The effect of scientific information and narrative on preferences for possible gene-edited solutions for citrus greening

Brandon R. McFadden¹ | Brittany N. Anderton² | Kelly A. Davidson¹ | John C. Bernard¹

¹Department of Applied Economics and Statistics, University of Delaware, Newark, Delaware, USA
²Biology, San Francisco, California, USA

Correspondence
Brandon R. McFadden, Department of Applied Economics and Statistics, 531 S. College Avenue, 224 Townsend Hall, Newark, DE, 19716, USA.
Email: foodecon@udel.edu

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Abstract
This study used a national survey to examine how information that compared and contrasted gene editing with other breeding techniques, as well as a narrative, influenced both attitudes towards gene editing generally and preferences between a gene-edited insect and gene-edited tree to combat citrus greening. Consumers had low familiarity with gene editing but linked it to genetic modification. For citrus greening, respondents equally supported a gene-edited insect or tree, but the narrative decreased the perceived safety of both. These findings suggest that in general, consumers may support gene editing approaches to combat citrus greening.

Keywords
bioengineering, citrus greening, genetic modification, perceived safety, science communication

JEL Classification
D83; Q13; Q16

Citrus greening¹ is a bacterial disease spread by the Asian citrus psyllid insect, an invasive species to the US. Once infected by citrus greening, a tree produces small, bitter fruit, serves as a source of infection for other trees, and eventually dies. Citrus greening is the most serious threat to the

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US citrus industry; the disease caused a $7.80 billion cumulative loss for the industry from growing seasons 2006/2007 to 2013/2014, an average of $975 million per year (Hodges et al., 2014).

The U.S. Department of Agriculture (USDA) has funded projects directly and indirectly, through the National Institute of Food and Agriculture Specialty Crop Research Initiative, to combat citrus greening using technologies such as vector control (i.e., targeting the Asian citrus psyllid) and host resistance (i.e., decreasing susceptibility of the citrus tree). Agricultural scientists could potentially establish vector control and host resistance through gene editing, a bioengineering approach that can make very precise changes to DNA. Yet, potential welfare gains of these technologies are bounded by consumer acceptance, which may be the limiting factor if the scenario for gene editing is similar to that of genetic modification, where consumers have a propensity to discount genetically modified products (Lusk et al., 2005).

Despite the promise of gene editing to address citrus greening and other threats to the food system, consumers receive mixed messages about the relationship between breeding techniques from advocacy groups and policymakers. Like genetic modification (typically referred to as GM or GMO), gene editing employs bioengineering to alter the genetic material of living organisms. However, unlike what is typically referred to as “genetic modification,” gene editing can make much smaller, and more precise, changes to DNA. In some cases, these changes can accelerate the development of traits that could otherwise be obtained through genetic variation and conventional breeding. Because of this reason, the USDA does not plan to regulate gene-edited plants that could otherwise be developed through and are indistinguishable from traditional breeding techniques (USDA, 2018). At the same time, consumer aversion to genetic modification is well documented (Bernard et al., 2006; Lusk et al., 2005) and anti-bioengineering advocacy groups coalesce genetic modification and gene editing (Malkan, 2018). Furthermore, recent evidence suggests that consumers will apply similar discounts to gene-edited products (Shew et al., 2018). If gene editing is viewed similarly to genetic modification by consumers, gene-edited approaches to combat citrus greening may be impeded.

Using a national survey, the objective of this study was to examine consumer acceptance of gene editing as a possible solution to the threat of citrus greening. A key element of this was to determine how acceptance could be influenced by information regarding breeding techniques and a narrative about citrus greening. Specifically, views were examined before and after providing information that compared and contrasted gene editing, genetic modification, and conventional breeding. Pre-information familiarity was also measured and compared. As another main goal, consumer preferences for gene editing the insect or the tree were captured, along with a choice experiment examining willingness to pay (WTP) for the two options. Ordered probit models were run to determine how different information treatments altered similarity ratings between the techniques, and safety perceptions of the gene editing applications. Results should be useful for all parties considering developing gene editing solutions to citrus greening or other possible uses.

BACKGROUND

The majority of citrus produced in the US are oranges (non-Valencia and Valencia) and are mostly grown in Florida and California with 71,750,000 and 49,800,000 boxes in 2018–2019, respectively (USDA, 2019a). Citrus huanglongbing, commonly called HLB or citrus greening, has affected citrus production in Asia for more than 100 years. The disease was first detected in Florida in 2005 and has since been identified in other citrus-producing states (NASEM, 2018). The bacterium that causes citrus greening belongs to the genus Candidatus Liberibacter.
Bové, 2006) and is spread by small plant-eating insects known as psyllids (e.g., Asian citrus psyllid). American citrus production has steadily declined since the 2005–2006 growing season, from 11,745,000 to 6,128,000 tons in 2017–2018 (Florida Department of Agricultural and Consumer Services [FDACS], 2019), and is projected to continue the decline due to continued spread of citrus greening (USDA, 2019b).

Insects create a particularly difficult problem in agriculture because they are efficient carriers of disease, and solutions typically available, like planting barriers, infected crop removal, and area-wide pest management, require coordination. Coordination across producers presents its own unique problem (Singerman & Useche, 2019), as any action taken will have positive spillover effects that may result in free riding and ultimately decrease effectiveness (Brown et al., 2002). Some domestic producers may benefit from invasive species, due to price increases resulting from a shift in supply (Acquaye et al., 2005); however, that is not likely true in the long run for citrus greening because so many acres are affected.

The National Research Council provided short-term and long-term recommendations to address citrus greening, with the latter including the release of modified psyllid males and the development of resistant citrus (National Research Council [NRC], 2010). Bioengineering has been used to combat a similar crop disease that nearly decimated papaya production in Hawaii; the papaya ringspot virus is transmitted by aphids and was ultimately controlled by the development of a transgenic papaya (Gonsalves, 1998). Bioengineering approaches, such as gene editing, provide a promising strategy for establishing vector control or host resistance through genetic means. There has been some work to slow development and reduce fecundity of the Asian citrus psyllid (Hunter et al., 2018), and vector control via gene editing has shown promise in other scenarios, like the mosquito and malaria (Gantz et al., 2015). Alternatively, increasing resistance to disease in the host can blunt the impact of citrus greening. Genetic information, via genome sequencing, provides the information necessary to understand processes that slow or prevent infection in the host, enabling the use of gene editing.

However, the potential advantages conferred by gene editing could be blunted if gene-edited crops are discounted by consumers, the way genetically modified crops have been. The discount placed on genetically modified foods reflects consumers’ tendency to rate perceived risks of genetic modification higher than perceived benefits of the technology. When a new food technology such as genetic modification is introduced, individuals in the general public tend to inflate the riskiness of the new technology by focusing on uncertainties or worst possible outcomes and overinflating low-probability risks (Lusk et al., 2014). Once a consumer perceives a technology as dangerous, information—even from major scientific authorities—may not sway their opinion (McFadden and Lusk, 2015). Instead, individuals often ignore new information or are receptive only to information that confirms their prior biases. Even among well-informed consumers, new information has little effect and negative prior beliefs dominate perceptions of genetically modified food (Huffman et al., 2007). Negative information about the technology can further degrade consumer preference for genetically modified food (Rousu et al., 2002; Valente & Chaves, 2018).

