenological adaptations	No change Implementation of specific adaptations (reverse osmosis, spinning cone, etc.)
Subsidy	0 €/ha, 1,000 €/ha, 3,000 €/ha, 5,000 €/ha, 7,000 €/ha, 9,000 €/ha

The final version of the questionnaire consisted of five choice tasks, each containing the status quo or business-as-usual option plus two alternative adaptation strategies (strategy A and strategy B). An example of a choice task translated into English is presented in Fig. 1. More details on the experimental design are included in section 3.3.

3.2. Econometric approach

To analyse the choice data, we used the McFadden (1974) random utility maximisation model, which is based on the assumption of the utility-maximising behaviour of individuals. Under this assumption, an individual n out of N individuals faces a choice between J alternatives on one or T repeated choice occasions. On a choice occasion t, the individual n obtains a certain level of indirect utility U_{njt} from an alternative j. This model also assumes that the researcher does not have complete information about the individual decision maker and that individual preferences are the sum of a systematic part (V_{njt}) and a random error term (ε_{njt}):

$$U_{njt} = V_{njt} + \varepsilon_{njt}.$$

	NO CHANGE	**STRATEGY A**	**STRATEGY B**
GRAPE	No change	Different clones	Different clones
RELOCATION	No change	No change	Change in location (in orientation, higher altitudes)
IRRIGATION	No change	Full irrigation	No change
GRAPE COVERAGE	No change	Pruning methods, conduction systems	Structural coverage (vegetative or artificial)
ENOLOGICAL ADAPTATIONS	No change	No change	Specific adaptations (reverse osmosis, spinning cone)
SUBSIDY	*0€/ha*	*3,000€/ha*	*7,000€/ha*
I choose (only one option)	☐	☐	☐

Fig. 1. Example of a choice task.

The deterministic utility V_{njt} is usually assumed to be linear in parameters, i.e., $V_{njt} = x_{njt}^{'}\beta$, where x_{njt} is a vector of attributes of the adaptation strategies (Table 1) and β is a vector of unknown coefficients. Thus, the model becomes:

$$U_{njt} = V_{njt} + \varepsilon_{njt} = x_{njt}^{'}\beta + \varepsilon_{njt}. \tag{1}$$

Alternative i is chosen by the individual n on choice occasion t if and only if $U_{nit} > U_{njt}, \forall j \neq i$. Different assumptions about Equation (1) elements lead to different models. In a Multinomial Logit (MNL) model, the error terms ε_{njt} are assumed to be independently identically distributed type I extreme values over time, individuals, and alternatives. In this case, the probability of choosing alternative i has a simple closed-form expression (Train 2009, Ch. 3):

$$P_{nit} = \frac{exp\left(x_{nit}^{'}\beta\right)}{\sum_{j=1}^{J} exp\left(x_{njt}^{'}\beta\right)},$$

and the parameters β can be easily estimated by the maximum likelihood method. The inclusion of the monetary attribute *Subsidy* allows calculation (Carson and Hanneman, 2005) of the Willingness To Accept (WTA). The WTA is the minimum amount of money an individual would be willing to accept as compensation for a negative externality or to give up a marginal change in an attribute. Given that the monetary attribute in our case is a subsidy to be received and not a price to be paid, the flow of money is reversed compared to a typical DCE valuation study that includes a price attribute. WTA values are, therefore, calculated as the change in an attribute relative to the cost (Train 2009) or:

$$WTA = \frac{\beta_{attribute}}{\beta_{price}}.$$

Since all of the attributes are dummy coded, the interpretation of the WTA is, in our case, the minimum amount of subsidy that the winemaker would accept in order to obtain a specific level of the non-subsidy attribute. All non-price attributes were dummy coded, with the *No Change* level being zero. For the *Grape Coverage* attribute, two dummy variables were defined, one for each of the two non-*No-Change* levels.

3.3. Testing the degree of precision of parameter estimates under small samples

Given that a small sample size was expected, we focused in detail on the efficiency of the experimental design of our DCE. We paid particular attention to the generation of design priors and the choice of design itself. Our goal was to generate an efficient experimental design with ten rows and two blocks that would allow us to obtain reliable parameter estimates even with a small sample. Therefore, we conducted the following simulation study to demonstrate the degree of precision of MNL results given a small dataset. The study consists of two main parts: first, we perform a series of exercises to determine the best possible priors: we follow the procedure recently proposed in Bliemer and Collins (2016). Second, we follow a novel approach described in Mariel et al. (2021, Ch. 3.3) and carry out a series of simulation exercises to determine an experimental design that would yield parameter estimates with the highest precision.

As it is well known, the definition of efficient designs is related to the minimisation of standard errors obtained as a result of estimating parameters from the data generated by the design. We know that standard errors are given as the square root of the diagonal terms of the asymptotic variance-covariance matrix, and their consistent estimator is given as the negative inverse of the matrix of second-order derivatives of the log-likelihood function (the Hessian matrix), i.e.:

$$\Omega_N(X, Y, \widetilde{\beta}) = -\left[\frac{\partial^2 L_N(X, Y, \widetilde{\beta})}{\partial\widetilde{\beta}\partial\widetilde{\beta}}\right]$$

where N is the number of respondents in the sample, X is the right-hand side matrix of explanatory variables of (1) based on the experimental design, Y represents the respondents' choices and $\widetilde{\beta}$ are the parameter estimates. Since the Hessian depends on $\widetilde{\beta}$, the procedure devoted to finding the experimental design involves the values of $\widetilde{\beta}$, and therefore correctly specifying the priors is crucial.

