December 2019

# A Neuroeconomic Investigation of Disgust in Food Purchasing Decisions

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APPLIED ECONOMICS & STATISTICS PSC

#### ABSTRACT

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Dealing with large-scale societal problems such as water scarcity often requires changes in behavior that consumers resist. Some sustainable, cost-effective, and safe solutions are even rejected because of a psychological response of disgust, such as food produced with recycled water to supplement traditional water supplies and crickets as a replacement for water-intensive proteins like beef. This study, involving 51 adult participants, used functional magnetic resonance imaging to explore consumers neural responses to these types of food and the role price plays in their decisions. A video that promotes the use of recycled water was also tested to determine whether consumers' aversion can be ameliorated. The results show activation in the insular cortex when presented with images of food produced with recycled water or crickets, indicating these foods are associated with feelings of disgust. After the treatment video, neural activity did not change in the insular cortex, however, respondent's decisions about food produced with recycled water did. Together, these findings suggest disgust is a part of the decision process, that it lingers and can be difficult to mitigate, but that behavioral interventions have the potential to overcome it.

#### ACKNOLWEDGEMENTS

This study received ethics approval from the Institutional Review Board at the University of Delaware (1152788-2). Funding for this research was provided by the U.S. Department of Agriculture's National Institute for Food and Agriculture, the CONSERVE project (a Center of Excellence designated by the U.S. Department of Agriculture at the nexus of sustainable water reuse, food, and health) (Grant No. 20166800725064), and the Delaware Environmental Institute. We also acknowledge the support of Naiim Mason for his assistance in programming the MATLAB portion of the experiment.

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#### **Suggested Citation for APEC Research Reports**

Ellis, S. F., M. Kecinski, K. D. Messer, and J. L. Lusk. 2019. "A Neuroeconomic Investigation of Disgust in Food Purchasing Decisions." *Applied Economics & Statistics Research Report*, University of Delaware, RR19-13.

## A NEUROECONOMIC INVESTIGATION OF DISGUST IN FOOD PURCHASING DECISIONS

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October 30, 2019

#### Abstract

Dealing with large-scale societal problems such as water scarcity often requires changes in behavior that consumers resist. Some sustainable, cost-effective, and safe solutions are even rejected because of a psychological response of disgust, such as food produced with recycled water to supplement traditional water supplies and crickets as a replacement for water-intensive proteins like beef. This study, involving 51 adult participants, used functional magnetic resonance imaging to explore consumers neural responses to these types of food and the role price plays in their decisions. A video that promotes the use of recycled water was also tested to determine whether consumers' aversion can be ameliorated. The results show activation in the insular cortex when presented with images of food produced with recycled water or crickets, indicating these foods are associated with feelings of disgust. After the treatment video, neural activity did not change in the insular cortex, however, respondent's decisions about food produced with recycled water did. Together, these findings suggest disgust is a part of the decision process, that it lingers and can be difficult to mitigate, but that behavioral interventions have the potential to overcome it.

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JEL Classification: D87; D91; Q25

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#### **1. Introduction**

Dealing with large-scale societal problems like a shortage of organ donations, where to put nuclear waste, and water scarcity often requires changes in behavior that consumers rebuff. In some instances, this resistance is driven by an overreaction to an underlying risk – a visceral, negative response, which may lead consumers to reject or reduce their demand for products and services produced using sustainable, cost-effective, and scientifically safe processes (Rozin, 2001). While 95% of the United States public supports organ donation, they are repulsed at the idea of using monetary incentives or an allocation rule that prioritizes registered donors on the waiting list to encourage organ donation and shrink the shortage (Roth, 2007; Herr and Normann, 2016; U.S. Department of Health and Human Services, 2019). Likewise, even though nuclear power is a historically popular source of energy (Bisconti, 2016), people overwhelmingly reject policies that propose storing nuclear waste in their community because of a deeply rooted sense of fear and revulsion toward the material (Slovic et al., 1991). Similarly, despite high concerns about water scarcity across the globe (Circle of Blue, 2009), several studies have suggested that food produced with recycled water (Rozin et al., 2015; Savchenko et al., 2019a) and the use of crickets as a protein substitute for water-intensive proteins such as beef (Hamerman, 2016) are unpopular solutions to it.

The gap between the "assessed" and "real" risks (Portney, 1992; Walker, 2001; Salanie and Treich, 2009) posed by such foods, is thought to be driven in part by a psychological offensiveness (Rozin, 2001; Lusk et al., 2014), such as disgust, that has stymied efforts to solve some large-scale environmental problems (Roth, 2007). In particular, the "yuck factor" brought on by the toilet-to-tap perception of recycled water has prevented large-scale potable recycledwater projects that offer a sustainable and cost-effective solution to water shortages from being

approved in countries such as Australia and the United States (Morgan and Grant-Smith, 2015; Uhlmann and Head, 2011; Morgan and Grant-Smith, 2015; Hummer and Eden, 2016).

Functional magnetic resonance imaging (fMRI) can add important insights into the study of how consumer choices are affected by factors, such as disgust, as it enables us to focus on the neurobiological process of decision-making. Fehr and Rangel (2011) argued that participants in traditional economic studies involving revealed preferences act "as if" they are maximizing their utility and that neuroeconomic studies aim to develop structural or "as is" models of behavior. Winkielman and Berridge (2004) contend that some of our emotional processes are entirely inaccessible to us even though these emotions drive our behavior. Thus, revealed-preference studies that report on complicated processes, such as the stigmatization of products, likely fall short of providing a cohesive picture-consumers simply may not be aware of what drives their decisions. Other related studies have found that neural activation in decision-making is a function of both conscious deliberation and automatic and emotional responses (Camerer et al., 2005; Crespi et al., 2016) that have recognizable brain-activation patterns, particularly for strong emotions like disgust (Kassam et al., 2013). Thus, to understand consumers' negative reactions to recycled irrigation water more fully, to determine if disgust drives their behavior, and to gain insights into how to mitigate their reactions, one must consider the neural processes underlying these decisions.

In this study, we combine fMRI and a revealed-preference, single-bounded, dichotomous-choice experiment to explore the neural responses of 51 participants to food produced with recycled water and the role price plays in their decisions. <sup>1</sup> We also examine the

<sup>&</sup>lt;sup>1</sup> Previous research has shown that on average consumers accept food produced with recycled water more when it is priced significantly lower than food produced with traditional water (Ellis et al., 2018; Savchenko et al., 2018, 2019b).

underlying neural responses to food made with cricket flour (crickets that were dried and milled into a protein powder) as a source of protein to provide a baseline measure of disgust. Finally, we test whether information from video messaging affects participants' neural activity and decisions related to recycled water and, if so, how.

The key results show that decisions involving foods irrigated with recycled water and foods made with cricket flour activate the insular cortex, the area of the brain associated with physical and emotional disgust. After participants viewed a video promoting the general benefits of recycled water the neural activity in these areas did not change, but their decisions about these types of foods did. Neural activity did decrease in areas of the brain related to language processing in general and interpreting written words in particular (the angular gyrus and the supramarginal gyrus) when they considered multi-attribute decisions in which the attributes are in conflict (produce irrigated with recycled water was the less expensive option). Together, these findings suggest disgust is a part of the decision process, that it lingers and could be difficult to mitigate, and that after a behavioral intervention there are other dimensions of the decision process that become more important.

Further, we find evidence supporting the proposition that the calculation of decision values can be modified by a behavioral intervention. According to the cognitive neuroscience theory that binomial decision making follows a diffusion process, the brain, when comparing two options, calculates a decision value for each option by integrating the attributes of each option over various dimensions and assigning some weight to each dimension. This study finds evidence that information and messaging can cause people to change how they weight certain attributes when integrating them over a particular dimension during the calculation of a decision value. The insights from this fMRI study have important and potentially transformative

implications for policies designed to solve large-scale societal issues whose existing solutions are stigmatized. Before presenting the experiment design, fMRI procedures and the results of our analysis, we review the literature related to the large-scale problem of water scarcity, the difficulty of assessing the role of emotions on decision-making using traditional economic methods, and how messaging affects consumers' preferences and neural correlates for stigmatized foods.