On the other hand, some studies find that exposing consumers to positive information about the benefits of genetic modification can improve consumer valuation of foods labeled as genetically modified (Lusk et al., 2004; Rousu et al., 2002). Information is especially effective among consumers who are already more accepting of genetically modified foods (; Lusk et al., 2004; McFadden and Lusk, 2015) or if the information comes from a third-party source (Rousu et al., 2002).

Many of the factors influencing consumer biases against genetic modification could carry over to perceptions of gene editing (Jones et al., 2019). In fact, consumers are known to judge
new food technologies based on associations with known technologies (Lusk et al., 2014). Rati-
fied approaches to communicating the new technology are necessary if consumer acceptance of
gene editing is to surpass that of genetic modification. Potential solutions to communicating
about new technologies include the use of targeted information through message framing or
narratives (stories) (Yang & Hobbs, 2020).

A framing effect, as defined by Druckman (2001), is the process by which frames in commu-
nication shape frames in thought. Messages about gene editing relative to other breeding
techniques are necessarily selective to simplify to a complex issue that the public has little
knowledge about (Nelson et al., 1997). Framing breeding techniques as being similar or dissimi-
lar to each other may affect attitudes about safety and ultimately influence acceptance of novel
approaches. For example, gene editing may be likened to conventional breeding because it can
create naturally occurring genetic changes, while it may be contrasted with genetic modifica-
tion because it is a much more precise technique. Currently, it is not clear how consumers view
gene editing relative to other breeding techniques, or how information about the similarities
and differences between gene editing and other breeding techniques affect consumer attitudes.

Recently, the use of narratives, or stories, has been appreciated as a tool for communicating
science and technology issues to nonexperts (Dahlstrom & Scheufele, 2018; Downs, 2014;
ElShafie, 2018; Lyons et al., 2019; Suzuki et al., 2018). Evidence suggests stories help individuals
process and recall new information (Dahlstrom, 2014), and conversational messages are more
likely to sway attitudes about genetically modified foods because they can demonstrate how
values are aligned with individuals who hold an opposing position (Lyons et al., 2019). Simply
providing information about the safety of genetically modified food has been found to only be
effective in swaying attitudes for individuals who thought the breeding technique was safe
before receiving the information, but not effective for those with an opposing position
(McFadden & Lusk, 2015). Therefore, a narrative about the effects of citrus greening on farmers
and consumers may be a more effective approach for science communication and may impact
consumer acceptance of gene editing approaches to combat citrus greening.

METHODS AND HYPOTHESES

Survey overview

The questions asked to respondents are described and discussed briefly in this section and more
details, including the survey flow, are provided in the Appendix, Figure A1. After consenting to
take the survey, respondents were asked about orange consumption and a few demographic
questions that were used as quotas (i.e., age, income, and sex) to determine eligibility. Respon-
dents were then asked about their familiarity with the following breeding techniques: gene
editing (also referred to as GE), conventional breeding (also referred to as selection or hybridiza-
tion), and genetic modification (also referred to as GMO). It was important to get a measure
of familiarity for gene editing compared to the other breeding techniques, which are more
established, but also to ensure respondents with relatively more familiarity with breeding
techniques were randomized across treatments (the treatments are described in this section).

After the familiarity questions, respondents were randomized into one of two blocks: (1) an
Information Block; or (2) a Narrative Block. All respondents completed both blocks; however,
the order of the blocks was randomized across respondents. In the Information Block, respond-
dents were first asked about the similarity of breeding techniques (i.e., gene editing and
conventional breeding, gene editing and genetic modification, and conventional breeding and genetic modification) and the safety of gene-edited insects, plants, and animals. Previous research has examined the acceptance of genetic modification and determined that consumers do not view the technology as a single entity; rather, there are subtle distinctions in acceptance. For example, Lusk et al. (2015) determined that consumers are more accepting of genetically modified plants relative to genetically modified animals. Next, respondents were randomly assigned to one of four interventions that presented information about the similarity or difference between various breeding techniques. The randomized intervention communicated either the (I1) similarity between gene editing and conventional breeding; (I2) difference between gene editing and conventional breeding; (I3) similarity between gene editing and genetic modification; or (I4) difference between gene editing and genetic modification. The specific information provided is presented in Figure 1. All respondents were provided definitions for an organism, beneficial traits, bioengineering, and gene editing. Any additional information depended on the randomized intervention. Questions were asked to determine how the information affected attitudes after the assigned intervention, and to measure motivated reasoning similar to Lord et al. (1979).

In the Narrative Block, respondents watched a CBS news clip (1:57 min in duration) about the effects of citrus greening on the citrus industry in Florida. Previous research on genetically modified food found consumers were relatively supportive of a genetic modification application that would keep production in the US (Lusk et al., 2015); therefore, we expect respondents to find citrus greening to be a compelling narrative. After watching the news clip, respondents were asked two questions to measure the level of support for two different gene editing applications to combat citrus greening. Although attitudes and preferences are generally consistent, choice-based questions may be perceived as having more immediate implications (Phillips et al., 2002). Therefore, respondents also completed a choice experiment for sets of three oranges that varied by gene editing application (i.e., grown in the context of either a gene-edited insect or gene-edited tree) and price ($1.50, $2.25, and $3.00).

Respondents finished the survey by completing two tasks and demographic questions. The two tasks were the Cognitive Reflection Test (Frederick, 2005) and the Cultural Cognition Thesis (Kahan, 2012; Kahan et al., 2009, 2011). These tasks were included to determine predisposition to rely on intuition versus reasoning and how aversion to technology may be influenced by cultural values and demographic characteristics, like political affiliation and sex (McFadden, 2016), which have been identified to be determinants of attitudes about safety of genetic modification. These covariates were collected to examine the determinants of perceived similarity and safety before receiving information. More information about these covariates is provided in the Appendix.

**Hypotheses, test, and models**

Chi-square tests were used for several hypotheses. First, a Chi-square test was used to determine if familiarity was equal across all breeding techniques (i.e., gene editing, conventional breeding, and genetic modification). Next, in the Information Block, Chi-square tests were used to determine if perceived similarity between breeding techniques was equal across all comparisons (i.e., gene editing and conventional breeding, gene editing and genetic modification, and conventional breeding and genetic modification) and if perceived safety of gene editing was equal across applications (i.e., insect, plant, and animal).
Definitions

Interventions $I_{1,2,3,4}$

Organism – Any living thing, such as a plant or animal (including insects).

Beneficial traits – Characteristics that are desired in an organism. For example, disease resistance is often a desired characteristic.

Bioengineering – The combination of biology and engineering to make changes to an organism to create products with beneficial traits.

Genome Editing (also referred to as gene editing) – A process by which breeders use bioengineering methods to make very specific changes to an organism’s genetic code by inserting, replacing, or removing DNA with hopes of introducing beneficial traits.