Given the relative novelty of the procedure, there are only a few very recent examples in the literature of DCEs that use the method developed by Bliemer and Collins (2016) to determine priors for the generation of efficient designs. Our paper contributes by extending the Bliemer and Collins (2016) methodology by including several simulation exercises, which provide insights into the expected precision levels of the estimated parameters of the model. The priors have been determined using the Bliemer and Collins (2016) procedure, also used by De Marchi et al.(2022), who focused on cisgenic foods and motivations for their acceptance, and Nthambi et al. (2021), who analysed farmers' preferences for climate change adaptation measures in Kenya. It has also been used in other areas, such as tourism, by Grilli et al. (2021) to explore prospective visitors' preferences for sustainable tourism development options in Small Island Developing States.

The procedure assumes that a prior parameter value of the coefficient corresponding to the k-th attribute, $\widetilde{\beta}_k$, follows a normal distribution with mean μ_k and standard deviation σ_k. Then, the scaled prior, $\widetilde{\beta}_k^*$, is normally distributed according to

$$\widetilde{\beta}_k^* \sim \mathbb{N}(\widetilde{\lambda}\mu_k, \widetilde{\lambda}\sigma_k), \tag{2}$$

where $\widetilde{\lambda}$ is the scaling parameter. The first step in this procedure is to determine the range of the attribute levels and rank them based on expected preferences. These values are presented in Table A.1 and correspond to the attribute definitions presented in Table 1.

The second assumption is that analysts use their expertise to determine Bayesian priors for μ_k and σ_k in collaboration with experts or by consulting the literature. This can be accomplished by comparing each attribute to the base attribute (in our case, cost) in a simple two-alternative choice task and providing a range of attribute levels at which both alternatives are assumed to be equally preferred. Rather than specifying a single level, experts in the field, typically in a focus group setting, are asked to provide a range that they believe contains the appropriate level with 95% confidence. These values, shown in square brackets in Table A.2, were agreed upon by three wine producers of the Rioja region. These ranges in square brackets in Table A.2 imply minimum and maximum trade-offs Δ^{min} and Δ^{max}. Then, according to Bliemer and Collins (2016), the Bayesian priors for μ_k and σ_k can be calculated as follows:

$$\mu_k = \frac{\Delta_s^{min} + \Delta_s^{max}}{\Delta_k^{min} + \Delta_k^{max}},$$

$$\sigma_k = \frac{1}{1.96}\left|\frac{\Delta_s^{max}}{\Delta_k^{max}} - \mu_k\right|,$$

where subindex s stands for subsidy and k for the k th attribute.

The next step is determining the scale $\widetilde{\lambda}$ in (2). To achieve this goal, 16 two-alternative sample choice tasks were created based on a fractional factorial design. Table A.3 shows these choice tasks and the deterministic utility V_{jt} and logit probabilities P_{jt} corresponding to the assumed prior values. It also includes educated guesses of the probability of choosing each alternative, denoted as f_{1t} and f_{2t}, where $f_{2t} = 1 - f_{1t}$. These probabilities were agreed by the same three wine producers who set up the ranges in Table A.2. The value of $\widetilde{\lambda}$ is then obtained by maximising the following log-likelihood function:

$$L(\widetilde{\lambda}) = \sum_{t=1}^{T=16} \sum_{j=1}^{J=2} f_{jt} \, log\left(P_{jt}\right).$$

The right-hand side columns of Table A.3 show all the calculations necessary to obtain the final prior values shown in Table 2, corresponding to the value $\widetilde{\lambda} = 0.313$. These values were finally used to generate a D-efficient experimental design for an MNL.

Having followed the procedure of Bliemer and Collins (2016) procedure to obtain the priors, the following step was to determine which experimental design to use. Given that our final dataset, presented in the next section, was relatively small (32 individuals), our simulation study was devoted to the simple question of whether there is an experimental design capable of identifying the correct signs of the analysed preferences with a certain degree of confidence, despite the expected wide sample variation. The simulation exercises closely resemble the procedure outlined by Mariel et al. (2021, Ch. 3.3) and applied in Lopes and Mariel (2021). The sequence of steps we follow in each of the simulation exercises is depicted in Fig. 2 in the form of a flowchart.

In our case, these exercises compare the sample variation of orthogonal, A-efficient, and D-efficient designs. Therefore, we generated an orthogonal design (60 rows) and A- and D-efficient designs (10 rows, 2 blocks) using the prior values shown in Table 2. Subsequently, for each of the three designs, we generated 10,000 hypothetical data sets corresponding to an MNL model defined in (1), assuming that the population values of the coefficients were the prior values from Table 2. These hypothetical data sets were generated for 32, 64, 128, and 256 respondents, and 5 choice occasions.