#### 2. Relevant Literature

Water is increasingly scarce in many areas across the globe as shifts in the global water cycle increase the disparities between wet and dry regions (International Panel on Climate Change, 2014). Already, 71% of people in the world suffer water shortages at least part of the year and 500 million suffer from shortages throughout the year (Mekonnen and Hoekstra, 2016). Water shortages have an outsized effect on the agricultural industry because it accounts for over 70% of global freshwater use (United Nations World Water Assessment Programme, 2016) and up to 90% of freshwater use in parts of the western United States (U.S. Department of Agriculture (USDA) Economic Research Service (ERS), 2017). Additionally, over 50% of global agriculture occurs in areas in which there is a high degree of water stress (World Resources Institute, 2013), and the agricultural industry' use of water is expected to climb. Agricultural production is predicted to double over the next thirty years in order to provide food for a human population that is expected to reach 9 billion by 2050 (World Bank, 2014).

An important way to mitigate water shortages sustainably and cost-effectively is to use recycled water – wastewater from various sources that has been treated to meet specific sanitation and safety standards so it can be reused. The standards can vary depending on the

planned use of the recycled water, from irrigating lawns and crops to potable drinking water (WateReuse, 2019). Recycled water has been used in Israel on a nation-wide scale for decades and in certain regions of Australia and the United States more recently, but numerous studies in these countries have found that consumers, on average, either require a significant price discount to purchase and eat food produced with it or completely reject those foods (Menegaki et al., 2007; Bakopoulou et al., 2008; Hui and Cain, 2017; Li et al., 2018; Savchenko et al., 2019b; Whiting et al., 2019). Their negative reactions are believed to stem from feelings of disgust arising from the perception that the water at the tap still contains whatever was in it, either physically or spiritually, at the source (Rozin et al., 2015). While this reaction is most visceral for recycled sewage effluent (recycled black water), it persists, albeit to a lesser extent, for other types, such as reclaimed water from laundering or bathing (recycled gray water) (Ellis et al., 2018; Kecinski and Messer, 2018).

When evaluating consumer demand for a product, economists have relied on revealedpreference studies that either ignored the emotional components of decision-making or used participant self-reporting methodologies to decipher the role emotions played (Lowenstein, 2000). However, self-reporting allows biases associated with demand effects and underestimation to proliferate (Winkielman and Berridge, 2004). Furthermore, economic studies typically treat consumer preferences as exogenous because a functional theory of their sources and effects has yet to be developed (Fehr and Rangel, 2011). Now, technological advances such as fMRI make it possible to observe decision processes in the brain, providing new insights.

fMRI is an indirect measure of neural activity, which cannot be directly observed because the chemical and electrical processes happen too quickly (Amaro and Barker, 2006). When neural activity occurs in a given area of the brain, local resources such as oxygen are expended,

and the brain responds by sending blood to those areas to replenish the resources. fMRI creates images of this change in blood flow, known as blood-oxygen-level-dependent (BOLD) contrasts, as a proxy for neural activity. Camerer et al., (2005) note that early fMRI studies showed that the process of making an economic decision involves several regions of a person's brain working in unison and that neurons in these regions fire in rapid succession to form neural networks that consist of automatic (subconscious) and controlled (conscious) processes. In a subsequent study, Kassam et al. (2013) found that emotions in general and visceral negative reactions such as disgust in particular, produce recognizable patterns of neural activation in the brain.

The food decision process, however, does not consist of only emotional responses to single attributes. When making decisions, consumers consider the multiple characteristics of a food, including not only the emotions it provokes but also its cost, over several dimensions such as quality, taste, healthiness, social implications (i.e. vegetarian versus animal protein), and the self-images they associate with it. Using fMRI, Bruce et al. (2014) found that food choices that involved multiple attributes, such as price and a controversial technology, resulted, on average, in greater neural activation than decisions made solely on a single characteristic such as price or the technology used to produce it. Studies have shown that this is a result of multi-attribute decisions being harder to make, as a reconciliation between desired characteristics (for example, low-priced milk free from growth hormones) and realized options (low-priced milk with growth hormones and high-priced milk without) must be made (Bruce et al., 2014; McFadden et al., 2015).

Exposing consumers to different types of information and/or messaging has been shown to affect their perception of foods produced using recycled water (Savchenko et al., 2018), to influence their food purchasing behaviors (Hayes et al., 2002; Marette et al., 2010; McFadden

and Huffman, 2017; Messer et al., 2017), and to alter their corresponding neural activity in the brain (Francisco et al., 2015; McFadden et al., 2015). Several studies have found that when considering multi-attribute options, such information and messaging tend to direct consumers' attention toward the characteristics addressed in the information, like the ethics of a production method, and away from characteristics such as price (Fehr and Rangel, 2011; Francisco et al., 2015), shifting how each characteristic is weighted in the decision-making process (Fehr and Rangel, 2011). For example, a food's affordability becomes less important as the consumer focuses on the social consequences associated with the choice. Considering these multiple, conflicting characteristics results in greater neural activity in the brain as the decision is harder to make (Francisco et al., 2015). Multiple neuroeconomic studies have analyzed the effects of food labeling and branding and have provided further evidence for how information, messaging, and framing redirect consumers' attention and neural processing (Linder et al., 2010; Grabenhorst et al., 2013; Fehse et al., 2017).

#### 3. Methods and Procedures

#### 3.1 Participants

The experiment was successfully administered to 51 adults<sup>2</sup>, age 25 or older who were righthanded and spoke English. They were recruited from and around a large U.S. East Coast research university. Criteria that excluded participation were (1) not regularly making food purchasing decisions, (2) having an allergy to shellfish, <sup>3</sup> (3) not consuming clementines, almonds, and/or protein bars, (4) currently taking psychopharmaceutic medication, (5) a history of mental illness

<sup>&</sup>lt;sup>2</sup> Informed consent was obtained from each participant.

<sup>&</sup>lt;sup>3</sup> This criterion was included because anyone with a shellfish allergy could also be allergic to the cricket flour due to biological similarities between shellfish and insects.

and/or substance abuse, and (6) ineligibility to be safely scanned by an MRI scanner. The requirement to be 25 or older and exclusions 1 and 3 were included to ensure participants were regular consumers and purchasers of the food used in the study. Requiring participants to be right-handed and including exclusions 4 and 5 increased physiological homogeneity within the sample population and increased its general representativeness of the broader population. Exclusions 2 and 6 were included to ensure the safety of participants.

The 51 participants were randomly assigned to either a treatment group – 26 participants, 13 of whom were female, who had a mean age of 37 and an age range of 25 to 77 – or to a control group – 25 participants, 13 of whom were female, who had a mean age of 35 and an age range of 25 to 62. In terms of gender, there was no statistically significant difference between the treatment and control groups. A total of 51 participants originally participated in the study, but nine had to be excluded from the imaging analysis because of excess head motion (motion in any direction exceeding 1.1 millimeters, which was half the size of the 2.2-cubic-millimeter voxel).<sup>4</sup> Consequently, in the imaging analysis, the treatment group was comprised of 19 participants, 9 of whom were female, who had a mean age of 35 and whose ages ranged from 25 to 60. The control group was comprised of 23 participants, 12 of whom were female, who had a mean age of 36 and whose ages ranged from 25 to 62.

