Received: 21 March 2023 | Accepted: 23 February 2024

DOI: 10.1002/jaa2.116

JOURNAL OF THE AGRICULTURAL AND APPLIED ECONOMICS ASSOCIATION
Open Access

ARTICLE

Preferences and willingness to pay for a novel carbon label: A choice experiment in the United States

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Funding information
National Natural Science Foundation of China, Grant/Award Number: 72103180

Abstract
This study investigates how US consumers respond to and value a new technology-based carbon label on food products. Results indicate that individual valuation of the carbon-labeled bread is \$4/20 oz, marginally lower than the valuation of the conventional and organic bread products. Moreover, individuals belonging to certain market segments, such as non-White, liberal, and well-educated consumers, and those having a high level of knowledge about the causes of climate change, exhibit a higher valuation for the novel carbon label.

KEYWORDS
bread, carbon label, carbon removal technology, consumer valuation

JEL CLASSIFICATION
Q01, Q1

1 | INTRODUCTION

Carbon neutrality has been one of the world's most urgent goals, with over 110 countries now committing to carbon dioxide emissions reduction. Decarbonizing the food system, despite receiving relatively limited attention, cannot be overlooked in becoming globally carbon neutral. The food system contributes to one-third of the global anthropogenic greenhouse gas emission (Crippa et al., 2021; Tubiello et al., 2021), and even if fossil fuel emissions were removed, emissions from the global food system alone would make achieving the Paris Agreement by 2050 impossible (Clark et al., 2020).

Carbon labels could be a promising policy instrument for the decarbonization of the food system. A carbon label on food products could improve a consumer's ability to make carbon-friendly choices via information provision and may induce producers to provide markets with lower-emission options (Vandenbergh et al., 2011). Prior work on food carbon labeling schemes relies on either a numeric carbon footprint label or a carbon-friendly claim for products (Brunner et al., 2018; Visschers & Siegrist, 2015; Vlaeminck et al., 2014). No other studies, however, have explored alternative carbon labels, such as a label indicating carbon removal technology. Our study focuses on investigating individual preference and valuation for a novel carbon label on food products. Unlike prior carbon labels, the novel carbon label in this study communicates additional information to consumers; it suggests that relative to unlabeled products the labeled product has lower carbon footprint, but also reveals the specific technology to reduce carbon dioxide emissions during food production.

Insight on individual valuation for a new technology-based carbon label is important for several reasons. First, public policymakers are likely interested in whether the market itself could provide agricultural producers with sufficient economic incentive to reduce carbon emissions. A limited understanding of consumer preferences and price premiums for carbon-labeled food products would hinder the voluntary adoption of carbon reduction technology among food producers as the adoption imposes extra costs. A successful voluntary carbon labeling scheme could relieve the pressure on governments to introduce more stringent policy instruments (Elofsson et al., 2016); for example, an emission tax and permit scheme, which could meet substantial resistance from different interest groups and even cause welfare loss (Baylis et al., 2013).

Second, the new technology-based carbon label examined in this study has important implications for carbon neutrality as well as food security. Among other carbon dioxide removal and storage technologies, we focus on enhanced silicate rock weathering of crushed basalt (ERW thereafter) applied to croplands. ERW technology amends soils with crushed calcium- and magnesium-rich silicate rocks, such as dunite and basalt, to accelerate the carbon dioxide sequestration process (Cox et al., 2020; Hartmann et al., 2013). Recent studies have shown that basalt, one of the most common rocks on Earth, is a potentially ideal rock for implementing ERW (Goll et al., 2021). Spreading basaltic rock dust on croplands would absorb billions of tonnes of carbon emissions from the air within months. Including the costs of mining, crushing, and grinding of rocks, and transport to and distribution on crop fields, the overall cost of basalt-based ERW ranges from about \$80 to \$200/ton of carbon dioxide in the current carbon price range (Beerling et al., 2020; Strefler et al., 2018). ERW of basalt, as a result, tends to be cost-effective for large-scale carbon removal, in particular, a prominent option for agricultural carbon sequestration (Goll et al., 2021), in contrast to other carbon removal technologies whose costs are prohibitive. Basalt-based ERW technology implies that reducing carbon dioxide emissions in agricultural and food systems may not hurt food security given that basalt could boost crop yields by increasing soil pH and resupplying depleted soil silica pools (Horton et al., 2021).