Fig. 3 shows the results of the simulation exercises. There are seven boxes, one for each of the seven attributes included in our study. Each box contains 12 simulated distributions, one for each of the three designs analysed and four different sample sizes. The labels of each distribution contain the name of the experimental design used and the number of respondents in the sample. The dashed vertical lines represent the assumed population values for each parameter. The comparison of the distributions presented in Table 2 leads to the following general conclusions.

The first finding, which was expected, is that all distributions are centred on the vertical lines, and the spread of the distributions narrows as the number of observations increases, demonstrating the consistency of the maximum-likelihood estimator used. The second finding, which was also expected, is that the spread of the distributions corresponding to the orthogonal designs is generally wider than those corresponding to the A- and D-efficient designs. The third finding is that the D-efficient design, widely used in the literature, does not uniformly produce better results than the A-efficient design. For example, the D-efficient design clearly outperforms the A-efficient design for the *Oenological adaptations* attribute, but it performs worse for the *Relocations* attribute. This means that the characteristics of each case study influence the performance of each type of experimental design.

The goal of this simulation was to demonstrate the accuracy of the MNL results, specifically tailored to a design and the priors that can be expected given a small dataset. The analysis focused on the results obtained for the D-efficient design (as shown in Fig. 3) with specific priors, which was ultimately used in our case study. It can be concluded that the estimated coefficients obtained from data of this sample size can be interpreted with a high degree of confidence, since the distributions corresponding to the sample of 32 respondents only contain predominantly positive or negative values, and the interquartile range is relatively narrow (Fig. 3).

Table 2
Scaled prior values.

Attribute:	Grape	Relocation	Irrigation	Coverage (pruning)	Coverage (structure)	Oenological adaptations	Subsidy
Scaled prior $\widetilde{\beta}_k^*$	−0.625	−0.782	0.782	0.469	0.469	0.234	0.313

Table 3
Characteristics of the winemakers.

Size of the vineyard (ha)		Percentage irrigated (%)		Is climate change real? (%)	
< 20	56	*0*	53	Yes	94
21–40	22	*1–10*	13	No	6
41–60	3	*11–20*	6		
61–80	3	*21–30*	9		
81–100	6	*31–40*	6		
> 100	10	*41–50*	3		
		>51	10		
Type of wine produced	(%)	**Year of foundation**	%		
		<1968	34		
Red	25	*1968–1977*	13		
Red, white	44	*1978–1987*	22		
Red, rosé	6	*1988–1997*	16		
Red, white, rosé	19	*1998–2007*	3		
Red, white, other	6	*>2008*	12		

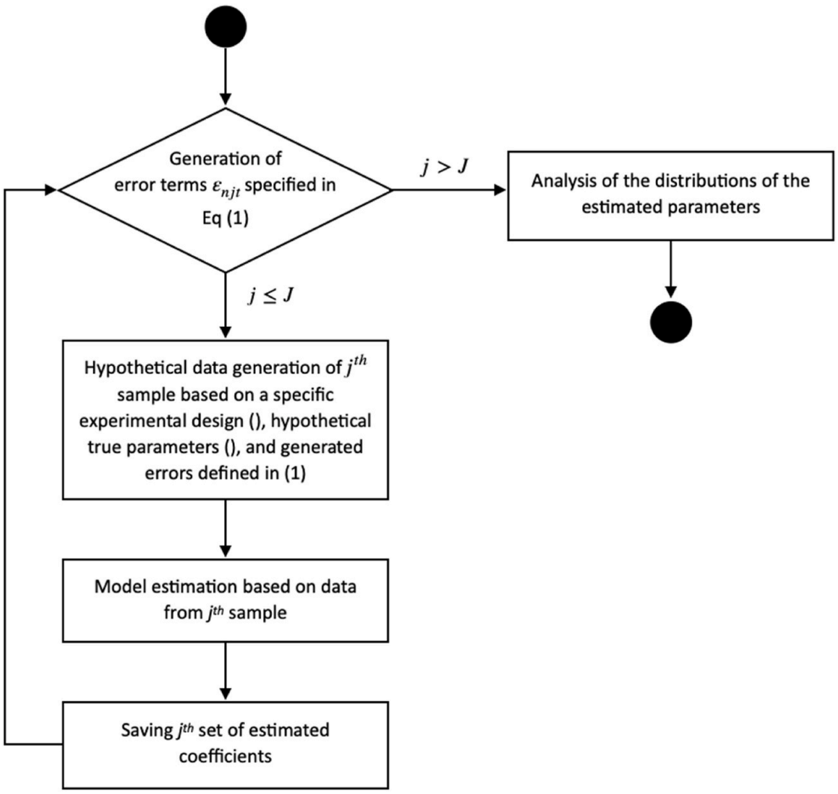

Fig. 2. Flowchart of the simulation exercise.

In essence, this section of the study aimed to demonstrate the effectiveness and reliability of MNL models when working with limited data. The results indicate that even with a small dataset, MNL models can produce reliable results that can be interpreted with confidence, provided that the appropriate design and priors are used. The study focused on the D-efficient design, which proved promising and was subsequently used in the case study. As such, these findings are relevant for researchers and practitioners who need to make informed decisions based on limited data, not only for the particular case study presented.