#### 3.2 Experiment Design

To generate revealed preference data, participants were given a participation fee of \$50 in small bills (three \$10 bills, two \$5 bills, and ten \$1 bills) at the beginning of the experiment and were instructed that they would use some of the participation fee to purchase food (see Appendix A

<sup>&</sup>lt;sup>4</sup> A voxel is a 3D pixel created by fMRI scanning software and is the most basic unit of an fMRI image.

for the experiment instructions). While undergoing a functional MRI scan, participants made a series of decisions involving tradeoffs for three foods: almonds and clementines irrigated with different types of water (traditional, recycled gray, and recycled black water) and protein bars made with different types of protein (soy and cricket flour). Each decision consisted of two identical black and white images of the food item, with text below each image indicating the impute (irrigation water or protein type) and the price of each option as shown in Figure 1. Participants revealed their preferences by selecting the option on the left side of the screen or the right. They were asked to eat some of their selected food after finishing the experiment to ensure they answered honestly and did not just chose the less expensive option.

Table 1 presents the 17 distinct types of tradeoffs presented to participants. Some of the tradeoffs were single-attribute decisions (either impute or price varied), while the other tradeoffs were multi-attribute decisions (both impute and price varied). Each participant completed two rounds (functional scans) consisting of 29 decisions: tradeoffs 1 through 12 for almonds and clementines and tradeoffs 13 through 17 for protein bars, resulting in 58 total tradeoff decisions. The structure and presentation of the decisions was similar to what was used in previous research by Cherry et al. (2015), Francisco et al. (2015), McFadden et al. (2015), and Lusk et al. (2016). The order in which participants saw the tradeoffs was randomized across participants to eliminate ordering effects.

While in the scanner, but prior to making actual tradeoff decisions during the first functional scan, participants were shown examples of the tradeoffs for each type of food to visually demonstrate the task. During each round of the experiment, to assess their understanding of the task, participants were presented with five dominated choices in which the sole difference between the two options was the price (tradeoffs 10, 11, 12, 16, and 17). Participants choose the

lower priced option 96.3% of the time, indicating that they understood the choice task. At no point did participants receive feedback about their decisions.

At the beginning of each round and between each tradeoff decision, participants viewed a fixation point for a jittered (i.e. variable) duration period that randomly ranged between 3 and 6 seconds in 1 second intervals. A jittered duration was used because it reduces participants ability to predict what will happen and when it will occur (Amaro and Barker, 2006). This helps to maintain participant's attention over the course of an event-related experiment and prevents them from falling into a rhythm where they reflexively, instead of intentionally, make choices.

Participants were then presented with the first tradeoff, which remained visible for 20 seconds or until they made a decision. If they did not make a decision during that 20 seconds, the message "Please Choose Now" appeared at the bottom of the screen and the images were shown for an additional 10 seconds. If no decision was made after 30 seconds, the screen automatically moved forward to the next tradeoff decision. Once the participant made a decision, the screen displayed a confirmation of the decision for a jittered duration that randomly varied between 0.5 and 3.0 seconds in intervals of 0.5 seconds. Participants who made a tradeoff decision in less than 3 seconds saw the confirmation screen for the rest of the initial 3 second period plus the additional 0.5 to 3.0 seconds. This process was repeated for each of the 29 tradeoff decisions in each round or until 7 minutes had elapsed, at which time the experimental round (the functional scan) ended. Figure 2 illustrates the tradeoff paradigm and experiment timeline.

Between the first and second scanning/decision rounds, participants viewed one of two different videos<sup>5</sup> to enable us to determine whether their choices and neural activity could be altered by information and messaging. The video presented to the treatment group showed a

<sup>&</sup>lt;sup>5</sup> The treatment and control videos can be viewed at http://canr.udel.edu/ceae/supplemental-fmri/

series of clips from a documentary film on recycled water. It communicated that there are water shortages in the United States, it described the hidden cost of water in everyday objects, it stated how the agricultural industry uses most of the water, and then presented recycled water as a solution to water shortages. The video presented to the control group simply showed a field of tall grass rippling in the wind, a neutral image that, unlike a fixation point, could keep participants' attention for the duration of the video, which was 2 minutes and 10 seconds.

Before entering the scanner, participants were shown the following definitions of the different types of water and protein in a randomized order and then quizzed about them on a tablet computer to reinforce their understanding. After entering the scanner and before both rounds (functional scans) each participant was shown the definitions again to refresh their memory.

**Traditional Water:** Conventional sources of water, such as surface water (rivers, lakes, ponds, and reservoirs) and well water

**Recycled Gray Water:** Treated wastewater from washing, laundering, bathing, or showering

Recycled Black Water: Treated wastewater from toilets and urinals

**Soy Protein:** Protein that is isolated from soybeans.

**Cricket Flour:** Crickets that are dried and milled into protein powder As noted in Table 1, the tradeoff decisions involved three price categories: same, lower,

and higher prices. The overall mean price<sup>6</sup> for each type of food was calculated using local grocery store prices, while the minimum price was half of the overall mean price and the maximum price was one and a half times the overall mean price. For the same-price category, prices ranged from the minimum price to the maximum price; for the low-price category, prices

<sup>&</sup>lt;sup>6</sup> The overall mean price for clementines (6 pounds) was \$8.64, for almonds (1 pound) was \$15.04, and for protein bars was \$15.66 (box of six bars).

ranged from the minimum price to the overall mean price; and for the high-price category, prices ranged from the overall mean price to the maximum price. Within each category, prices were drawn randomly in \$0.25 increments from a normal distribution with a standard deviation of one-quarter of the overall mean price.

After exiting the scanner, participants completed a survey on a tablet computer that collected their demographic information and then rolled a digital die to determine which of their tradeoff decisions would be implemented. Participants then received the food they had selected in that tradeoff, paying for it using the \$50 they received at the beginning of the experiment. In the instructions at the start of the experiment and while in the scanner before each round (functional scan), participants were told that each tradeoff decision was equally likely to be binding at the end of the experiment to encourage them to consider each decision carefully (see Appendix A). After receiving their food, participants sampled it to ensure they did not just choose the least costly option.

#### 3.3 fMRI Data

The fMRI scans were conducted at a U.S. East Coast research university's biomedical and brain imaging center using a Siemens Prisma 3-Tesla scanner with a 64-channel head/neck coil. The structural images were obtained using a MPRAGE sequence and the scan time was 4 minutes and 51 seconds. The functional images were collected using an EPI sequence that created 66 oblique interleaved slices covering the whole brain. There were two functional scans (round one and two of the experiment), each was 7 minutes and created 410 time points. Further details about how the structural and functional scans were acquired can be found in Table 2. Tradeoff decisions were displayed on an LCD monitor and viewed by participants through a mirror

attached to the head coil. The tradeoff decisions (stimuli) were presented to participants using MATLAB and their decision responses were collected using a fiber optic response box (Current Designs) that they controlled using whichever hand they preferred.

#### 3.4 Theoretical Framework of Decision Process

According to theory and a growing body of empirical evidence from behavioral neuroscience (Ratcliff and McKoon, 2008; Fehr and Rangel, 2011; Krajbich et al., 2014; Ratcliff et al., 2016; Konovalov and Krajbich, 2019), the decision process for a binomial tradeoff consists of a subject dynamically calculating a relative decision value signal represented by S that measures the difference in their valuations of the option shown on the left side of the screen, l, and the option shown on the right side of the screen, r. The signal S starts at zero and evolves along a diffusion process according to the equation

$$S_{t+1} = S_t + \theta \big( v(l) - v(r) \big) + \varepsilon_t \tag{1}$$

where  $S_t$  is the level of the signal at time t, v(l) and v(r) are the decision values that are generated for each of the options,  $\theta$  is a constant that affects the speed of the process, and  $\varepsilon_t \sim$ N(0,  $\sigma^2$ ). The subject's decision-making process lasts until a predefined threshold is reached

$$S = \pm a \qquad (2)$$

where +a represents choosing option l and -a represents choosing option r. In other words, the decision process lasts until a subject determines, to some level of certainty, which option has the greater expected utility.