Interventions $I_{1,2}$

Conventional Breeding (also referred to as selection or hybridization) – A process by which breeders identify individual organisms with beneficial traits, and then breed these to create the next generation with hopes of passing on the beneficial traits.

$I_1$. How are Gene Editing and Conventional Breeding similar?

Gene Editing is similar to Conventional Breeding because it allows breeders to make genetic changes that could occur in nature to develop organisms with beneficial traits.

$I_2$. How are Gene Editing and Conventional Breeding different?

Gene Editing is different from Conventional Breeding because Conventional Breeding relies on chance to develop organisms with beneficial traits. In contrast, Gene Editing allows breeders to make precise genetic changes to develop organisms with beneficial traits.

Interventions $I_{3,4}$

Genetic Modification (also referred to as GMO) – A process by which breeders use bioengineering methods to introduce new DNA with hopes of passing beneficial traits between organisms.

$I_3$. How are Gene Editing and Genetic Modification similar?

Gene Editing is similar to Genetic Modification because it allows breeders to use bioengineering methods to develop organisms with beneficial traits.

$I_4$. How are Gene Editing and Genetic Modification different?

Gene Editing is different from Genetic Modification because Gene Editing can make small genetic changes that could occur in nature, in order to develop organisms with beneficial traits. In contrast, Genetic Modification involves larger genetic changes (such as transferring a gene from one organism to another) that typically could not occur in nature, in order to develop organisms with beneficial traits.

**FIGURE 1** Information presented about the similarity or difference between breeding techniques

Ordered probit models were used to examine how the information interventions affected perceived similarity between breeding techniques or perceived safety of gene editing applications. The indicator variables $I_1$, $I_2$, $I_4$, are equal to one if a respondent was exposed to that
information intervention, where $I_1$ was the similarity between gene editing and conventional breeding, $I_2$ the difference between gene editing and conventional breeding and $I_4$ the difference between gene editing and genetic modification. $I_3$ was the base captured by the intercept for respondents exposed to the information intervention of the similarity between gene editing and genetic modification. Levels of perceived similarity or safety were also included in the models to account for biased assimilation. Ordered probit models were also estimated to examine determinants of perceived similarity between breeding techniques and perceived safety of gene editing applications before an intervention. These results are reported in the Appendix.

In the Narrative Block, Chi-square tests were used to determine if the level of support was equal for both proposed gene editing applications (i.e., gene-edited insect versus gene-edited tree) to combat citrus greening. Further analyses were conducted for any null hypotheses rejected by Chi-square tests using pairwise comparisons with Bonferroni-corrected $p$-values. To examine if preferences for a gene-edited insect or gene-edited tree to combat citrus greening were consistent with attitudes about supporting the gene editing solutions, the choice experiment questions were analyzed using a random utility model (McFadden, 1974). The mathematical framework for this analysis is provided in the appendix.

**Respondents**

To address the research questions, an internet survey was developed and administered to an online panel of 1185 respondents maintained by Qualtrics from May 2, 2019 through May 12, 2019. Consumers of oranges were qualified to take the survey and respondents were prescreened to ensure the sample was representative of the US population by age, income, and sex. Summary statistics for characteristics for respondents are presented in Table 1. The median age and income category were 43 and $50,000 to $74,999, and 50% of the survey sample was comprised of females. Multivariate analysis of variance was used to determine whether characteristics are similar across treatment groups. The null hypothesis of no differences in characteristics across the Information and Narrative Blocks was not rejected at an alpha level of 0.05 for orange consumption, familiarity with breeding techniques, Cognitive Reflection Test scores, Cultural Cognition Quiz scores, age, density of population, education, sex, income, or political affiliation. Additionally, the null hypothesis that characteristics were not different across information interventions (i.e., $I_1$, $I_2$, $I_3$, $I_4$) was also not rejected at an alpha level of 0.05 for all the same variables.

**RESULTS**

The self-reported level of familiarity with the breeding techniques is shown in the Appendix, Figure A2. The Chi-Square test statistic was 81.60 (df = 8, $p$-value <0.01), indicating that familiarity was dependent on breeding technique, and pairwise tests indicate that respondents had the highest familiarity with genetic modification and lowest familiarity with gene editing (all corrected pairwise comparisons had $p$-values <0.01).

In the Information Block, respondents were asked to rate the similarity between breeding techniques before and after an intervention. The results from these questions are shown in Figure 2. Before information, the Chi-Square test statistic was 88.68 (df = 8, $p$-value <0.01), indicating that the level of perceived similarity was dependent on the two breeding techniques.
being compared by respondents. Pairwise tests indicate that respondents thought gene editing and genetic modification were more similar than gene editing and conventional breeding (corrected \( p \)-value <0.01) or conventional breeding and genetic modification (corrected \( p \)-value <0.01); however, the pairwise comparison between gene editing and conventional breeding and conventional breeding and genetic modification was not significant (corrected \( p \)-value = 1).

| Variable                                      | Levels                                              | Median or frequency |
|-----------------------------------------------|-----------------------------------------------------|---------------------|
| Cognitive reflection test (0–3)               | 0                                                   | 68.52%              |
|                                               | 1                                                   | 20.51%              |
|                                               | 2                                                   | 6.50%               |
|                                               | 3                                                   | 4.47%               |
| Cultural cognition quiz (0–1)                  | 0 - Egalitarian communitarians                      | 49.70%              |
|                                               | 1 - Hierarchical individualists                     | 50.30%              |
| Age                                           |                                                     | 43                  |
| Density (1–3)                                 | 1 – Rural                                           | 21.18%              |
|                                               | 2 – Suburban                                        | 45.91%              |
|                                               | 3 – Urban                                           | 32.91%              |
| Education (1–8)                               | 1 - Less than high school degree                    | 2.78%               |
|                                               | 2 - High school graduate (high school diploma or equivalent including GED) | 21.35%              |
|                                               | 3 - Some college but no degree                      | 22.53%              |
|                                               | 4 - Associate degree in college (2-year)            | 12.24%              |
|                                               | 5 - Bachelor’s degree in college (4-year)           | 23.29%              |
|                                               | 6 - Master’s degree                                 | 13.59%              |
|                                               | 7 - Doctoral degree                                 | 1.60%               |
|                                               | 8 - Professional degree (JD, MD)                    | 2.62%               |
| Sex (0–1)                                     | 0 - Male                                            | 50%                 |
|                                               | 1 - Female                                          | 50%                 |
| Income (0–9)                                  | 1 - Less than $20,000                               | 14.77%              |
|                                               | 2 - $20,000 to $34,999                              | 14.09%              |
|                                               | 3 - $35,000 to $49,999                              | 10.63%              |
|                                               | 4 - $50,000 to $74,999                              | 18.82%              |
|                                               | 5 - $75,000 to $99,999                              | 13.59%              |
|                                               | 6 - $100,000 to $119,999                            | 8.95%               |
|                                               | 7 - $120,000 to $139,999                            | 5.32%               |
|                                               | 8 - $140,000 to $159,999                            | 6.58%               |
|                                               | 9 - $160,000 or greater                             | 7.26%               |
| Political affiliation                         | Democrat                                            | 33.50%              |
|                                               | Republican                                          | 31.98%              |
|                                               | Independent, other, or no preference                 | 34.52%              |
Coefficients from the ordered probit models examining how information affected perceived similarity between breeding techniques are shown in Table 2 (partial effects are shown in the Appendix, Table A2). How respondents perceived the similarity between breeding techniques before an intervention influenced the impact of information. This effect is further highlighted in the Appendix by Figure A3, which shows how respondents perceived the similarity between gene editing and conventional breeding after information given the level of perceived similarity before information. The coefficients for the information treatment variables (I1, I2, and I4) in Table 2 are relative to respondents who received information about the similarity between genetic modification and gene editing. The variables I2 and I4, which both represent a respondent received information about differences between breeding techniques, were significant and negative across all three comparisons. While I1 was positive in both the gene editing and conventional breeding comparison and gene editing and genetic modification comparison, it was significant and negative for the conventional breeding and genetic modification comparison. These respondents received information about the similarity between gene editing and conventional breeding, which appears to have been effective in changing perceived similarity for those breeding techniques.