In addition, and to validate this assertion in a more adaptive context, we have extended the simulation exercise by focusing on the scenario labelled D-efficient (32) in Fig. 3, which uses the same sample size as the case study presented in the following section. The scenario labelled as D-efficient (32) relies on the fixed priors detailed in Table 2 and assumes that the underlying population values of

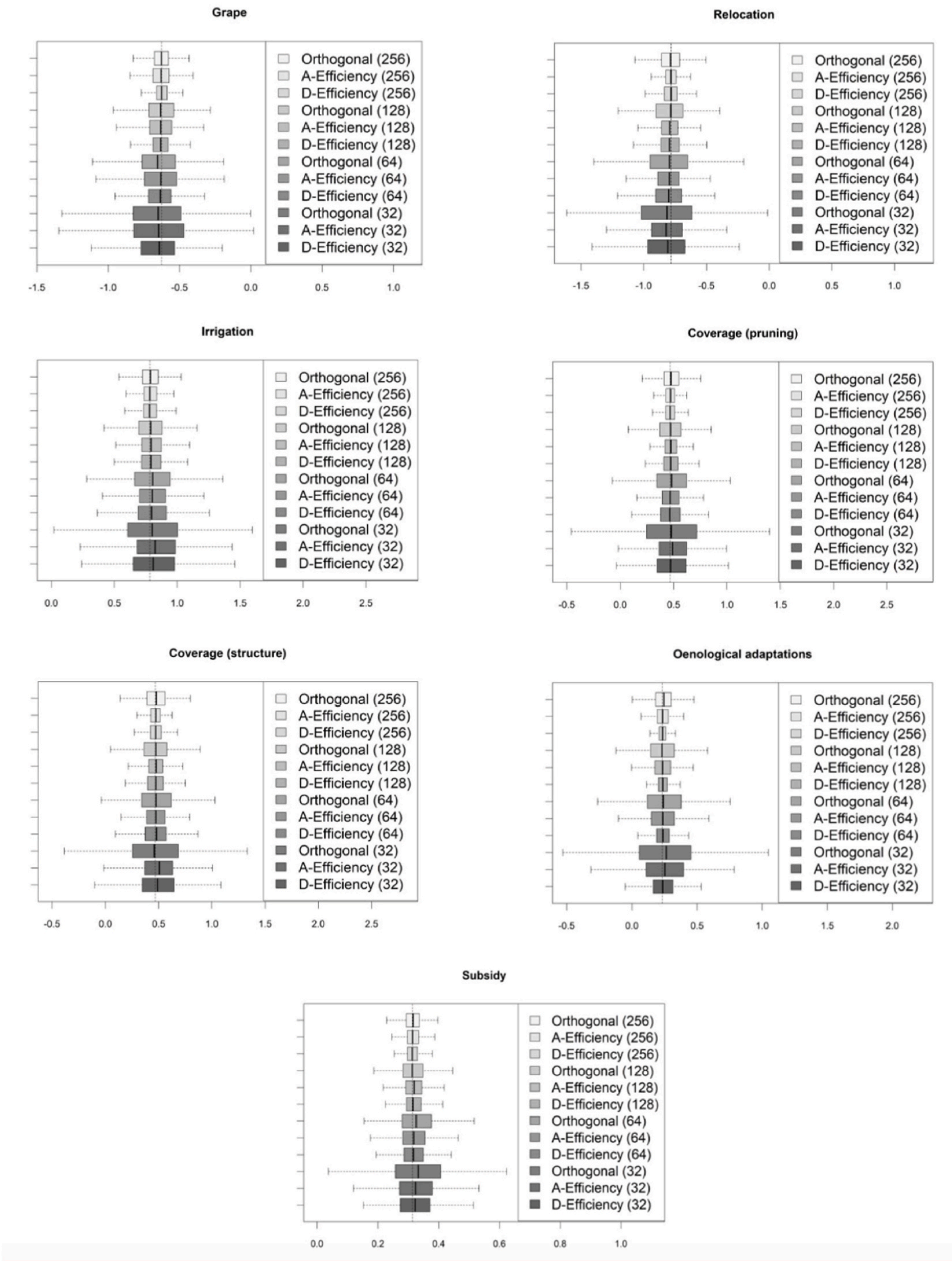

Fig. 3. Distributions of parameter estimates between statistical designs.

the data generation process are consistent with these priors. This second simulation exercise incorporates two additional assumptions, namely the presence of uncertainty in the prior values used to generate the design and the presence of a certain degree of preference heterogeneity in the data generation mechanism.

Bayesian priors were employed to account for the uncertainty associated with the prior values used to generate the D-efficient design. Specifically, all priors were assumed to be normally distributed, with the means reported in Table 2, and standard deviations equal to 25% of the absolute value of the mean. In addition, preference heterogeneity was introduced in the data generation process by assuming that all parameters follow a normal distribution with the mean values also shown in Table 2, and standard deviations equal to

25% of the absolute value of the mean. Notably, the estimated model remains an MNL model, despite the presence of random parameters in this case. This approach is similar to our case study, where preference heterogeneity may occur, but an MNL model is estimated due precisely to the small sample size.