The stochastic evolution of decision value S reflects the stochasticity of neural activity. However, there is an inverse relationship between the value of S and the relative intensity of the BOLD signals (our proxy for neural activity) measured. When the difference in a subject's valuations of the options, |v(l) - v(r)|, is large, *S* evolves along a sharp curve and a choice is reached relatively quickly, generating little neural activity. Consider, for example, a participant who is disgusted by recycled black irrigation water. In that case, choosing between purchasing and consuming a pound of almonds irrigated with traditional water that costs \$10 and a pound of almonds irrigated with recycled black water that costs \$20 is an easy decision to make – the option that does not disgust the participant costs less. But when the difference in valuations is minor, *S* evolves along a flattened curve and the subject's decision-making process is slower, which leads to greater neural activity.

To see how the value curve changes the process, take the preceding example and simply swap the prices of the almonds so that the almonds irrigated with traditional water cost \$20 and the almonds irrigated with (disgusting) recycled black water cost \$10. This decision is more difficult for subjects to make. They are disgusted by recycled black water and do not want to purchase and consume food produced with it. However, they likely also want to spend the least amount of money possible so they can retain more of the participation fee. As the difference in *S* approaches zero and the subjects' choices approach indifference, their decision-making process is driven by noise but still generates greater neural activity than the steep-sloped easy decision.

Decision values for options l and r are generated by integrating their attributes – price, food type, and impute (type of irrigation water or protein) – over various dimensions, such as taste, level of disgust, healthiness, social implications of producing this food, and subjects' selfimage related to the food. Formalized for option l, the model assumes that

$$v(l) = \sum w_i d_i(l) \qquad (3)$$

where  $d_i(l)$  is a matrix of the attributes of option l for dimension i and  $w_i$  is some set of weights applied to each dimension.

Fehr and Rangel (2011) proposed that the calculation of decision values can be modified by attention and Krajbich et al. (2011) showed how the comparison of decision values could be. We propose that behavioral interventions have a similar effect, as decision values can be viewed as a participant's expected utility and thus can be altered by factors such as messaging that emphasize some dimensions over others. The treatment video in this experiment emphasizes the positive social benefits of using recycled water as a remedy for water scarcity. Participants who internalize that issue may incorporate acceptance of recycled irrigation water as a part of their self-image. Thus, the treatment video, denoted as x, potentially affects how a subject generates a value for attributes (impute or price) and how attributes are weighted in the decision value computation. Equation 2 thus becomes

$$v(l) = \sum w_i(x)d_i(l,x).$$
(4)

The end result of the decision process can be observed through the choices participants make and the calculation of decision values and the stochastic comparison of them can be observed using fMRI. Thus, evidence in support of this proposition that a behavioral intervention can modify the calculation of decision values can be provided by analyzing the difference in decisions and BOLD activations pre (round one) and post (round two) video.

#### 4. Analysis and Results

#### 4.1 Behavioral Analysis

To see the effect of the treatment video on the choices participants made, a difference-indifference model was estimated using OLS for the tradeoff decisions involving recycled water.<sup>7</sup> The coefficients were estimated using clustered standard errors and with a fixed effects'

<sup>&</sup>lt;sup>7</sup> An affirmation of the parallel trend assumption can be found in Figure 3

specification since participants made several decisions per round.<sup>8</sup> Since tradeoffs 10, 11, and 12 were dominated choices and only included in the experiment as a means to evaluate participants understanding of the task, they were excluded from the analysis. The dependent variable  $C_{ij}$  equals one if participant *i* chose produce irrigated with traditional water (versus recycled) or recycled gray water (versus recycled black) for tradeoff decision *j* (i.e. chose the supposedly less disgusting option):

$$C_{ij} = \beta_1 P_{ij} + \beta_2 V_j + \beta_3 V_j T_i + \beta_4 Q_j + \beta_5 R_{ij} + \alpha_i + \varepsilon_{ij}$$
(5)

where  $P_{ij}$  is the price difference between the two options,  $V_j$  is a dummy variable for post-video (round two),  $Q_j$  is a vector of dummy variables for tradeoffs two through nine with tradeoff one being the omitted variable,  $R_{ij}$  is participant *i*'s response time to tradeoff decision *j*,  $\alpha_i$  is the unobserved time-invariant individual fixed effect, and  $\varepsilon_{ij} \sim N(0, \sigma^2)$ .  $T_i$  is a dummy variable for the treatment group and is not included in the model outside of the interaction term as it is time invariant and therefore collinear with the fixed effect. The coefficient  $\beta_3$ , of the interaction term  $V_jT_i$ , is the difference-in-difference estimator. It measures the effect the treatment video had on participants tradeoff decisions.

Table 3 displays the OLS results of Equation 5. The coefficient of the interaction term for post-video and treatment ( $V_jT_i$ ) is significant ( $\rho < 0.01$ ) and shows that participants chose the supposedly less disgusting option 12% less after watching the treatment video. These results suggest exposure to a video promoting recycled water made the use of recycled irrigation water less of a factor in participants decisions.

<sup>&</sup>lt;sup>8</sup> The random effects version of the model can be found in Table 3, along with the results of the Sargan-Hansan specification test that showed the fixed effects model was the more appropriate model. A Sargan-Hansen test was used instead of the traditional Hausman test since the standard errors were clustered.

The effect of the treatment video can be seen visually in Figures 4 and 5. Each display inverse demand curves of the percent of participants who, when given the opportunity, purchased (vertical axis) almonds and clementines irrigated with each type of water within a given price range (horizontal axis) in each round. Note that, for the treatment group, the curves for the three types of water converge and become steeper in the second round (after they view the video). Conversely, in the control group, there is no change in the steepness of the curves between rounds.

Looking at the effect of the treatment video in more detail, a Wilcoxon signed-rank test was used to identify statistically significant differences between the first and second rounds for each decision. Table 1 reports the percentage of participants who made each of the tradeoff decisions presented in rounds one and two of the experiment. We find significant changes in the percentage of participants who selected tradeoffs 1, 2, 4, and 9 at  $\rho < 0.01$  and tradeoff 5 at  $\rho < 0.05$ . Following the video, the treatment groups' decisions generally shifted toward favoring produce irrigated with recycled water (versus traditional) and produce irrigated with recycled black water (versus recycled gray) when the price was lower than (tradeoffs 1, 4, and 9) or the same as (tradeoffs 2 and 5) the alternative. The exception was tradeoff 8 in which the cost of the produce was the same and participants chose between recycled gray and recycled black irrigation water. This result is likely related to the fact that the treatment video recommended recycled water in general to resolve water scarcity and did not promote any particular type of recycled water. It aligns with results from Ellis et al. (2018), which found that consumers preferred recycled gray water over recycled black water for irrigation purposes.

These results suggest that the video had a mitigating effect on the treatment groups' concerns about recycled water. The results for the tradeoff decisions involving recycled water,

for both the treatment and control groups, are robust regardless of produce type, as there is no statistically significant difference ( $\rho < 0.05$ ) in the tradeoff decisions participants selected for almonds and clementines.

#### 4.2 Imaging Analysis

The imaging data was analyzed using the FMRIB Software Library (FSL). Preprocessing of the functional scans included MCFLIRT motion correction (Jenkinson et al., 2002), a 5-millimeter spatial smoothing kernel, and interleaved slice-timing correction. The images were co-registered with the participant's structural scan and the MNI152 standard-space T1-weighted average structural template image. The first-level statistical analysis consisted of a general linear model

$$Y_{ik} = \beta_{ik} X_{ik} + \alpha_{ik} M_{ik} + \varepsilon_{ik} \tag{6}$$

where response *Y* at each voxel for individual *i* during round *k* was modeled as a linear combination of one or more predictors stored in the columns of matrix *X*, with standard motion parameters *M*, and  $\varepsilon_{ik} \sim N(0, \sigma^2)$ . In matrix *X*, every second of the tradeoff decision-making task was modelled and grouped into one of nine experimental variables (EVs) that were analyzed using a three-column format and a double-gamma hemodynamic response function:

EV1: Produce irrigated with recycled water cost less than produce irrigated with traditional water (tradeoffs 1 and 4); and produce irrigated with recycled black water cost less than produce irrigated with recycled gray water (tradeoff 9).