Also in the Information Block, respondents were asked about the safety of gene editing an insect, plant, and animal before and after information. The results from these questions are...

**FIGURE 2** Perceived similarity between breeding techniques before and after information

**TABLE 2** The effects of information intervention on perceived similarity between breeding techniques

| Variable                  | Gene editing and conventional breeding | Gene editing and genetic modification | Conventional breeding and genetic modification |
|---------------------------|----------------------------------------|--------------------------------------|-----------------------------------------------|
| Constant                  | 0.641***(0.080)                        | 0.554***(0.082)                      | 0.852***(0.092)                               |
| Perceived similarity      | 0.437***(0.025)                        | 0.479***(0.026)                      | 0.420***(0.029)                               |
| before information        |                                        |                                      |                                               |
| I1                        | 0.207**(0.087)                         | 0.222**(0.088)                       | −0.218**(0.088)                               |
| I2                        | −0.314***(0.089)                       | −0.275***(0.089)                     | −0.468***(0.089)                               |
| I4                        | −0.316***(0.089)                       | −0.406***(0.090)                     | −0.728***(0.090)                               |
| Log likelihood function   | −1630                                  | −1616                                | −1630                                         |

Note: There are coefficients from ordered probit models, all with 1185 observations. Standard errors are in parentheses. *, **, and *** denote significance level at 0.10, 0.05, and 0.01, respectively.

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Also in the Information Block, respondents were asked about the safety of gene editing an insect, plant, and animal before and after information. The results from these questions are...
shown in Figure 3. The Chi-Square test statistic before information was 62.33 (df = 8, p-value <0.01), indicating that level of safety was dependent on what is gene edited. Pairwise Chi-Square tests indicate that respondents thought gene editing plants is safer than an insect (corrected p-value <0.01) or animal (corrected p-value <0.01); however, the comparison of an insect and animal was not significant (corrected p-value = 0.10).

Coefficients from the ordered probit models examining determinants for perceived safety of gene editing applications are shown in Table 3 (partial effects are shown in the Appendix, Table A3). Respondents who completed the Narrative Block prior to answering questions about the safety of gene editing were less likely to perceive the application of gene editing to insects and plants as safe. This is counterintuitive given that the narrative about citrus greening and the questions in the Narrative Block specifically discussed gene editing insects and plants.

| Variable                | Insects         | Plants          | Animals         |
|-------------------------|-----------------|-----------------|-----------------|
| Constant                | 1.186*** (0.173)| 1.380*** (0.174)| 1.070*** (0.173)|
| Narrative               | −0.233*** (0.062)| −0.121** (0.062)| −0.090 (0.062) |
| Cognitive reflection test| −0.018 (0.040) | 0.088*** (0.040) | −0.022 (0.040) |
| Hierarchical individualists | 0.128** (0.065) | 0.067 (0.065) | 0.131** (0.065) |
| Age                     | −0.007*** (0.002)| −0.005** (0.002)| −0.007*** (0.002)|
| Density                 | 0.155*** (0.046) | 0.065 (0.046) | 0.112** (0.045) |
| Education               | 0.026 (0.022) | 0.038* (0.022) | 0.047** (0.022) |
| Female                  | −0.547*** (0.066) | −0.546*** (0.066) | −0.669*** (0.066) |
| Income                  | 0.087*** (0.015) | 0.075*** (0.015) | 0.082*** (0.015) |
| Democrat                | 0.060 (0.077) | 0.100 (0.077) | 0.066 (0.078) |
| Republican              | 0.126 (0.079) | 0.177*** (0.080) | 0.051 (0.079) |
| Log likelihood function | −1725 | −1686 | −1748 |

Note: There are coefficients from ordered probit models, all with 1185 observations. Standard errors are in parentheses. *, **, and *** denote significance level at 0.10, 0.05, and 0.01, respectively.
Table 4: The effects of information intervention on perceived safety of gene-edited applications

| Variable                                | Insects                  | Plants                  | Animals                  |
|-----------------------------------------|--------------------------|-------------------------|--------------------------|
| Constant                                | 0.431*** (0.091)         | 0.308*** (0.100)        | 0.612*** (0.086)         |
| Perceived safety before information     | 0.670*** (0.028)         | 0.626*** (0.029)        | 0.572*** (0.027)         |
| I1                                      | 0.028 (0.089)            | 0.097 (0.088)           | −0.098 (0.088)           |
| I2                                      | −0.030 (0.090)           | 0.025 (0.090)           | −0.161* (0.089)          |
| I4                                      | −0.023 (0.091)           | 0.000 (0.091)           | −0.175* (0.090)          |
| Log likelihood function                 | −1436                    | −1489                   | −1511                    |

Note: There are coefficients from ordered probit models, all with 1185 observations. Standard errors are in parentheses. *, **, and *** denote significance level at 0.10, 0.05, and 0.01, respectively.

Perceived safety varied by respondent characteristics such as hierarchical individualism, political affiliation, gender, and age.

Coefficients from the ordered probit models examining how information affected perceived safety of gene editing applications are shown in Table 4 (partial effects are shown in the Appendix, Table A4). The information interventions had almost no effect on perceived safety. Again, attitudes after information were influenced by attitudes before information. This effect is further highlighted by Figure A4 in the appendix, which shows how respondents perceived the safety of gene-edited plants after information given the level of perceived safety before information.