Boxplots akin to those in Fig. 3 are shown in Fig. 4 for the following four cases. In the first case, the data generation mechanism combines Bayesian priors with random parameters. In the second case, fixed priors are used in conjunction with random parameters, while in the third case Bayesian priors and fixed parameters are used. Finally, in the fourth case, both priors and parameters remain fixed in the data generation process. This case corresponds to the boxplot designated as D-efficient (32) in Fig. 3.

From Fig. 4, it can be concluded that the widths of the boxplots for each attribute are generally comparable, except for the *Oenological Adaptations* attribute, which shows a greater degree of dispersion in the estimations for the Bayesian priors. In general, the boxplots obtained by MNL estimation, corresponding to the combination of random parameters representing potential preference heterogeneity in the data generation process (RandParam) and fixed priors (non-RandPrior), generally exhibit the narrowest boxplots.

Therefore, the conclusion drawn from the second set of simulations is consistent with that drawn from Fig. 3, reinforcing the reliability of the estimated coefficient signs when using data of this sample size. The results therefore emphasise the importance of using an appropriate design and priors for MNL models when working with a limited sample size. These findings are of particular relevance to researchers and practitioners who require accurate and reliable results, especially when faced with constraints such as a shortage of data. Confirming the accuracy of the MNL model in producing reliable results in such scenarios has practical implications, since it ensures that decisions based on such data are robust.

3.4. DCE sample

The target population was identified through a list of winemakers in the Rioja region drawn up by the Regulatory Council (2021), which contains 567 wineries. To generate the sample for the survey, wineries were randomly selected from this list. The questionnaire was administered by the authors through individual face-to-face pencil-and-paper home interviews over several working days in March 2019. A large proportion of the wineries contacted were unavailable or unwilling to participate. The number of questionnaires collected was 42, but the final sample was reduced to 32 because ten respondents protested their answers. The reasons given were that not enough information was provided, respondents objected to the way in which the questions were asked, or they did not want to implement a strategy because they did not believe that climate change was real. Given that each winemaker responded to five choice cards, the final number of observations was $32 \times 5 = 160$.

Table 3 shows the basic characteristics of the wineries in the sample. More than half of the respondents were small producers, with less than 20 ha of vineyards, and more than half of them did not have an irrigation system. Given that the Rioja appellation is known for its high-quality red wines, it is not surprising that all of the wineries in the sample produce red wine, with a relatively high presence of white wine and a very low presence of rosé. Table 3 also shows that the majority of the wineries have a long history and only 15% of them were established after 1998. Finally, as expected, given that the respondents agreed to fill in the questionnaire voluntarily, knowing what it was about, 94% of the respondents stated that they believe that climate change is real.

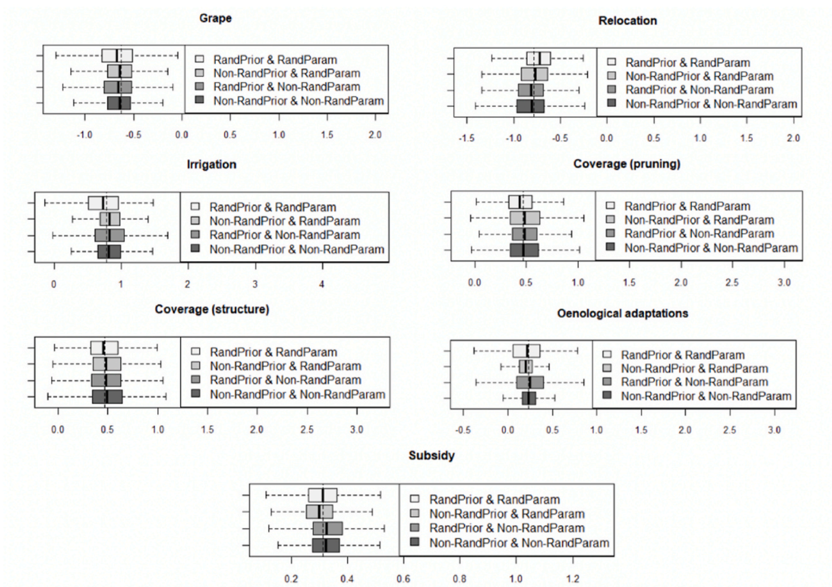

Fig. 4. Distributions of parameter estimates including Bayesian priors and preference heterogeneity.

4. Results

The distribution of choices among the three alternatives presented in the choice tasks is shown in Table 4. The *No Change* option was chosen in only 26% of all choice occasions, indicating a relatively high level of interest among the winemakers in our sample in adapting their wineries to climate change.

Given the small sample size, we estimated a simple MNL model without considering any observed or unobserved preference heterogeneity among winemakers. To verify the validity of the MNL estimations presented in Table 5, several simulation exercises were performed in Section 3.3. The purpose of the simulation presented in this study was to demonstrate the precision of MNL model results tailored to a specific design and priors that can be expected from a small dataset.

In summary, the estimation process of the MNL model has been carried out with caution and based on the results of our simulation exercises. Our results suggest that the estimated coefficients can be interpreted with a certain degree of confidence despite the small sample size. The use of the D-efficient design and specific priors was effective in producing reliable results in this case study and provided a valuable tool for other future research with small datasets.