With this as backdrop, the present study contributes to the literature by eliciting individual preferences and valuation for the basalt-based ERW technology label using a discrete choice experiment conducted on US respondents. Bread is used as the food product of interest in our study since bread is made from grains planted in the croplands, where basalt dust could be applied to lock the greenhouse gas into carbonates. Our findings show that US consumers in general prefer organic bread most, followed by conventional bread and ERW-labeled bread products. Average willingness to pay (WTP) for ERW-labeled bread is \$4, slightly lower than the valuation of organic (\$4.76) and conventional (\$4.70) bread. This finding implies that US consumers would not be willing to pay a price premium for ERW-labeled bread versus the existing bread products, and US consumers discount ERW-labeled bread to some extent. Nevertheless, consumer preferences and valuation for ERW-labeled bread are not homogeneous across individuals. WTP for ERW-labeled bread is significantly greater among those who are non-White, liberal, more knowledgeable about the causes of climate change and have at least college degrees. Our results highlight that relying in the market itself to promote voluntary adoption of carbon mitigation technology among agricultural producers would not be successful, which calls for extra interventions from public and private organizations.

2 | STUDY DESIGN

2.1 | Experimental design

We conducted an online choice experiment survey to elicit customer preferences and valuation of the basalt-based ERW technology label in the United States. Given that the basalt-based ERW technology labeled bread is not yet in the market, we conduct a hypothetical choice experiment to assess US consumer bread preferences. Specially, whole-grain bread is chosen as our experimental product. Bread is widely consumed by US households, over 98% US population consuming bread products. With the increasing health-consciousness of consumers, whole grain and multigrain breads have become more and more popular (Mancino & Kuchler, 2012). Three different types of whole-grain bread products are included in the experimental design, namely, conventional and unlabeled whole-grain bread, organic-labeled whole-grain bread, and ERW carbon-labeled whole-grain bread. Four price levels are specified based on the range of offline market prices of 20 oz of whole-grain bread and online retail store prices in the United States. The price levels include $2.37, $3.27, $4.19, $5.09. Table 1 details the attributes and attribute levels used in the choice experimental design.

We design a labeled choice experiment using a sequential Bayesian approach (Scarpa & Rose, 2008). First, an efficient design is constructed using the Ngene software for a pilot study. A total of 26 individuals are collected for the pilot survey. The estimation results of the multinomial logit model from the pilot survey data are then used as the priors for the final design. In light of the results from our pilot study, and to reflect real market situation, the price of organic whole-grain bread in the final choice tasks is set higher than conventional whole-grain bread's price. Higher organic prices are associated with higher environmental benefits and production costs for organic agriculture. Similarly, one would argue that the price of the basalt-based ERW technology labeled bread may also be higher. We do not constrain the ERW-labeled prices for several reasons. First, despite the basalt dust application imposes extra costs, it could improve crop yields (Horton et al., 2021), which potentially lowers bread production costs. Besides, unlike organic labeled breads, the ERW-labeled product is not yet in the market. Studies show consumer preferences for novel and controversial food products are uncertain (Ortega et al., 2020), implying that the product can be either positively or negatively valued by individuals. Finally, we use the sequential Bayesian design to construct eight choice sets, and divide them into two blocks of four choice tasks each. The D-efficiency is 85.42%. Respondents are randomly assigned into one of the two blocks. Each choice task is composed of three whole-grain bread products aforementioned, plus an opt-out option which is the last alternative in each choice task (Supporting Information S1: Figure A1). The choice tasks are randomized within each block, and the three bread products are also randomized within each

TABLE 1 Attributes and attribute levels.

Attribute	Attribute level
Whole-grain bread	Conventional
	USDA organic labeled
	ERW carbon labeled
Price ($/20 oz)	2.37
	3.27
	4.19
	5.09

Abbreviation: ERW, enhanced silicate rock weathering of crushed basalt; USDA, US Department of Agriculture.

choice task. We calculate the minimum sample size required based on the widely used method by Lancsar and Louviere (2008) and de Bekker-Grob et al. (2015), and the minimum sample size for our experimental design is 250 respondents.