EV2: Protein bars made with cricket flour cost less than the bars made with soy protein (tradeoff 13).

EV3: Produce irrigated with recycled water cost more than produce irrigated with traditional water (tradeoffs 3 and 6); and produce irrigated with recycled black water cost more than produce irrigated with recycled gray water (tradeoff 7).

EV4: The protein bars made with cricket flour cost more than the bars made with soy protein (tradeoff 15).

EV5: The product (produce, protein bars) options have the same impute (irrigation water type, protein source) but different prices (tradeoffs 10, 11, 12, 16, and 17).

EV6: Produce irrigated with recycled water cost the same as produce irrigated with traditional water (tradeoffs 2 and 5); and produce irrigated with recycled black water cost the same as produce irrigated with recycled gray water (tradeoff 8).

EV7: The protein bars made with cricket flour cost the same as the bars made with soy protein (tradeoff 14).

EV8: Fixation point.

EV9: Confirmation screen.

Aside from EV5 (dominated choices), the tradeoff decisions were grouped into experimental variables by price category and impute (irrigation water or protein). For example, tradeoffs where the produce irrigated with the supposedly more disgusting type of water cost less (EV1), cost more (EV3), and was the same price as the alternative (EV6). The tradeoffs were put into these bins so that the effect that price variations have on participants' levels of neural activity, or the regions of the brain in which said activity occurs, could be determined for each impute (irrigation water or protein type).

A higher level within-group analysis was then performed for the treatment and control groups using FMRIB's Local Analysis of Mixed Effects Stage One (FLAME 1) technique. Using

Bayesian modelling and estimation, each participant's results from the first-level statistical analysis were imputed into a general linear model with a mixed effects specification to conduct a multiple-regression analysis for group g (treatment or control):

$$\beta = \beta_g X_g + \mu \tag{7}$$

where  $\beta$  is the combined first level parameter estimates of the group,  $X_g$  is the group-level design matrix,  $\beta_g$  is a vector of group-level parameters, and  $\mu$  the residuals of the group activation parameter ~ N(0,  $\sigma^2$ ). The fixed effect variance from the first-level analysis was carried up to the higher level within-group analysis; whereas estimation of the mixed effect variance involved implicit estimation that makes use of Metropolis-Hastings Markov Chain Monte Carlo sampling. The resulting distribution was then fitted to a general t-distribution so hypothesis testing could be conducted. A more detailed explanation of this model can be found in Beckmann et al. (2003) and Woolrich et al. (2004).

Mean BOLD activation during the first round of the experiment for the treatment and control groups shows activation ( $\rho < 0.01$ ) in the insular cortex<sup>9</sup> when participants made decisions about tradeoffs involving produce irrigated with recycled water and protein bars made with cricket flour (EV1 through EV7), but not when they were staring at the fixation point (EV8). Previous studies have shown that the insular cortex is the main neural structure involved in the feeling of disgust. (Camerer et al., 2005; Caruana et al., 2011; Papagno et al., 2016). It has also been shown to play a role in other emotions that could be driving consumers' negative response to recycled irrigation water and cricket flour, such as fear and risk (Phan et al., 2002; Rao et al., 2008; Goodwin and Norbury, 2016). However, the amygdala and ventral striatum are

<sup>&</sup>lt;sup>9</sup> Brain regions were identified using the Harvard-Oxford cortical and subcortical structural atlases (Desikan et al., 2006) and the Talairach atlas (Talairach and Tournoux, 1988).

the key neural structures associated with feelings of fear and risk, respectively, and activation was not observed in either region. The analysis also reveals activation ( $\rho < 0.05$ ) throughout the prefrontal cortex, which is thought to be the executive region of the brain and responsible for decision-making (Camerer et al., 2005).

To determine whether variations in price affected participants' levels of neural activity or the regions of the brain in which activity occurred when they made choices about clementines and almonds irrigated with recycled water, we generated three types of BOLD contrasts<sup>10</sup> (differences) from the results of the first-round functional images. First, we compared BOLD activation from the tradeoffs where produce irrigated with recycled water (versus traditional) and recycled black water (versus recycled gray) were the less expensive option (EV1 – tradeoffs 1, 4, and 9) with activation from the tradeoffs in which produce irrigated with recycled water (versus traditional) and recycled black water (versus recycled gray) were the more expensive option (EV3 – tradeoffs 3, 6, and 7). Results show that the EV1 decisions generated greater BOLD activation in the prefrontal cortex than the EV3 decisions in the treatment ( $\rho < 0.05$ ) and control  $(\rho < 0.01)$  groups (see Table 4 and Figure B.1). Specifically, the increased activation in the treatment group occurred in the superior frontal gyrus portion of Brodmann Area 8, which is believed to be involved with the management of uncertainty (Volz et al., 2005). For the control group, the increase in activation occurred in the medial frontal gyrus portion of Brodmann Area 10, which has been linked to the subconscious, executive part of the decision process preceding an individual's conscious awareness that a decision has been made (Soon et al., 2008).

Multi-attribute decisions, like the EV1 tradeoffs where the attributes are in conflict, have been shown to generate more neural activity than single attribute decisions because desired

<sup>&</sup>lt;sup>10</sup> The contrast mechanism is a method used to observe the difference in BOLD activation at different time points or as a result of different stimuli.

characteristics (less expensive option and traditional irrigation water) and realized options (less expensive and recycled irrigation water) must be reconciled (Bruce et al., 2014; McFadden et al., 2015). While irrigation water type and price varied in the EV3 tradeoffs, they were effectively single attribute decisions since the more desired water type was the less expensive option, making the attributes not in conflict.

Next, we compared activation during the EV1 tradeoffs with activation during the EV6 tradeoffs (2, 5, and 8) in which produce irrigated with recycled water (versus traditional) and recycled black (versus recycled gray) is the same price as the alternative. We found that BOLD activation was greater when making EV1 decisions than when making EV6 decisions in both the treatment group ( $\rho < 0.01$ ) and the control group ( $\rho < 0.05$ ) (see Table 4 and Figure B.2). For both the treatment and control groups, part of this increased activation occurred in the medial frontal gyrus portion of Brodmann Area 10 and in the cingulate gyrus, areas of the brain that have been linked to the executive function (Talati and Hirsch, 2005; Soon et al., 2008). Lusk et al. (2015) found increased BOLD activation in the same areas of the brain when participants made decisions about a food with multiple attributes (price and use of a controversial technology) rather than a single attribute (price). In our study, the EV1 tradeoffs required participants to consider two attributes, price and irrigation water, since the option prices were the same.

In the treatment group, we also found that BOLD activation in the angular gyrus was greater when they made the EV1 decisions than when they made the EV6 decisions. The angular gyrus is associated with connecting visually perceived words to their meanings. Whereas, in the control group, there was increased activation in the superior frontal gyrus portion of Brodmann

Area 8 and the medial frontal gyrus portion of Brodmann Area 9, which makes up part of the dorsolateral prefrontal cortex (dlPFC) (Mylius et al., 2013), an area identified in previous studies as playing a major role in multi-attribute decision-making (Khant et al., 2011). It has also been shown that the dlPFC is more activated when making multi-attribute decisions than when making single-attribute decisions (McFadden et al., 2015).