It is worth noting that interactions between the attributes and the characteristics of the winemakers and their vineyards could explain the observed preference heterogeneity. However, we have left this type of analysis for future research with larger samples. Furthermore, given the relatively small sample size, we considered it reasonable to work with a 10% significance level.

All attributes except one (*Grape*) are significant at least at the 10% level. The attributes *Irrigation*, *Grape Coverage – Pruning*, *Grape Coverage – Structure,* and *Oenological Adaptations* have a positive sign, which means that their implementation increases the winemakers' utility. As expected, the same conclusion can be drawn regarding the effect of *Subsidy*. The higher the subsidy for an alternative, the higher the probability that the respondent will accept that alternative, other things being equal.

However, the attribute *Grape* is not significant even at the 10% significance level, and the standard error of this coefficient may indicate the controversial nature of this attribute. There are probably winemakers who are willing to accept a change in the clones of the varieties authorised by the Regulatory Council and winemakers who reject this adaptation strategy. A plain MNL model cannot represent this heterogeneity among winemakers, which is why the estimated preference for this attribute is close to zero with a relatively large standard error.

Finally, the only attribute with a negative and significant coefficient is *Relocation*. This is not an entirely unexpected result, since changing the location of the vineyard requires a very high investment, both in terms of money and time. Even the highest level of the subsidy offered might not cover a sufficient proportion of the costs a winery would face, potentially making this an unattractive adaptation option, especially if we consider the long-time horizon required to make this option feasible. Furthermore, this change could lead to conservation conflicts over land use and freshwater ecosystems (Ashenfelter and Storchmann 2016).

The last column of Table 5 presents the WTA values calculated on the basis of the MNL estimates. Fig. 5 presents the same values graphically, with the addition of the 95% confidence intervals computed using the Delta method. As can easily be seen, the WTA values for *Irrigation*, *Grape Coverage – Pruning,* and *Grape Coverage – Structure* are between about 6,000 and 8,000 €/ha, and the WTA for the *Oenological Adaptations* is about half this value. The negative value of the WTA for *Relocation* indicates a clear rejection of this adaptation strategy by the winemakers, and the estimated value represents the number of euros they would give up to avoid a change in this attribute.

5. Conclusions

Adapting to climate change is becoming more and more necessary for many businesses, including those in the agricultural sector, particularly the wine sector. As this research shows, there are technical innovations that producers can introduce, such as the installation of irrigation systems and cover crops, but there are several other considerations related to the code of production that producers need to overcome in order to implement these changes.

Relocation of a vineyard is, in theory, an adaptation option but producing wine at higher altitudes usually means working on steeper slopes, which in turn means adapting wine-growing processes to the new working environment. In this respect, it is worth mentioning a recent study by Strub et al. (2021) on the impact of mechanisation in viticulture on labour time and costs, as it shows how different types of intervention can reduce the impact of these two critical production factors.

Related to the adaptation option *Relocation* is the issue of the regulatory framework governing the way in which quality wines are produced. Protected Designations of Origin, such as Rioja wines, are governed by a strict production code that defines which grape varieties can be grown where, how much they can produce per hectare, what containers can be used to package these wines, and so on. Production codes can be changed, but the process has historically been very slow, requiring difficult discussions with all the stakeholders involved before a new consensus can be reached. At the same time, producers cannot afford to ignore the impact of climate change. Reduced wine quality can have a knock-on effect, reducing the ability to charge a premium for that wine, devaluing the land

Table 4
Choice across alternatives.

	Frequency	Percentage (%)
No change	42	26
Strategy A	69	43
Strategy B	49	31

Table 5
MNL estimations.

	MNL			
	Estimate	Robust st. err.		*WTA* (€/ha)
ASC 2	−1.161	1.06		
ASC 3	−1.546	1.09		
Grape	0.003	0.41		12
Relocation	−0.556	0.33	*	−2,436
Irrigation	0.821	0.44	*	3,593
Grape coverage – pruning	0.721	0.44	*	3,158
Grape coverage – structure	0.985	0.58	*	4,313
Oenological adaptations	0.396	0.22	*	1,733
Subsidy	0.228	0.11	**	
LogL	−160.07			
N	160			
AIC	338.14			
BIC	365.82			

*,**, and *** indicate 10, 5, and 1% significance levels, respectively.

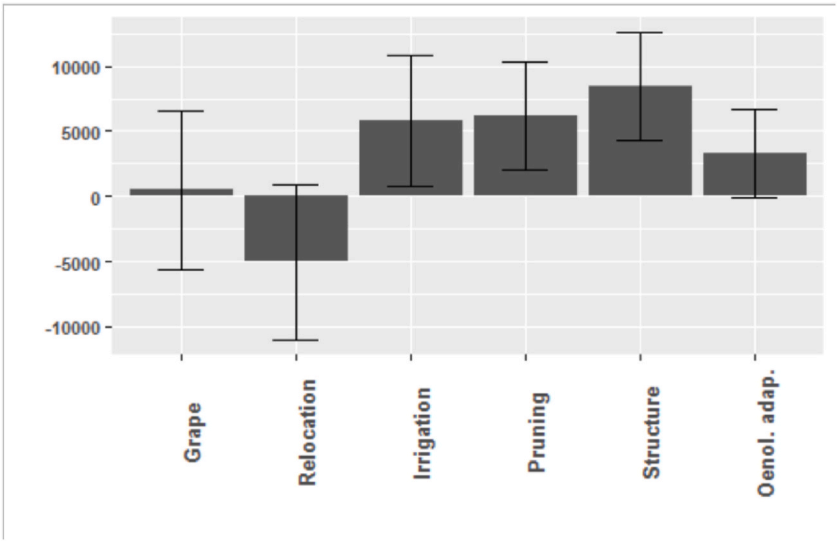

Fig. 5. WTA with CI at 95%.

from which those wines come, and impacting the communities in those areas.