Figure 4 illustrates the stated level of support for a gene-edited insect versus a gene-edited tree to combat citrus greening. The majority of respondents were either very or extremely supportive of a gene-edited tree (60.5%) or a gene-edited insect (57.81%). The null hypothesis that level of support was not dependent on the proposed gene editing solution to combat citrus greening was not rejected with a Chi-Square test statistic of 7.13 (df = 8, p-value 0.13), and this indicates that respondents were equally supportive of one solution relative to the other. Moreover, support for the gene editing solutions was equal when respondents were forced to choose between either supporting the gene-edited tree or insect. The letters above the response options in the “Relative Level of Support” graph in Figure 4 denote that the responses for the gene-edited tree and gene-edited insect were not significantly different (hence the “A” above those response options). The response option of equally supporting both solutions was chosen more
than the other possible response options (hence the “B” above this response option), which further highlights that respondents are equally supportive of a gene-edited insect and gene-edited tree to combat citrus greening. This suggests some difference in support and perceived safety when a gene-editing solution is linked to a specific cause. Before information, respondents perceived gene-edited plants to be safer than gene-edited insects. However, respondents express equal support for the two solutions when provided a narrative about citrus greening solution.

The results from the discrete choice experiment further demonstrate that support was equal for a gene-edited insect and tree. Specification 1 of the choice model in Table 5 shows no significant effect on willingness to pay (WTP) for oranges when produced because of a gene-edited insect solution relative to a gene-edited tree solution. The coefficient for $\text{Insect}_k$ is negative and significant in Specification 2, indicating a discount (approximately $0.19 for a set of three oranges) associated with oranges produced because of a gene-edited insect solution for respondents who were randomly assigned to view the Narrative Block first. However, the interaction $I_1 \ast \text{Insect}_k$ had a positive and significant coefficient, indicating that the information intervention $I_1$ (similarity between gene editing and conventional breeding) decreased aversion to a gene-edited insect solution.

### CONCLUSION

The sharing of species is an inevitable cost of trade (Hulme, 2009), and the annual economic impact of invasive species, like the Asian citrus psyllid, is significant (Olson, 2006). It is estimated that the economic cost of invasive species in the US is approximately $219 billion per year (Pimentel, 2011). Modern biotechnology has created new tools to aid agriculture. One of the first of these, genetic modification, has become a concern to many consumers with questionable acceptance in the marketplace. A newer technique, gene editing, is very flexible and may be a useful solution to many agricultural issues if consumers are willing to accept it. Because gene editing approaches allow agricultural scientists to accelerate the development of crops and livestock that could occur naturally through conventional breeding, there is an implicit expectation that gene editing will be more readily accepted by consumers than genetic modification. An area where gene editing could be of substantial benefit is in the citrus industry, where citrus greening is causing large losses. The flexibility of gene editing can be seen in that it could be used either to change the insect carrier of citrus greening or the citrus tree itself.

### TABLE 5 Coefficient estimates from the choice experiment

| Variable | Specification 1 | Specification 2 |
|----------|----------------|----------------|
| Intercept | 2.620*** (0.108) | 2.622*** (0.108) |
| Insect   | $-0.034$ (0.035) | $-0.113***$ (0.050) |
| Price    | $-0.603***$ (0.038) | $-0.604***$ (0.038) |
| $I_1 \ast \text{Insect}$ | – | 0.243** (0.108) |
| $I_2 \ast \text{Insect}$ | – | 0.110 (0.107) |
| $I_3 \ast \text{Insect}$ | – | 0.153 (0.114) |
| $I_4 \ast \text{Insect}$ | – | 0.104 (0.105) |
| Log likelihood function | $-6649.74$ | $-6961.47$ |

**Note:** There are 7110 observations (1185 individuals made six choices) in both specifications. Clustered standard errors are in parentheses. *, **, and *** denote significance level at 0.10, 0.05, and 0.01, respectively.
Respondents reported highest familiarity with genetic modification and were least familiar with gene editing. There is likely some availability bias in the degree of familiarity with breeding techniques due to the amount of information currently available to consumers about genetic modification. Nevertheless, respondents found gene editing to be more similar with genetic modification than conventional breeding. While information about how gene editing and conventional breeding are similar increased perceived similarity among respondents, it also increased the perceived similarity between gene editing and genetic modification. Thus, consumers may apply similar discounts to gene-edited products that have been estimated for genetically modified products despite a positive message strategy.

At baseline, respondents perceived gene-edited plants to be safer than gene-edited insects and supported the likelihood that a gene-edited crop would be approved more quickly than a gene-edited insect because of fewer social and legal concerns. However, after the information interventions, there was no difference between the perceived safety of gene editing for insects, plants, and animals. Interestingly, this result was not the effect of any specific information intervention. Although insects and animals were perceived to be less safe applications of gene editing, there was no difference in the level of support for a gene-edited insect versus gene-edited tree solution to citrus greening. This highlights the complexity of conceptual understanding of bioengineering approaches—consumers can have seemingly misaligned affective and behavioral responses.

Narratives are an increasingly popular mode for communicating science and technological information with nonexperts. However, the narrative in this study produced unintended effects. Respondents who completed the narrative block prior to the perceived safety question were less likely to find gene-edited insects or plants as safe. Despite concerns, respondents were supportive of any solution that would successfully eradicate citrus greening despite possible safety concerns.

These findings provide insight on mechanisms for policy makers and scientists to communicate with the public about gene editing. There is risk that the association between gene editing and genetic modification will lead to consumer biases against gene editing due to concerns about genetic modification. Communicating information about the similarities and differences between gene editing and conventional breeding can help overcome consumer aversion to gene editing. As in the case of genetic modification (McFadden & Lusk, 2015), prior perceptions were most influential on perceived safety about gene editing after receiving information. Due to the influence of prior perceptions, it is important to communicate early about the new technology. The acceptance despite concern by those randomly exposed to the narrative first highlight the need to explain the possible applications and benefits of gene-editing technology, like resistance to disease and drought, polled livestock, and changes in fatty acid composition, that can increase producer, animal, and consumer welfare, respectively. The mechanism that caused greater safety concerns for respondents randomized to complete the Narrative Block first is unknown; however, priming respondents about their knowledge of genetic modification increased perceived safety (McFadden & Lusk, 2016). Perhaps providing a narrative causes an opposite effect.

The results show favorable implications for the citrus industry. In general, consumers are supportive of gene-edited plants and insects to combat citrus greening. Vector control and host resistance have the potential to be accepted by consumers if information is communicated while the technology is still new. Results regarding the determinants of perceived similarity and safety indicate a “blanket approach” that uses a single strategy to communicate the potential benefits of gene editing is unlikely to be effective for a wide swath of the public.

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ENDNOTES

1 For a comprehensive review of citrus greening, read National Academies of Sciences, Engineering, and Medicine [NASEM], 2018.

2 For the purposes of this study, the authors chose to define genetic modification in terms of transgenesis, which is the process of transferring genes from one organism to another. At the time that this study was conducted, the majority of commercially available genetically modified crops were developed via transgenesis.

3 Definitions and similarity statements were developed by two individuals with expertise in agricultural biotechnology approaches, in conjunction with the research team.

4 The video is available at: https://www.cbsnews.com/video/florida-farmers-struggling-with-citrus-greening-disease/ Accessed May 9, 2019.