2.2 | Survey design

Our survey has two main sections, one related to bread choice tasks and the other about demographic and climate knowledge information. In the bread choice task section, before choice task questions, we provide respondents with some information that are common practice for choice experiment research. The information includes the introduction about organic label and carbon removal technology, as well as a cheap talk script to mitigate the possible hypothetical bias in hypothetical choices. After the bread choice tasks, respondents are asked to fill out a questionnaire about their knowledge related to climate change and their demographics. Twelve statements are used to evaluate respondents' overall objective knowledge of climate change (Supporting Information S1: Table A3) (Shi et al., 2016). This knowledge scale includes multiple items and is generally thought to be a stronger assessment of knowledge than the previous single-item or self-reported assessment (Wong-Parodi & Rubin, 2022). Each respondent is asked to make a choice about each statement whether it is "correct," "do not know," or "incorrect." If individuals give correct response for a statement, we code the statement as 1, otherwise as 0. The 12 questions can be classified into three scales of climate knowledge that addressed three aspect of climate change, including physical characteristics of climate change, causes of climate change and consequences of climate change. Each climate knowledge scale consists of four questions adopted from Shi et al. (2016). For example, knowledge about the causes of climate change is elicited by statements such as "climate change is mainly caused by human activities" and "The global CO_2 concentration in the atmosphere has increased during the past 250 years."

Our survey is programmed in Qualtrics and administered by a consumer panel company, Dynata, to recruit a representative sample. As a professional online market research firm worldwide that maintains over 67 million users, Dynata recruits respondents via email and has been used previously to implement large-scale or nationally representative surveys (Caputo & Lusk, 2020; Milosh et al., 2021; Panzone et al., 2022). The respondents of this study are selected based on their age and bread shopping frequency. The qualified participants are those who are at least 18 years old and have shopped bread in the last 3 months. To ensure response quality, subjects that are not willing to read carefully, reject to provide honest answers, and fail attention trap questions are excluded from the final sample.

3 | ECONOMETRIC MODEL

Consumers' bread purchasing decisions are modeled using a utility function, based on Lancaster's theory of consumer demand (Lancaster, 1966). Following random utility theory (McFadden, 1974), choice experiments rely on the assumption that the utility of individual n choosing alternative j in choice situation t can be expressed as:

$$U_{njt} = V_{njt} + \varepsilon_{njt} = \alpha_n \mathrm{Price}_{njt} + \beta_{n1}\mathrm{Conventional}_{njt} + \beta_{n2}\mathrm{Organic}_{njt} + \beta_{n3}\mathrm{ERW}_{njt} + \mathrm{ecm}_n + \varepsilon_{njt},$$

where V_{njt} is the systematic portion of the utility function, depending on the experimentally designed product attributes of alternative j. Price_{njt} is a continuous variable populated with the four price levels in the design; $\text{Conventional}_{njt}$, Organic_{njt}, and ERW_{njt} are dummy variables for the conventional, US Department of Agriculture organic labeled, and ERW carbon-labeled bread products, respectively. They all take a value of 1 when the product belongs to that category, and 0 otherwise. α_n is individual n's price preference coefficient and the βs are the nonprice taste coefficients. ecm_n refers to error component accounting for correlation across individual utilities due to extra variance shared by the experimentally designed alternatives, relative to the opt-out option (Caputo, 2020). ε_{njt} is the stochastic and unobservable (to researchers) component of consumer utility. To identify the α and βs, we normalize the utility of choosing the opt-out option to be zero.

We use a mixed logit model to estimate the consumer utility function. Mixed logit models allow consumer tastes to vary with respect to unobserved factors, and thus are highly flexible (McFadden & Train, 2000). We specify the coefficients of the three nonprice product attributes to be random and to follow normal distributions since either positive or negative values would be placed by individuals on these bread products. The price coefficient, α, is set to be negative and one-sided constrained triangularly distributed. Last, we allow for correlations between taste parameters, which may be caused by individual taste as well as scale heterogeneity (Hess & Train, 2017).

To assess preference heterogeneity across demographics, we estimate the model in WTP space using the entire sample and obtain individual conditional mean WTPs. These mean WTPs were later correlated with individual demographics to determine if variations in WTP exist among individuals with different demographic characteristics, whose results are shown in Table 5.

4 | DATA

The survey is programmed, pretested, and formally administered in December 2020. As previously discussed, to participate in the survey, individuals must be at least 18 years of age. Individuals who could not promise to provide truthful answers, failed the attention check questions, or completed the survey outside of the 95% confidence interval of survey time were excluded from our sample. A final sample of 263 consumers are collected, and the participants, on average, took 8 min to complete the survey.