No research is without caveats, and this study is no exception. The first limitation is the small sample size. The response rate for this study was around 5%, and consequently, the sample's representativeness is limited. It could be argued that our sample has an over-representation of wineries willing to adapt to climate change. In addition, given the small sample size, there may be a concern that we are not able to recover the true parameter values. This concern is valid, but given the results of the simulation study, our estimates recover the correct sign of the parameters with a high degree of confidence, even in this very small sample of business owners. The simulation study also illustrates a novel approach described in Mariel et al. (2021, Ch. 3.3) and applied in Lopes and Mariel (2021).

Therefore, future studies must aim to obtain larger samples by expanding the response base in Rioja and extending the research to other countries, especially those less affected by production codes (i.e., Australia, Chile, and New Zealand). In addition, comparisons could be made with companies in other major European wine-producing countries, such as Italy and France, which also face climate change's effects. These comparisons would allow the results of the present study to be validated and extended.

The third limitation is related to the simplicity of the DCE adopted in this study. Each attribute of our DCE has either two or three levels, a factor that prevents us from capturing all the complexity of the combinations that an ideal solution requires. For example, one could consider adding one or more levels related to the container used to package a wine to the attribute Oenological Adaptations. An often-overlooked factor is that glass bottles account for almost 70% of the wine industry's carbon footprint (Smart, 2021). At the same time, 90% of the wine is consumed within two weeks of purchase, with only 6% purchased for ageing (Thach and Camillo, 2018). The ability to switch these quickly consumed wines to alternative packaging (e.g., bag-in-box, plastic bottles, cans, etc.) will have a significant impact on the sustainability of the wine industry.

A fourth limitation could be due to the payment vehicle and the levels of the cost vector. We used a subsidy as a payment vehicle; i.

e., the respondent would receive public money for adaptation measures, which might set incentives to exaggerate the true need. In general, a DCE should reduce this risk, as the subsidy is linked by the experimental design to specific alternatives consisting of combinations of attribute levels. Thus, it would not be in the winemaker's interest to choose alternatives with high subsidies if the measures were not suitable for their business. It should also be kept in mind that the subsidies offered were not meant to cover all the full costs of all adaptation measures. Winemakers would thus have to use their private money in addition to the subsidy setting an incentive to report their true preferences. Nevertheless, future studies should pay more attention to both the payment vehicle and the range of the levels of the cost vector. This is essential as adaptation will require significant private but also public investment (Resco et al., 2016), and the costs might vary considerably between adaptation measures as some are rather short-term and others are relatively long-term, requiring not only a one-time payment but continuous support to ensure that winegrowers can survive in the market.

Finally, this study aims to present a methodological approach that could be used to support the development of adaptation strategies. Climate change is underway, and the need to choose effective and efficient measures increase accordingly. According to Ollat et al. (2016), there is no single technical solution or institutional solution for effective and efficient adaptation, but there are different combinations of several technological and institutional innovations that could play a role in the adaptation process. Therefore, DCEs attractive because they allow us to identify trade-offs between different options and to derive information on preferred combinations of technological and institutional innovations. However, winemakers' preferences for adaptation options may not be sufficient to develop those strategies, as, for example, knowledge about consumers' willingness to accept new, different qualities is also needed (Schäufele and Hamm, 2017; Tait et al., 2019). Providing more evidence on both the need for producers to adapt and the willingness of consumers to support adaptation measures is, therefore, an important task for future research.

CRediT author statement

Ainhoa Vega-Bayo: Data Curation, Software, Formal Analysis, Writing - Original Draft.
Peter Mariel: Conceptualization, Methodology, Formal Analysis, Writing - Original Draft.
Jürgen Meyerhoff: Writing- Reviewing and Editing, Validation.
Armando Maria Corsi: Writing- Reviewing and Editing, Validation.
Milan Chovan: Formal Analysis.

Declaration of competing interest

None.

Data availability

The authors do not have permission to share data.