Finally, we compared BOLD activation for the EV3 tradeoff decisions (produce irrigated with recycled water (versus traditional) and recycled black water (versus recycled gray) were the more expensive option) with activation in the EV6 tradeoff decisions (produce irrigated with recycled water (versus traditional) and recycled black (versus recycled gray) is the same price as the alternative). No significant differences ( $\rho < 0.05$ ) in BOLD activation were seen in this case.<sup>11</sup>

The results of these comparisons of first-round (pre-video) BOLD activations indicate that the EV1 decisions, in which produce irrigated with recycled water (versus traditional) and recycled black water (versus recycled gray) were the less expensive option, were relatively more difficult for participants to make, generating greater neural activity. This is likely a result of participants weighing a less expensive price against the disgust they felt about the irrigation water used.

Paired two-sample t-tests were conducted to identify any differences in BOLD activation in the three EV comparisons (contrasts) pre (round one) and post (round two) video. No significant differences in BOLD activation were found between pre and post video except for the treatment group contrast comparing EV1 with EV6. Figure 6 shows this decrease in activity in a cluster of 1,163 voxels and a cluster of 727 voxels (see Table 4). The significant decrease in

 $<sup>^{11}</sup>$  FSL, the software we used to analyze the imaging data, does not report results that are insignificant at  $\rho < 0.05$  as per the common practices of the fMRI literature.

BOLD activation ( $\rho < 0.01$ ) occurred when the participants made EV1 decisions in the second round, conducted after the participants watched the video promoting recycled water. There was no statistically significant change in BOLD activity when the treatment group made its secondround EV6 decisions (tradeoffs 2, 5, and 8).

These decreases in activation in the treatment group occurred in the supramarginal gyrus portion of Brodmann Area 40 and the angular gyrus, both of which are associated with language processing, including connecting written words with their meanings (Stoeckel et al., 2009; Hall and Guyton, 2011). Table 1 shows that, during the second round of the experiment, participants' EV1 choices (tradeoffs 1, 4, and 9) shifted significantly ( $\rho < 0.01$ ) toward the less expensive option regardless of the type of water used. Together these results provide evidence that the treatment video made the decision process less difficult for participants – they worried less about the type of water and focused instead primarily on relative prices. Consequently, this simpler decision process resulted in reduced neural activity in the second round. Interestingly, we found no significant changes ( $\rho < 0.05$ ) in BOLD activation in the insular cortex of treatment group participants in the second round, which suggests that viewing the video did not affect whatever level of disgust they associated with recycled water.

We made similar comparisons (contrasts) of participants' functional images when choosing between protein bars made with soy and cricket flour during the first round: (1) EV2 (tradeoff 13) in which the protein bars made with cricket flour were less expensive versus EV4 (tradeoff 15) in which the protein bars made with cricket flour were more expensive; (2) EV2 (tradeoff 13) versus EV7 (tradeoff 14) in which the cricket and soy protein bars were the same price; and (3) EV4 (tradeoff 15) versus EV7 (tradeoff 14). This analysis revealed no significant differences ( $\rho < 0.05$ ) in BOLD activation between the different tradeoffs, indicating that price did not play a significant role in the decision process for the protein bars. These imaging results align with the participants' choices in the tradeoff decisions. Participants in the treatment and control groups overwhelmingly preferred the bars made with soy over the ones made with cricket flour except when the cricket flour option was less expensive. We further found that the treatment video had no significant effect ( $\rho < 0.05$ ) on participants' BOLD activity when they made decisions for the EV2, EV4, and EV5 tradeoffs.

#### **5. Summary and Conclusions**

Solutions to large-scale societal problems like a shortage of organ donations, where to put nuclear waste, and water scarcity can entail changes in behavior that consumers resist. At times this aversion is driven by a visceral, negative reaction that may lead consumers to reject or reduce their demand for products and services produced using sustainable, cost-effective, and scientifically safe processes. While 95% of the United States public supports organ donation, people are repulsed by the idea of using monetary incentives or an allocation rule that prioritizes registered donors on the waiting list to boost the number of organ donors and shrink the shortage (Roth, 2007; Herr and Normann, 2016; U.S. Department of Health and Human Services, 2019). Likewise, nuclear energy remains popular with the United States public but the difficulty of finding a community willing to host a permanent repository for nuclear material persists because of a deeply rooted sense of fear and revulsion towards it (Slovic et al., 1991; Bisconti, 2016; Rott, 2019). Similarly, despite global concern about water scarcity (Circle of Blue, 2009), recycled irrigation water evokes strong negative reactions from many consumers, and most want either a substantial price discount to purchase and eat food produced with recycled water or completely reject those foods. These negative reactions to recycled water have been attributed in

recent studies to a visceral psychological response of disgust brought on by the toilet to tap perception (Rozin et al., 2015; Kecinski et al., 2016, 2018; Kecinski and Messer, 2018). However, this is a relatively new area of research and the support so far for disgust as an explanation comes primarily from self-reporting. This study uses functional magnetic resonance imaging (fMRI) to measure neural activity in areas of the brain associated with disgust to provide concrete, measurable evidence of the effects of disgust on consumer purchasing decisions.

In a revealed-preference experiment, involving 51 adult participants, we examined consumers underlying neural activity when making decisions about purchasing and consuming foods irrigated with recycled water. As a baseline measurement of the neural activity associated with participants' feelings of disgust, we also examined participants neural correlates when considering buying protein bars made with flour produced from crickets.

The results of our experiment and analysis suggest that disgust is a dimension of consumers' decision-making processes, confirming the results of previous studies. When participants were presented with tradeoffs involving produce irrigated with recycled water and protein bars made with cricket flour, we observed significant neural activation in the insular cortex, which is associated with the feeling of disgust (Camerer et al., 2005; Caruana et al., 2011; Papagno et al., 2016). We also observed activation in the prefrontal cortex, the executive region of the brain which previous studies have found plays a significant role in food decision-making (Camerer et al., 2005; Bruce et al., 2014; Cherry et al., 2015; Lusk et al., 2015; McFadden et al., 2015).

These finding extend previous work on multi-attribute decision-making by demonstrating the crucial role price plays in consumers' decision-making process (Khant et al., 2011; Bruce

et al., 2014; Cherry et al., 2015; Lusk et al., 2015; McFadden et al., 2015). When produce irrigated with recycled water (versus traditional) and recycled black water (versus recycled gray) were the less expensive option, we observed significantly greater neural activity compared to decisions in which the two options were the same price and when recycled water (versus traditional) and recycled black water (versus recycled gray) were the more expensive option. In other words, multi-attribute decisions where the attributes are in conflict generate greater neural activity than single-attribute decisions or multi-attribute decisions where the attributes are not in conflict. The increased neural activity took place in parts of the prefrontal cortex—specifically, the medial frontal gyrus portion of the Brodmann Area 10, which has been linked to the subconscious, executive part of the decision process preceding an individual's conscious awareness that a decision has been made ; and the superior frontal gyrus portion of Brodmann Area 8, which is linked to the experience of uncertainty.

The results of the treatment video promoting the benefits of recycled water show that the information/messaging primarily reduced the effort required by participants to make multiattribute decisions in which produce irrigated with recycled water (versus traditional) and recycled black (versus recycled gray) were the less expensive option. This finding suggests that the messaging affected how people generate a value for irrigation water attributes and how they weight them in the calculation of a decision value for a tradeoff option. After watching the video, their choices shifted in favor of the cheaper option, regardless of water type, and their level of neural activity during the decision process decreased in regions of the brain associated with connecting written words with their meanings (the angular gyrus and supramarginal gyrus portion of Brodmann Area 40).

The treatment video promoting recycled water did not affect neural activity in the insular cortex, the area of the brain associated with feelings of disgust. This finding suggests that participants' greater acceptance of recycled irrigation water came not from overcoming whatever psychological reactions of disgust they experienced but from reweighting its importance in their decisions.