Table 2 describes the demographics and bread choice frequencies of our sample. Around half the sample is female (51%), married (52%), holds a college degree, and has family pretax total annual income ranging from \$60,000 to \$99,999. Above 60% of the sample is white, nonliberal, and lives in urban areas with 1000–99,999 inhabitants. The demographic characteristics of our respondents are largely in line with that of recent food valuation studies focusing on US consumers (Lin & Nayga, 2022). In terms of individual bread choices in the choice experiment, the conventional and unlabeled bread has been selected most frequently by an average consumer (40%), followed by organic bread (21%), ERW-labeled bread (21%), and opt-out option (17%). Infrequent choices of organic bread could be partly explained by our experimental design where organic bread is set expensive than conventional bread.

Table 3 reports individual knowledge concerning climate change, including overall knowledge level and three types of knowledge. The average consumer makes approximately five correct responses among the 12 climate-change-related knowledge questions, suggesting that the subjects are knowledgeable about climate change to some extent. Among three types of climate knowledge, our respondents score highest in consequences knowledge and causes knowledge, followed by physical knowledge. We note that this pattern is similar to the result by Shi et al. (2016), while our climate knowledge scores are lower. A possible reason includes that we focus on US consumers but Shi et al. (2016) used a sample of over 2000 consumers from six countries, including European consumers that are usually found to have higher levels of climate knowledge.

TABLE 2 Sample descriptive analysis.

Variable	Definition	Mean
Gender	1 = Female, 0 = Male	0.51 (0.50)
Urban	1 = Less than 1000 inhabitants 2 = 1000–99,999 inhabitants 3 = More than 100,000 inhabitants	2.31 (0.72)
Marriage	1 = Married, 0 = others	0.52 (0.50)
Education	1 = Below college 2 = College 3 = Graduate	1.98 (0.67)
Household annual pretax income	1 = Less than \$20,000 2 = \$20,000–\$59,999 3 = \$60,000–\$99,999 4 = \$100,000–\$139,999 5 = \$140,000 and above	2.90 (1.30)
Political attitude	1 = Liberal, 0 = others	0.27 (0.44)
Race	1 = White, 0 = non-White	0.62 (0.49)
Choice frequency of conventional bread	%	40.49 (0.35)
Choice frequency of organic labeled bread	%	21.20 (0.33)
Choice frequency of ERW carbon-labeled bread	%	20.91 (0.25)
Choice frequency of opt-out option	%	17.40 (0.32)
Observations	people	263

Note: Standard errors are in parentheses.
Abbreviation: ERW, enhanced silicate rock weathering of crushed basalt.

TABLE 3 Climate knowledge scores.

Types of climate knowledge	Definition	Our sample	Shi et al. (2016)
Overall knowledge	[0–12]	4.94 (2.75)	7.18
Physical knowledge	[0–4]	1.22 (1.14)	1.96
Causes knowledge	[0–4]	1.82 (1.21)	2.40
Consequences knowledge	[0–4]	1.90 (1.22)	2.82

Note: Higher score indicates higher level of knowledge. Standard errors are in parentheses.

5 | RESULTS

The estimation results of mixed logit models in preference space and WTP space are presented in Table 4. All product attributes and prices significantly affect consumer bread selection in an expected way. In general, ERW-labeled bread is favored least by US subjects, followed by conventional bread and organic-labeled bread, despite strong heterogeneity found in consumer bread tastes.

TABLE 4 Mixed logit models in preference and WTP space.

	Preference space		WTP space	
	Coef.	***Z* value**	**Coef.**	***Z* value**
Mean				
Price	−2.25***	−9.71		
	(0.23)			
Conventional	16.51***	9.50	4.62***	15.23
	(1.74)		(0.30)	
Organic	16.84***	8.72	4.71***	15.22
	(1.84)		(0.31)	
ERW carbon	16.44***	9.55	4.02***	11.01
	(1.72)		(0.37)	
Standard deviation				
Conventional	0.605	1.14	0.85***	7.79
	(0.53)		(0.11)	
Organic	1.15***	3.93	0.16	0.50
	(0.29)		(0.33)	
ERW carbon	2.34***	6.35	1.83***	8.62
	(0.37)		(0.21)	
Price	2.25***	9.41		
	(0.53)			
ECM	8.60***	7.50	2.06***	7.82
	(1.15)		(0.26)	
Price/scale			13.28***	4.42
			(3.01)	
Observations	1188		1188	
Log-likelihood	−1020.31		−1020.31	
AIC/N	1.66		1.67	

Note: Standard errors are in parentheses.