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APPENDIX

Additional details about the survey overview

Figure A1 illustrates the survey flow and how respondents were randomized in the various treatments. As illustrated by Figure A1, 1605 respondents viewed the Information Block first and 580 respondents viewed the Narrative Block first. The order of the familiarity questions was randomized across respondents and the response options were a five-point scale from “extremely familiar” to “not familiar at all.” The order of the similarity and safety questions were randomized across respondents and the response options were five-point scales from “extremely similar” to “not at all similar” and “extremely safe” to “extremely unsafe.”

The gene editing applications presented to respondents were a gene-edited insect and a gene-edited tree and the response options were a five-point scale from “extremely supportive” to “not supportive at all” for both. Respondents were asked a third question that measured relative support for a gene-edited insect and a gene-edited tree with response options that varied...
Respondents finished the survey by completing the Cognitive Reflection Test to determine predisposition to rely on intuition versus reasoning, the Cultural Cognition Quiz to determine cultural values, and demographic questions. Particular demographic characteristics have been identified to be determinants of attitudes about safety of genetic modification, like political affiliation and sex (McFadden, 2016). However, other characteristics, like an overreliance on heuristics and cultural values, may be more relevant in the context of aversion to technology. The Cognitive Reflection Test, introduced by Frederick (2005), uses three questions designed to generate incorrect intuitive answers and measures an individual’s predisposition to rely on intuition versus reasoning (Kahan, 2012). Higher scores on the Cognitive Reflection Test indicate an individual is more likely to engage in higher forms of reasoning. The Cultural Cognition Thesis uses two scales, one scale determines whether a person is egalitarian or hierarchical and the other scale determines whether a person is communitarian or individualistic (Kahan et al., 2011). Respondents who were categorized in the top half of both the hierarchy and individualism scales were designated “hierarchical individualists,” while respondents who were categorized in the bottom half of both scales were designated “egalitarian communitarians.”

Additional details about the hypotheses, test, and models

In the Information Block, ordered probit models were estimated to examine determinants of perceived similarity between breeding techniques and perceived safety of gene editing applications before an intervention. Ordered probit models were chosen because the independent variables were measured on five-point scales. Approximately half of the sample was randomized to answer questions in the Narrative Block prior to the Information Block; therefore, an indicator variable (i.e., Narrative) was included as an independent variable to examine how a story about the real-world effects of citrus greening affected perceived similarity and safety. Other independent variables included were demographics (i.e., age, density of population, education, sex, income, political affiliation), scores from the Cognitive Reflection Test, and variables from the Cultural Cognition Quiz that classified respondents as either hierarchical individualists or egalitarian communitarians, as in Kahan et al. (2011).

Let the utility derived by person i from alternative k be represented by:

\[ U_{ik} = V_{ik} + \varepsilon_{ik}, \]  

where \( V_{ik} \) and \( \varepsilon_{ik} \) are the deterministic and stochastic portions of utility, respectively. If faced with \( K \) choice options, a respondent is assumed to choose option \( k \) if \( U_{ik} > U_{il} \) for all \( k \neq l \). Assuming the \( \varepsilon_{ik} \) are independent and identically distributed as a type 1 extreme value random variable, then the probability of individual i choosing option k is:

\[ \text{Prob (alternative } k \text{ is chosen)} = \frac{e^{V_{ik}}}{\sum_{i=1}^{K} e^{V_{il}}} \]  

The choice experiment questions used conjoint analysis in which respondents made choices between alternative bundles of attributes. The attributes included a solution for citrus greening (gene-edited tree and gene-edited insect), and price ($1.50, $2.25, $3.00). These prices were chosen to match the range found in field experiment results on willingness to pay (WTP) for conventional and organic oranges in Kramer (2018). As described in Louviere et al. (2000), a full
factorial design is a design in which every level of each attribute is combined with every level of all other attributes. For this study, which has two attributes, one varied at two levels and one varied at three levels, a full factorial design required $2^1 \times 3^1 = 6$ choice sets.

For the choice experiment analysis, the deterministic portion of the utility for option $k$ for respondent $i$ was estimated as:

$$V_{ik} = \beta_0 + \beta_1 \text{Insect}_k + \gamma_1 \text{Price}_k,$$  \hspace{1cm} (A3)

and

$$V_{ik} = \beta_2 + \beta_3 \text{Insect}_k + \gamma_2 \text{Price}_k + \beta_4 I_1 \text{Insect}_k + \beta_5 I_2 \text{Insect}_k + \beta_6 I_3 \text{Insect}_k + \beta_7 I_4 \text{Insect}_k,$$  \hspace{1cm} (A4)

where $\text{Insect}_k$ is equal to one if option $k$ was produced using the gene-edited insect, and $\text{Price}_k$ is equal to the price of option $k$. In Equation A3, the estimated coefficient of interest is $\beta_1$, which indicates whether there is a preference for one gene editing solution for citrus greening relative to the other.

The indicator variables for information interventions ($I_1, I_2, I_3, I_4$) are interacted with $\text{Insect}_k$ in Equation A4 to examine how messages about the similarities and differences between breeding techniques affect preferences for gene editing solutions to combat citrus greening. Approximately half of the sample was randomized to answer questions in the Information Block prior to the Narrative Block; therefore, the information indicator variables are the same as described above, with the exception that they are only equal to one for respondents randomized to complete the Information Block first.

Determinants of perceived similarity and safety prior to information results

Coefficients from the ordered probit models examining determinants of perceived similarity between breeding techniques are shown in Table A1. Several variables were significant with the same sign across the three comparisons of breeding techniques, showing some common trends. For example, Narrative was significant and negative across all comparisons, indicating that respondents who completed the Narrative Block prior to this question were more likely to perceive all breeding techniques as dissimilar. Females, older individuals, those with lower incomes, and from more rural areas also viewed the techniques as being less similar. Also interesting were the results for the Cognitive Reflection Test and Republican variables. Respondents who scored higher on the Cognitive Reflection Test were more likely to perceive gene editing and genetic modification to be dissimilar with conventional breeding but there was not a significant effect on perceived similarity between gene editing and genetic modification. Respondents who identified as Republican were more likely to perceive both gene editing and genetic modification to be similar with conventional breeding.