The novel contribution of this study is two-fold. First, we showed that activation in the insular cortex indicates disgust is a part of the decision process when it comes to purchasing and consuming food irrigated with recycled water, and the lack of change in neural activity pre and post treatment video (between rounds) in these regions indicates participants level of disgust did not change. However, their decisions about the tradeoffs did change. Together, these findings suggest disgust is a part of the decision process, that it lingers and could be difficult to mitigate, and that after a behavioral intervention there are other dimensions of the decision process that become more important.

Second, the results support the proposition that the computation and comparison of decision values can be modified. Fehr and Rangel (2011) and Krajbich et al. (2011) argued that this was the case with attention, and we find that it also occurs in response to a behavioral intervention. According to the cognitive neuroscience theory that binomial decision making follows a diffusion process, the brain, when comparing two options, first calculates a decision value for each option by integrating the attributes of each option over various dimensions and assigning some weight to each dimension. This study finds evidence that information and messaging can cause people to change how they weight certain attributes when integrating them over a particular dimension during the calculation of a decision value.

The results of this study have important implications for policymakers and the agriculture industry because they suggest that an array of potential mitigation strategies could increase consumers' acceptance of recycled irrigation water even if they do not reduce feelings of disgust. Further work is needed to see if other interventions can eradicate or reduce the feelings of disgust associated with recycled water. Future research should also build on these results to see if there are other market constraints caused by disgust, beyond recycled water and outside of agricultural technology, that do not require an elimination of disgust for the market constraints to be eased.

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# Table 1. Percent of Participants Who Made Each Tradeoff Decision and the Results of Wilcoxon Signed-Rank Tests<sup>12</sup>

Tradeoff Choice	Rnd1	Rnd2	Z-Stat	P.V.
		Trea	atment	
Tradeoff 1: Traditional (higher price) over Recycled Black (lower price)	77%	44%	3.710	0.000
Tradeoff 2: Traditional over Recycled Black (same price)	94%	75%	3.162	0.002
Tradeoff 3: Traditional (lower price) over Recycled Black (higher price)	96%	92%	0.816	0.414
Tradeoff 4: Traditional (higher price) over Recycled Gray (lower price)	60%	25%	4.025	0.000
Tradeoff 5: Traditional over Recycled Gray (same price)	88%	73%	2.309	0.021
Tradeoff 6: Traditional (lower price) over Recycled Gray (higher price)	98%	88%	1.890	0.059
Tradeoff 7: Recycled Gray (lower price) over Recycled Black (higher price)	94%	98%	-1.414	0.157
Tradeoff 8: Recycled Gray over Recycled Black (same price)	87%	90%	-0.816	0.414
Tradeoff 9: Recycled Gray (higher price) over Recycled Black (lower price)	63%	42%	2.524	0.012
Tradeoff 10: Traditional (higher price) over Traditional (lower price)	10%	4%	1.342	0.180
Tradeoff 11: Recycled Black (higher price) over Recycled Black (lower				
price)	6%	0%	1.732	0.083
Tradeoff 12: Recycled Gray (higher price) over Recycled Gray (lower price)	10%	4%	1.342	0.180
Tradeoff 13: Soy Protein (higher price) over Cricket Flour (lower price)	50%	35%	1.633	0.103
Tradeoff 14: Soy Protein over Cricket Flour (same price)	69%	73%	-0.577	0.564
Tradeoff 15: Soy Protein (lower price) over Cricket Flour (higher price)	92%	92%	0.000	1.000
Tradeoff 16: Soy Protein (higher price) over Soy Protein (lower price)	4%	4%	0.000	1.000
Tradeoff 17: Cricket Flour (higher price) over Cricket Flour (lower price)	0%	0%	0.000	1.000
		Co	ntrol	
Tradeoff 1: Traditional (higher price) over Recycled Black (lower price)	46%	46%	0.000	1.000
Tradeoff 2: Traditional over Recycled Black (same price)	88%	84%	1.414	0.157
Tradeoff 3: Traditional (lower price) over Recycled Black (higher price)	100%	100%	0.000	1.000
Tradeoff 4: Traditional (higher price) over Recycled Gray (lower price)	34%	28%	1.134	0.257
Tradeoff 5: Traditional over Recycled Gray (same price)	86%	88%	-1.000	0.317
Tradeoff 6: Traditional (lower price) over Recycled Gray (higher price)	98%	98%	0.000	1.000
Tradeoff 7: Recycled Gray (lower price) over Recycled Black (higher price)	94%	98%	-1.000	0.317
Tradeoff 8: Recycled Gray over Recycled Black (same price)	96%	92%	1.414	0.157
Tradeoff 9: Recycled Gray (higher price) over Recycled Black (lower price)	54%	42%	1.897	0.058
Tradeoff 10: Traditional (higher price) over Traditional (lower price)	0%	4%	-1.414	0.157
Tradeoff 11: Recycled Black (higher price) over Recycled Black (lower				
price)	10%	2%	1.633	0.103
Tradeoff 12: Recycled Gray (higher price) over Recycled Gray (lower price)	4%	0%	1.414	0.157
Tradeoff 13: Soy Protein (higher price) over Cricket Flour (lower price)	20%	24%	-1.000	0.317
Tradeoff 14: Soy Protein over Cricket Flour (same price)	76%	76%	0.000	1.000
Tradeoff 15: Soy Protein (lower price) over Cricket Flour (higher price)	100%	100%	0.000	1.000
Tradeoff 16: Soy Protein (higher price) over Soy Protein (lower price)	4%	0%	1.000	0.317
Tradeoff 17: Cricket Flour (higher price) over Cricket Flour (lower price)	0%	0%	0.000	1.000

<sup>&</sup>lt;sup>12</sup> Results are for all 51 participants who successfully completed the experiment

## Table 2. fMRI Data Acquisition Details

Structural Images
Pulse sequence = T1-weighted
Repetition time $(TR) = 2.08$ seconds
Echo time (TE) = $4.45$ milliseconds
Inversion Time $(TI) = 1.05$ seconds
Isotropic voxel size = 1 cubic millimeter
Flip angle = 9 degrees
Parallel imaging (iPAT) acceleration factor $= 2$
Bandwidth = 140 Hertz per pixel
Functional Images
Pulse Sequence = T2-weighted
Repetition Time $(TR) = 1$ second
Echo Time $(TE) = 39.4$ milliseconds
Multi-band acceleration factor $= 6$
Slice thickness = $2.2$ millimeters
Gap between slices = $0.33$ millimeters (15%)
$A \rightarrow P$ phase encoding
Field of view $= 210$ millimeters
Voxel size = $2.2$ cubic millimeters
Flip angle = $90 \text{ degrees}$
Bandwidth = 1,796 Hertz per pixel

	Fixed Effects	Random Effects
Price Difference	-0.015***	-0.015***
	(0.003)	(0.003)
Post-Video	-0.027**	-0.028**
	(0.013)	(0.012)
Treatment		0.070
		(0.049)
Post-Video*Treatment	-0.121***	-0.121***
	(0.036)	(0.036)
Tradeoff 2	0.230***	0.229***
	(0.058)	(0.058)
Tradeoff 3	0.266***	0.265***
	(0.070)	(0.070)
Tradeoff 4	-0.166***	-0.166***
	(0.039)	(0.039)
Tradeoff 5	0.215***	0.214***
	(0.060)	(0.060)
Tradeoff 6	0.244***	0.243***
	(0.073)	(0.073)
Tradeoff 7	0.252***	0.252***
	(0.070)	(0.070)
Tradeoff 8	0.291***	0.291***
	(0.066)	(0.066)
Tradeoff 9	-0.026	-0.025
	(0.026)	(0.026)
Response Time	-0.004	-0.005
-	(0.003)	(0.003)
R <sup>2</sup>	0.29	0.29
Total N	1,836	1,836
Groups	51	51
Sargan-Hansen Statistic		103.768***
Ch		