Abbreviations: ERW, enhanced silicate rock weathering of crushed basalt; WTP, willingness to pay.

$^{*}p \le 0.1$; $^{**}p \le 0.05$; $^{***}p \le 0.01$.

TABLE 5 WTP and WTP heterogeneity, $/12 oz.

	Obs.	Conventional	Organic labeled	ERW carbon labeled
Full sample	263	4.70 (0.09)	4.76 (0.35)	4.07 (0.90)
By demographics				
Female	135	4.71 (0.08)	4.75 (0.31)	4.05 (0.89)
Male	128	4.71 (0.10)	4.76 (0.39)	4.08 (0.92)
Below 100,000 inhabitants	142	4.71 (0.08)	4.76 (0.33)	3.99 (0.84)
100,000 inhabitants and above	121	4.70 (0.09)	4.75 (0.38)	4.15 (0.96)
Married	136	4.71 (0.09)	4.76 (0.35)	4.01 (0.85)
Not married	127	4.71 (0.08)	4.76 (0.35)	4.13 (0.95)
Below college	61	4.70 (0.07)	4.78 (0.32)	3.88 (0.85)*
College and above	202	4.71 (0.09)	4.74 (0.36)	4.07 (0.92)
Liberal	70	4.72 (0.08)	4.70 (0.36)	4.24 (1.02)**
Nonliberal	193	4.71 (0.09)	4.78 (0.35)	4.00 (0.64)
White	163	4.72 (0.08)***	4.73 (0.28)	3.95 (0.82)***
Non-White	100	4.68 (0.09)	4.80 (0.22)	4.26 (0.99)
By climate knowledge				
Below or equal to median knowledge	149	4.71 (0.09)	4.76 (0.35)	4.04 (0.86)
Above median knowledge	114	4.71 (0.09)	4.75 (0.35)	4.09 (0.96)
Below or equal to median physical knowledge	175	4.71 (0.09)	4.76 (0.37)	4.06 (0.83)
Above median physical knowledge	88	4.72 (0.08)	4.75 (0.31)	4.07 (1.03)
Below or equal to median causes knowledge	174	4.71 (0.08)	4.78 (0.34)	3.97 (0.83)***
Above median causes knowledge	89	4.71 (0.10)	4.72 (0.37)	4.24 (0.10)
Below or equal to median consequences knowledge	183	4.71 (0.09)	4.75 (0.37)	4.09 (0.88)
Above median consequences knowledge	80	4.72 (0.07)	4.76 (0.30)	3.99 (0.94)

Abbreviations: ERW, enhanced silicate rock weathering of crushed basalt; WTP, willingness to pay.

*$p \leq 0.1$; **$p \leq 0.05$; ***$p \leq 0.01$, which are calculated using t tests between subsamples.

Table 5 shows the simulated means of WTPs using the full sample and subsamples. We note that the simulated means of WTPs are close to those obtained from mixed logit model in WTP space, suggesting our simulated WTPs are robust to model specification. Looking at the finding from the full sample, average WTP for the ERW-labeled whole-grain bread is smallest, being $4.07/20 oz, followed by the conventional ($4.70) and organic ($4.76) whole-grain bread. Although the WTP of ERW-labeled bread is lower compared to the other two bread products, the price discount on the novel carbon-labeled bread is not substantial. This indicates that US consumers are likely to embrace the novel bread product with certain price discount. The result is consistent with previous studies suggesting that consumers favor carbon labels to some extent (Brunner et al., 2018; Canavari & Coderoni, 2020; Guenther et al., 2012). The result also reveals that US respondents favor organic bread most, likely driven by consumer perceived health and environmental benefit associated with organic foods.