Coefficients from the ordered probit models examining determinants for perceived safety of gene editing applications are shown in Table A3. Respondents who completed the Narrative Block prior to this question were less likely to perceive the application of gene editing to insects and plants as safe. This is counterintuitive given that the narrative about citrus greening and the questions in the Narrative Block specifically discussed gene editing insects and plants. Respondents who were categorized as hierarchical individualists by the Cultural Cognition Quiz were more likely to perceive insects and animals as safe gene editing applications, as were those who live in more dense locations. Conversely, those who scored relatively higher on the Cognitive Reflection Test and Republicans were more likely to think gene-edited plants were safe. Older respondents and females were less likely to perceive any gene editing application as being safe, while respondents with higher income were just the opposite.
### Table A1  Determinants of perceived similarity between breeding techniques before an information intervention

| Variable                        | Gene editing and conventional | Conventional and genetic modification | Gene editing and genetic modification |
|---------------------------------|-------------------------------|--------------------------------------|--------------------------------------|
|                                 | Prob(Y = Not at all similar)  | Prob(Y = Slightly similar)           | Prob(Y = Moderately similar)         |
| Narrative                       | 0.06466***                    | 0.03391***                           | 0.01389***                           |
| Hierarchical individualists     | −0.03092**                   | −0.01639**                           | −0.00682**                           |
| CRT                             | 0.04939***                   | 0.02625***                           | 0.01095***                           |
| Age                             | 0.00338***                   | 0.00180***                           | 0.00075***                           |
| Density                         | −0.02788***                  | −0.01481***                          | −0.00562**                           |
| Education                       | −0.01658**                   | −0.01481***                          | −0.00562**                           |
| Female                          | 0.08864***                   | 0.004632***                          | 0.00696***                           |
| Income                          | −0.01733***                  | −0.00921***                          | −0.00921***                          |
| Democrat                        | −0.03119*                    | −0.01731*                            | −0.02969***                          |
| Republican                      | −0.05268***                  | −0.05675***                          | −0.05675***                          |
|                                 |                               |                                      |                                      |
|                                 |                               |                                      | (Continues)                          |
| Variable                  | Gene editing and conventional | Conventional and genetic modification | Gene editing and genetic modification |
|--------------------------|-------------------------------|---------------------------------------|--------------------------------------|
| CRT                      | −0.03796***                  | −0.02910***                          | 0.00387                              |
| Age                      | −0.00266***                  | −0.00274***                          | −0.00109***                         |
| Density                  | 0.02142***                   | 0.02929***                           | 0.01368***                          |
| Education                | 0.00813**                    | 0.00613                              | 0.00768***                          |
| Female                   | −0.06693***                  | −0.06831***                          | −0.03022***                         |
| Income                   | 0.01332***                   | 0.01399***                           | 0.00866***                          |
| Democrat                 | 0.02403*                     | 0.02208*                             | −0.00144                            |
| Republican               | 0.04052***                   | 0.04568***                           | 0.00912                             |

Prob(Y = Extremely similar)

| Variable                   | Gene editing and conventional | Conventional and genetic modification | Gene editing and genetic modification |
|----------------------------|-------------------------------|---------------------------------------|--------------------------------------|
| Narrative                 | −0.06326***                  | −0.06095***                          | −0.04340***                         |
| Hierarchical individualists | 0.03042**                   | 0.02175                              | 0.00703                             |
| CRT                       | −0.04864***                  | −0.03779***                          | 0.00889                             |
| Age                       | −0.00333***                  | −0.00355***                          | −0.00249***                         |
| Density                   | 0.02745***                   | 0.03803***                           | 0.03143***                          |
| Education                 | 0.01042**                    | 0.00797                              | 0.01765***                          |
| Female                    | −0.08727***                  | −0.09029***                          | −0.06986***                         |
| Income                    | 0.01707***                   | 0.01817***                           | 0.01989***                          |
| Democrat                  | 0.03236*                     | 0.03007*                             | −0.00328                            |
| Republican                | 0.05724***                   | 0.06675***                           | 0.02201                             |
| Log likelihood function   | −1742                        | −1732                                | −1674                               |

Note: There are partial effects from ordered probit models, all with 1185 observations. *, **, and *** denote significance level at 0.10, 0.05, and 0.01, respectively.
### Table A2  The effects of information intervention on perceived similarity between breeding techniques

| Variable                  | Gene editing and conventional | Conventional and genetic modification | Gene editing and genetic modification |
|---------------------------|-------------------------------|---------------------------------------|---------------------------------------|
|                           | Prob(Y = Much less similar)   |                                       |                                       |
| Perceived similarity      | −0.06006***                   | −0.06415***                          | −0.04952***                          |
| before information        | I1                            | −0.02647**                           | 0.02784***                           |
|                           | I2                            | 0.04835***                           | 0.06643***                           |
|                           | I4                            | 0.04908***                           | 0.11585***                           |
|                           | Prob(Y = Slightly less similar)|                                       |                                       |
| Perceived similarity      | −0.05139***                   | −0.06004***                          | −0.04909***                          |
| before information        | I1                            | −0.02376**                           | 0.02598**                            |
|                           | I2                            | 0.03742***                           | 0.05648***                           |
|                           | I4                            | 0.03777***                           | 0.08728***                           |
|                           | Prob(Y = Neither more nor less similar)|                           |                                       |
| Perceived similarity      | −0.06283***                   | −0.06697***                          | −0.06717***                          |
| before information        | I1                            | −0.03166**                           | 0.03253***                           |
|                           | I2                            | 0.03888***                           | 0.06197***                           |
|                           | I4                            | 0.03872***                           | 0.08063***                           |
|                           | Prob(Y = Slightly more similar)|                                       |                                       |
| Perceived similarity      | 0.05925***                    | 0.06648***                           | 0.04749***                           |
| before information        | I1                            | 0.02523***                           | −0.02762**                           |
|                           | I2                            | −0.04799***                          | −0.06626***                          |
|                           | I4                            | −0.04873***                          | −0.11207***                          |
|                           | Prob(Y = Much more similar)   |                                       |                                       |
| Perceived similarity      | 0.11502***                    | 0.12468***                           | 0.11830***                           |
| before information        | I1                            | 0.05667**                            | −0.05873***                          |
|                           | I2                            | −0.07658***                          | −0.11862***                          |
|                           | I4                            | −0.07684***                          | −0.17169***                          |
|                           | Log likelihood function       | −1630                                | −1616                                | −1630                                |

*Note: There are partial effects from ordered probit models, all with 1185 observations. *, **, and *** denote significance level at 0.10, 0.05, and 0.01, respectively.*
### Table A3 Determinants of perceived safety of gene-edited applications before an information intervention