## Table 3. OLS Results from Difference-in-Difference Model

Chi-square (10) \*\*\*Significant at the 1% level \*\*Significant at the 5% level

	Local Max Vox Coord				
Brain Region	х	у	Z	Z-Stat	Voxel
Treatment					
EV1 > EV3					
L. Superior Frontal Gyrus, Brodmann Area 8	-22	33	53	4.25**	654
R. Superior Frontal Gyrus, Brodmann Area 8	23	55	32	4.15**	650
EV1 > EV6					
R. and L. Cingulate Gyrus, Brodmann Area 31	3	-46	47	4.06***	2628
L. Angular Gyrus, Brodmann Area 39	-41	-75	35	4.06***	1244
R. Medial Frontal Gyrus, Brodmann Area 10	4	58	2	4.02***	861
Control					
EV1 > EV3					
L. Medial Frontal Gyrus, Brodmann Area 10	-6	55	7	3.9***	1171
EV1 > EV6	-			• • •	
L. Cingulate Gyrus, Brodmann Area 31	-6	-58	34	4.32***	1286
R. Superior Frontal Gyrus, Brodmann Area 8	22	46	40	4.37***	1211
R. and L. Medial Frontal Gyrus, Brodmann Area 10	-11	51	4	3.9**	687
R. and L. Cingulate Gyrus	1	38	-8	3.8**	648
R. Medial Frontal Gyrus, Brodmann Area 9; and L. Cingulate	5	53	20	4.09**	625
Gyrus	-				
Treatment, Round $1 > Round 2$					
EV1 > EV6					
R Angular Gyrus: and R Supramarginal Gyrus Brodmann Area	53	_51	35	4 07***	1163
40	55	51	55	r.07	1105
L. Angular Gyrus; and L. Supramarginal Gyrus	-50	-52	24	3.75***	727

#### Table 4. BOLD Contrasts of Interest from the Whole-Brain Imaging Analysis<sup>13</sup>

\*\*\*BOLD contrast statistically significant at 1% level \*\*BOLD contrast statistically significant at 5% level

**EV1:** Produce irrigated with recycled water cost less than produce irrigated with traditional water (tradeoffs 1 and 4); and produce irrigated with recycled black water cost less than produce irrigated with recycled gray water (tradeoff 9).

**EV3:** Produce irrigated with recycled water cost more than produce irrigated with traditional water (tradeoffs 3 and 6); and produce irrigated with recycled black water cost more than produce irrigated with recycled gray water (tradeoff 7).

**EV6:** Produce irrigated with recycled water cost the same as produce irrigated with traditional water (tradeoffs 2 and 5); and produce irrigated with recycled black water cost the same as produce irrigated with recycled gray water (tradeoff 8).

Note: The BOLD contrasts of interest show regions of the brain that had significantly greater activation when participants made decisions about tradeoffs 1, 4, and 9 (EV1) than when they made decisions about tradeoffs 3, 6, and 7 (EV3) or tradeoffs 2, 5, and 8 (EV6).

<sup>&</sup>lt;sup>13</sup> Brain regions identified using the Harvard-Oxford cortical and subcortical structural atlases (Desikan et al., 2006) and the Talairach atlas (Talairach and Tournoux, 1988).



## **Figure 1. Examples of Tradeoff Options**



**Figure 2. Tradeoff Paradigm and Experiment Timeline** 



Figure 3. Parallel Trend Assumption



Figure 4. Percent of Participants Who Purchased Almonds in a Given Price Range



Figure 5. Percent of Participants Who Purchased Clementines in a Given Price Range

Figure 6. Treatment Effect on the BOLD Contrast of EV1 compared to EV6



Lower Activation Higher Activation

**EV1:** Produce irrigated with recycled water cost less than produce irrigated with traditional water (tradeoffs 1 and 4); and produce irrigated with recycled black water cost less than produce irrigated with recycled gray water (tradeoff 9).

**EV6:** Produce irrigated with recycled water cost the same as produce irrigated with traditional water (tradeoffs 2 and 5); and produce irrigated with recycled black water cost the same as produce irrigated with recycled gray water (tradeoff 8).

Note: The BOLD contrast of EV1 compared to EV6 shows the regions of the brain that had significantly greater activation when participants made decisions about tradeoffs 1, 4, and 9 (EV1) than when they made decisions about tradeoffs 2, 5, and 8 (EV6). This figure shows the activations that were significantly greater for the treatment group in the first round than in the second.

## **Appendix A. Experiment Instructions**

## **Instructions:**

*Please read these instructions carefully and feel free to ask an administrator if you have any questions.* 

- We will give you \$50 for showing up and agreeing to participate in this research after you are finished reading these instructions.
- You will use some of the \$50 to purchase food during your participation in this research. You will go home with a food product and the remaining balance of your \$50.
- You will be asked a series of purchasing questions where you must choose between two options. The two options will be identical, except for their price and some other attribute. Specifically, the type of water the clementines and almonds were irrigated with, and the type of protein the protein bars were made with.
- There will be several questions. After you have answered all the questions, and you are out of the MRI scanner, we will randomly select one to be implemented. You will then have to eat some of the food you purchased, so do not purchase a type of food you are unwilling to eat.
- Before entering the MRI scanner an administrator will review the eligibility criteria for a final time to ensure your safety.
- You will be in the MRI scanner for approximately 30 minutes. If you wish to end your participation at any time, please inform an administrator.

## **Guidelines:**

Before entering the MRI scanner

1. Receive \$50 payment.

In the MRI scanner

- 2. For each option, decide if you want to buy the produce at the listed price by selecting 'Yes' or 'No'.
- After exiting the MRI scanner
  - 3. Complete a short survey.
  - 4. Roll a digital die to determine which purchasing question will be implemented (only one will be implemented).
  - 5. Purchase your food using your \$50 and eat some of it.

## **Consider the following Examples:**

**Example 1:** If you selected Option A with Attribute X for a purchasing question that is implemented, and it cost \$15, you will receive the food and go home with \$35 in cash (\$50 - \$15 = \$35).

**Example 2:** If you selected Option B with Attribute Y for a purchasing question that is implemented, and it cost \$20, you will receive the food and go home with \$30 in cash (\$50 - \$20 = \$30).

Appendix B. Round 1 BOLD Contrasts of Interest from Whole Brain Analysis Figure B.1. BOLD Contrast of EV1 compared to EV3



**EV1:** Produce irrigated with recycled water cost less than produce irrigated with traditional water (tradeoffs 1 and 4); and produce irrigated with recycled black water cost less than produce irrigated with recycled gray water (tradeoff 9).

**EV3:** Produce irrigated with recycled water cost more than produce irrigated with traditional water (tradeoffs 3 and 6); and produce irrigated with recycled black water cost more than produce irrigated with recycled gray water (tradeoff 7).

Note: The top panel is the treatment group and the bottom panel is the control. The BOLD contrasts of interest show regions of the brain that had significantly greater activation when participants made decisions about tradeoffs 1, 4, and 9 (EV1) than when they made decisions about tradeoffs 3, 6, and 7 (EV3).



#### Figure B.2. BOLD Contrast of EV1 compared to EV6

Lower Activation Higher Activation

**EV1:** Produce irrigated with recycled water cost less than produce irrigated with traditional water (tradeoffs 1 and 4); and produce irrigated with recycled black water cost less than produce irrigated with recycled gray water (tradeoff 9).

**EV6:** Produce irrigated with recycled water cost the same as produce irrigated with traditional water (tradeoffs 2 and 5); and produce irrigated with recycled black water cost the same as produce irrigated with recycled gray water (tradeoff 8).

Note: The top panel is the treatment group and the bottom panel is the control. The BOLD contrasts of interest show regions of the brain that had significantly greater activation when participants made decisions about tradeoffs 1, 4, and 9 (EV1) than when they made decisions about tradeoffs 2, 5, and 8 (EV6).

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