We then compare the differences in WTP estimates across different demographic subsamples and between consumers with different levels of climate knowledge. In general, heterogeneity analysis reveals that consumer valuation of the ERW carbon label tends to be significantly greater among liberal, non-White consumers and those with at least a college degree and those with high level of knowledge about the causes of climate change. Specifically, subjects who self-identify as liberals reveal $0.24 significantly higher WTP for the novel carbon label, relative to those placed by nonliberals. This is partly because liberals tend to be more likely to believe in climate change than those who align themselves with relatively conservative political parties (Hornsey et al., 2016), and thus would like to pay additionally for climate change mitigation. Second, the WTP for ERW-labeled bread is $4.26 among non-White respondents, which is $0.3 significantly higher than the value of white consumers. Third and expectedly, better educated individuals are more receptive to the ERW carbon label, relative to people without college degrees (the WTP for the novel carbon label being $3.88 vs. $4.07). This finding could be explained by the existing literature, which has indicated that education positively correlates with pro-environmental behavior (Meyer, 2015; Panzone et al., 2016), and more educated subjects have greater valuation for environmentally friendly labels (Lin & Nayga, 2022).

Last, we examine whether the difference in individual WTP for ERW-labeled bread would be attributable to the difference in climate change-related knowledge. To do so we divide our sample into two subgroups with above and below median knowledge, respectively. Findings suggest that overall climate knowledge may not be a good predictor for consumer valuation of the novel carbon label. This is because there exists no significant difference in the valuation of ERW-labeled bread between the above- and below-median overall knowledge subsamples. Looking into the three types of climate knowledge, knowledge about the causes of climate change significantly enhances consumer preference and WTP for the novel carbon label. People with the above-median knowledge about climate change causes would like to pay $4.24 for the ERW-labeled bread, in contrast to the value of $3.97 among the below-median subsample. The result somehow mirrors the previous heterogeneity analysis about education, revealing that US consumers less knowledgeable about climate change favor the ERW carbon label-less. We note that this finding is not surprising given that prior research has shown that individual knowledge about climate change leads to environmentally sustainable food choices (Peschel et al., 2016; Schmidt, 2021). But unlike the previous studies, our result not only reinforces the importance of improving public knowledge about climate change, but also highlights which type of climate knowledge is most helpful in improving environmentally friendly food behavior. Climate-related knowledge plays an important role in enhancing consumer preferences for food carbon label, which in turn promotes voluntary adoption of carbon removal technologies.

Our results also indicate that there is no heterogeneity in our results across gender. This finding is somewhat different from previous studies showing that men tend to have higher climate knowledge, but are less supportive of climate policies than women (Douenne & Fabre, 2020; Grebitus et al., 2015; Stern et al., 1993). In this regard, whether gender affects the valuation of novel carbon label needs further investigation. Similarly, whether consumers live in populated areas exerts insignificant effects on their valuation of bread products. The valuation of the ERW-labeled bread per 20 oz is just $0.15 higher for individuals in areas with at least 100,000 inhabitants, compared with those below 100,000 inhabitants. Populated areas such as big cities typically produce high carbon dioxide emissions, and are more cost-effective to implement environmental information campaigns, which would let their residents be more aware of the importance of carbon removal.

6 | CONCLUSION

Promoting the voluntary adoption of carbon removal technology during agricultural production is a promising tool for decarbonizing the food system, which receives insufficient research focus in the literature. The adoption of carbon removal technology, however, will not be successful unless consumer preferences and valuation of technology are understood. This study investigates how US consumers respond to a new technology-based carbon label on food products, focusing on the basalt-based ERW technology, a prominent option for agricultural carbon sequestration, whose market potential has not been evaluated by prior research.

Our results indicate that on average US consumers would be willing to pay $4/20 oz for the ERW-labeled bread, marginally lower than the WTPs of conventional and organic bread products; implying that the ERW-labeled bread may fail to gain market shares when competing with the conventional and organic bread products. However, consumer valuation of the ERW-labeled bread would be greater if targeted towards certain market segments, including non-White, liberal, well-educated consumers, and those having high level of knowledge about the causes of climate change. Our findings are informative to policymakers since they imply that promoting the adoption of carbon emission mitigation technologies could not count on the consumer market alone. Among others, governmental interventions may be warranted for successful adoption of ERW basalt carbon emission mitigation technology among agricultural producers, including technology adoption subsidies and climate knowledge education programs. Finally, it is worth noting that while our sample size is adequate given our choice of experimental design, future studies could enhance the robustness of our findings with a larger and more diverse sample of US consumers.

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (No. 72103180).

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Lin, Wen, Rodolfo M. Nayga, and Wei Yang. 2024. "Preferences and willingness to pay for a novel carbon label: A choice experiment in the united states." *Journal of the Agricultural and Applied Economics Association*. 1–12. https://doi.org/10.1002/jaa2.116