| Variable                  | Insects       | Plants       | Animals       |
|---------------------------|---------------|--------------|---------------|
|                           | Prob (Y = Extremely unsafe) |               |               |
| Narrative                 | 0.03516***    | 0.01330*     | 0.01681       |
| Hierarchical individualists | −0.01918**   | −0.00735     | −0.02431**    |
| CRT                       | 0.00266       | −0.00960**   | 0.00411       |
| Age                       | 0.00105***    | 0.00050**    | 0.00132***    |
| Density                   | −0.02317***   | −0.0071      | −0.02092**    |
| Education                 | −0.00393      | −0.00412*    | −0.00877**    |
| Female                    | 0.08285***    | 0.06079***   | 0.12553***    |
| Income                    | −0.01309***   | −0.00821***  | −0.01518***   |
| Democrat                  | −0.00887      | −0.01052     | −0.01208      |
| Republican                | −0.01828      | −0.01836**   | −0.00937      |
|                           | Prob(Y = Slightly unsafe) |               |               |
| Narrative                 | 0.03526***    | 0.01755**    | 0.01346       |
| Hierarchical individualists | −0.01937**   | −0.00972     | −0.01946**    |
| CRT                       | 0.0027        | −0.01270**   | 0.0033        |
| Age                       | 0.00106***    | 0.00067**    | 0.00106***    |
| Density                   | −0.02345***   | −0.0094      | −0.01678**    |
| Education                 | −0.00398      | −0.00546*    | −0.00704**    |
| Female                    | 0.08101***    | 0.07756***   | 0.09586***    |
| Income                    | −0.01325***   | −0.01087***  | −0.01217***   |
| Democrat                  | −0.00909      | −0.01417     | −0.00984      |
| Republican                | −0.01901      | −0.02511**   | −0.00762      |
|                           | Prob(Y = Neither safe nor unsafe) |               |               |
| Narrative                 | 0.02109***    | 0.01746**    | 0.00424       |
| Hierarchical individualists | −0.01168*    | −0.00969     | −0.00615*     |
| CRT                       | 0.00163       | −0.01268**   | 0.00105       |
| Age                       | 0.00064***    | 0.00067**    | 0.00033***    |
| Density                   | −0.01417***   | −0.00938     | −0.00532**    |
| Education                 | −0.0024       | −0.00545*    | −0.00223*     |
| Female                    | 0.04837***    | 0.07622***   | 0.02996***    |
| Income                    | −0.00800***   | −0.01085***  | −0.00386***   |
| Democrat                  | −0.00567      | −0.01458     | −0.00333      |
| Republican                | −0.01235      | −0.02656**   | −0.00255      |
|                           | Prob (Y = Slightly safe) |               |               |
| Narrative                 | −0.02995***   | −0.01321*    | −0.0138       |
| Hierarchical individualists | 0.01643*     | 0.00731      | 0.01994**     |
| CRT                       | −0.00229      | 0.00955**    | −0.00338      |
| Age                       | −0.00090***   | −0.00050**   | −0.00108***   |
| Variable          | Insects    | Plants    | Animals   |
|-------------------|------------|-----------|-----------|
| Density           | 0.01990*** | 0.00706   | 0.01719** |
| Education         | 0.00337    | 0.00410*  | 0.00721** |
| Female            | −0.06808***| −0.05737***| −0.09765***|
| Income            | 0.01124*** | 0.00817***| 0.01247***|
| Democrat          | 0.00761    | 0.0103    | 0.00996   |
| Republican        | 0.01567    | 0.01763** | 0.00773   |

Prob (Y = Extremely safe)

| Variable          | Insects    | Plants    | Animals   |
|-------------------|------------|-----------|-----------|
| Narrative         | −0.06156***| −0.03509**| −0.02071  |
| Hierarchical individualists | 0.03381**   | 0.01946   | 0.02998** |
| CRT               | −0.0047    | 0.02543** | −0.00508  |
| Age               | −0.00185***| −0.00134**| −0.00163***|
| Density           | 0.04090*** | 0.01882   | 0.02582** |
| Education         | 0.00694    | 0.01093*  | 0.01083** |
| Female            | −0.14415***| −0.15719***| −0.15370***|
| Income            | 0.02310*** | 0.02176***| 0.02187***|
| Democrat          | 0.01601    | 0.02897   | 0.01528   |
| Republican        | 0.03397    | 0.05240** | 0.01182   |
| Log likelihood function | −1725          | −1686          | −1748          |

Note: There are partial effects from ordered probit models, all with 1185 observations. *, **, and *** denote significance level at 0.10, 0.05, and 0.01, respectively.
Table A4: The effects of information intervention on perceived safety of gene–edited applications

| Variable                          | Insects          | Plants           | Animals          |
|-----------------------------------|------------------|------------------|------------------|
| Prob (Y = Much less safe)         |                  |                  |                  |
| Perceived safety before information | $-0.03939^{***}$ | $-0.04094^{***}$ | $-0.05184^{***}$ |
| $I_1$                             | $-0.00164$       | $-0.00611$       | $0.0092$         |
| $I_2$                             | $0.00181$        | $-0.00162$       | $0.01565^*$      |
| $I_4$                             | $0.00134$        | $0.00001$        | $0.01720^*$      |
| Prob (Y = Slightly less safe)     |                  |                  |                  |
| Perceived safety before information | $-0.07318^{***}$ | $-0.06937^{***}$ | $-0.06951^{***}$ |
| $I_1$                             | $-0.00306$       | $-0.01058$       | $0.01203$        |
| $I_2$                             | $0.00334$        | $-0.00276$       | $0.02005^*$      |
| $I_4$                             | $0.00247$        | $0.00003$        | $0.02188^*$      |
| Prob (Y = Neither more nor less safe) |                  |                  |                  |
| Perceived safety before information | $-0.15402^{***}$ | $-0.13937^{***}$ | $-0.10327^{***}$ |
| $I_1$                             | $-0.00654$       | $-0.02217$       | $0.01691$        |
| $I_2$                             | $0.00691$        | $-0.00561$       | $0.02694^*$      |
| $I_4$                             | $0.00514$        | $0.00005$        | $0.02896^{**}$   |
| Prob (Y = Slightly more safe)     |                  |                  |                  |
| Perceived safety before information | $0.10924^{***}$  | $0.08671^{***}$  | $0.09425^{***}$  |
| $I_1$                             | $0.00456$        | $0.01295$        | $-0.01643$       |
| $I_2$                             | $-0.00499$       | $0.00343$        | $-0.02751^*$     |
| $I_4$                             | $-0.0037$        | $-0.00010$       | $-0.03007^*$     |
| Prob (Y = Much more safe)         |                  |                  |                  |
| Perceived safety before information | $0.15734^{***}$  | $0.16297^{***}$  | $0.13036^{***}$  |
| $I_1$                             | $0.00668$        | $0.02591$        | $-0.02171$       |
| $I_2$                             | $-0.00706$       | $0.00656$        | $-0.03512^*$     |
| $I_4$                             | $-0.00525$       | $-0.00034$       | $-0.03797^{**}$  |
| Log likelihood function           | $-1436$          | $-1489$          | $-1511$          |

Note: There are partial effects from ordered probit models, all with 1185 observations. *, **, and *** denote significance level at 0.10, 0.05, and 0.01, respectively.
**FIGURE A1**  Survey design and flow

- **Qualifier and Quota** ($N=1,185$)
  - **Familiarity Questions**
    - **Narrative Block** ($n=580$)
      - **Information Block**
        - $I_1=157$  $I_2=148$
        - $I_3=151$  $I_4=124$
    - **Information Block** ($n=605$)
      - $I_1=160$  $I_2=148$
      - $I_3=141$  $I_4=156$
  - **Narrative Block**
  - **Cognitive Reflection Test**
  - **Cultural Cognition Quiz**
  - **Demographic Questions**

**FIGURE A2**  Stated familiarity with breeding techniques

- Genome editing
- Conventional breeding
- Genetic modification

**Proportion of the Sample (%)**

- **Not at all familiar**
- **Slightly familiar**
- **Moderately familiar**
- **Very familiar**
- **Extremely familiar**
FIGURE A3 Perceived similarity between genome editing and conventional breeding after information, given perceived similarity before information

FIGURE A4 Perceived safety of gene-edited plants after information, given perceived safety before information