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Appendix A

Table A.1
Range of the corresponding attribute levels

Attribute	Range					
Grape	0	1				
Relocation	0	1				
Irrigation	0	1				
Coverage – pruning	0	1				
Coverage – structure	0	1				
Oenological adaptations	0	1				
Subsidy (€000/ha)	0	1	3	5	7	9

Table A.2
Calculation of μ_k and σ_k through two utility-balanced options

1	Option 1	Option 2	Δ^{min}	Δ^{max}	μ_k	σ_k
Subsidy	5	[2.5, 3.5]	−2.5	−1.5	−2.00	0.26
Grape	0	1	1	1		
2	Option 1	Option 2	Δ^{min}	Δ^{max}	μ_k	σ_k
Subsidy	5	[2, 3]	−3	−2	−2.50	0.26
Relocation	0	1	1	1		
3	Option 1	Option 2	Δ^{min}	Δ^{max}	μ_k	σ_k
Subsidy	5	[7, 8]	2	3	2.50	0.26
Irrigation	0	1	1	1		
4	Option 1	Option 2	Δ^{min}	Δ^{max}	μ_k	σ_k
Subsidy	5	[6, 7]	1	2	1.50	0.26
Coverage (pruning)	0	1	1	1		
5	Option 1	Option 2	Δ^{min}	Δ^{max}	μ_k	σ_k
Subsidy	5	[6, 7]	1	2	1.50	0.26
Coverage (structure)	0	1	1	1		
6	Option 1	Option 2	Δ^{min}	Δ^{max}	μ_k	σ_k
Subsidy	5	[5.5, 6]	0.5	1	0.75	0.13
Oenological adaptations	0	1	1	1		

Table A.3
Determination of scale

	μ_k	−2	−2.5	2.5	1.5	1.5	0.75	1	$\widetilde{\lambda} = \mathbf{0.313}$				
	$\widetilde{\beta}_k^* = \widetilde{\lambda}\mu_k$	−0.625	−0.782	0.782	0.469	0.469	0.234	0.313					
Choice situation (t)	Alternative ($j = 1, 2$)	Grape	Relocation	Irrigation	Coverage (pruning)	Coverage (structure)	Oenological adaptations	Subsidy	V_{jt}	P_{jt}	$log(P_{jt})$	f_{jt}	$f_{jt}\ log(P_{jt})$
1	1	1	1	0	1	0	1	7	1.485	0.331	−1.106	0.1	−0.111
1	2	0	0	1	1	0	0	3	2.189	0.669	−0.402	0.9	−0.362
2	1	0	1	1	0	0	0	5	1.563	0.281	−1.268	0.1	−0.127
2	2	0	1	0	1	0	0	9	2.501	0.719	−0.330	0.9	−0.297
3	1	1	0	0	1	0	1	5	1.641	0.777	−0.252	0.5	−0.126
3	2	0	1	0	0	0	1	3	0.391	0.223	−1.502	0.5	−0.751
4	1	0	1	0	1	0	1	5	1.485	0.101	−2.295	0.2	−0.459
4	2	1	0	1	1	0	1	9	3.674	0.899	−0.106	0.8	−0.085
5	1	0	0	0	1	0	1	5	2.267	0.815	−0.204	0.9	−0.184
5	2	0	1	1	1	0	0	1	0.782	0.185	−1.689	0.1	−0.169
6	1	1	1	0	1	0	1	3	0.234	0.049	−3.020	0.01	−0.030
6	2	0	0	1	0	0	1	7	3.205	0.951	−0.050	0.99	−0.050
7	1	1	1	1	1	0	0	1	0.156	0.162	−1.819	0.2	−0.364
7	2	0	1	1	0	0	1	5	1.798	0.838	−0.177	0.8	−0.142
8	1	1	0	1	0	0	1	1	0.703	0.422	−0.862	0.4	−0.345
8	2	1	0	0	1	0	1	3	1.016	0.578	−0.549	0.6	−0.329
9	1	1	0	1	0	0	1	9	3.205	0.539	−0.618	0.6	−0.371
9	2	1	0	1	0	1	1	7	3.048	0.461	−0.774	0.4	−0.310
10	1	0	1	1	1	0	1	1	1.016	0.266	−1.325	0.4	−0.530
10	2	1	1	1	1	0	0	7	2.032	0.734	−0.309	0.6	−0.185
11	1	1	1	1	1	0	1	1	0.391	0.066	−2.725	0.01	−0.027
11	2	0	0	0	0	0	1	9	3.048	0.934	−0.068	0.99	−0.067
12	1	1	1	0	0	0	1	3	−0.234	0.197	−1.626	0.3	−0.488
12	2	1	0	0	0	0	1	5	1.172	0.803	−0.219	0.7	−0.153
13	1	1	1	0	1	0	1	7	1.485	0.173	−1.753	0.2	−0.351
13	2	0	1	1	0	0	1	9	3.048	0.827	−0.190	0.8	−0.152
14	1	0	1	0	0	0	1	1	−0.234	0.025	−3.699	0.05	−0.185
14	2	0	0	1	1	0	0	7	3.439	0.975	−0.025	0.95	−0.024
15	1	1	0	0	0	0	0	7	1.563	0.061	−2.799	0.01	−0.028
15	2	0	0	1	1	0	1	9	4.299	0.939	−0.063	0.99	−0.062
16	1	0	0	1	1	0	0	5	2.814	0.858	−0.153	0.95	−0.146
16	2	1	0	0	1	0	1	3	1.016	0.142	−1.951	0.05	−0.098
									$L(\widetilde{\lambda}) = \sum_{t=1}^{T=16} \sum_{j=1}^{J=2} f_{jt}\ log(P_{jt}) = -\mathbf{7.106}$				

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