CONSUMER PERCEPTIONS AND WILLINGNESS-TO-PAY FOR NANOTECHNOLOGY APPLICATIONS THAT ENHANCE FOOD SAFETY

Van T. Tran
Department of Resource Economics
University of University Amherst
217C Stockbridge Hall
Amherst, MA 01003
miah.tran@umass.edu

Amalia Yiannaka
Department of Agricultural Economics
University of Nebraska-Lincoln
314B Filley Hall
Lincoln NE, 68583-0922
ayiannaka2@unl.edu

Konstantinos Giannakas
Department of Agricultural Economics
University of Nebraska-Lincoln
217 Filley Hall
Lincoln NE, 68583-0922
kgiannakas2@unl.edu

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Abstract

A survey instrument was developed to examine the factors that shape consumers' risks and benefits perceptions and the effects of the provision of balanced information on consumers' willingness-to-pay (WTP) for nano-based packaging that could improve food safety. We also examine and contrast the effect of loss and gain information framings and investigate whether the framing increased acceptance and WTP by emphasizing the enhanced attributes of nanotechnology or whether it produced, instead, anxiety that spilled over to nanotechnology. The empirical findings show that, even though consumers are willing to pay a premium for nanotechnology-based packaging that improves food safety, they discount such packaging when informed that nanotechnology is used to produce it. Preference for organic production practices, concern about foodborne bacteria, involvement with the issues outlined in the survey, work status, income, race, age, number of children, trust in the food industry and political affiliation all had a statistically significant impact on WTP. In addition, the study provides evidence of positive associations between consumers' risk tolerance of food nanotechnology and the expected probability of buying a nanofood product as well as WTP for food nanotechnology innovations. Comparisons of consumers' WTP for the use of nanotechnology in food packaging across information treatments reveal a statistically significant negative effect of the provision of additional information, albeit a balanced one, on consumers' WTP. In addition, the provision of gain and loss framed information reinforces the effects of balanced information on consumers' WTP for nano-food packaging that reduces food safety risks. However, the effect of information framings on consumers' WTP when balanced information is also provided is not statistically significant.

I. Introduction

As food safety issues are an increasing concern to consumers,[1] new production methods that can reduce the risk of being inflicted with food-borne illnesses[2] are greatly desired. In recent years nanotechnology has emerged as a production method that can be used to enhance nutrition and provide new varieties of food products as well as reduce food safety risks. Examples include carbon nanotubes embedded into packaging that can kill *E.coli* bacteria, a microbial pathogen responsible for numerous foodborne illnesses and deaths per year; nanosensors that can be used to detect allergen proteins such as peanut and gluten proteins, or contaminants such as melamine – which was the cause of thousands of infant deaths in China in 2008 and illnesses in pets in the US in 2006-2007 (Sekhon 2010). In addition, nano-encapsulated ingredients and nanofood packages help extend shelf life and reduce the amount of preservatives used in food, thus decreasing food spoiling and food poisoning risks.

Even though food nanotechnology applications hold promise for enhancing food quality and food safety, there is uncertainty regarding the potential health and environment risks of nanotechnology, raising concerns over its use in the food sector. Thus, consumers face the following tradeoff – on one hand food nanotechnology can reduce or eliminate certain known food risks and on the other hand the technology itself may pose new, unfamiliar risks. Public acceptance of nano-based applications which aim at reducing known food risks will depend on consumer assessment of the

[1] A survey of 1,000 consumers conducted in June 2015 by Daymon Worldwide's Custom Shopper Insights team found that American shoppers have become more concerned about food safety and quality; 33% and 50% of these consumers were more concerned at the time of the survey than a year and five years prior to the survey, respectively (Crawford 2015).

[2] A 2011 report from the Center of Disease Control and Prevention (CDC) shows that foodborne illnesses cause more than 48 million Americans to get sick and more than 3,000 deaths per year. See http://www.cdc.gov/foodborneburden/2011-foodborne-estimates.html.

potential benefits and risks of food nanotechnology. It is, thus, critically important to understand what shapes public perceptions regarding the benefits and risks of food nanotechnology.

Studies have shown that consumer behaviors are, to some extent, the derivatives of "consumers' interpretation of the chance to be exposed to the content of risk" (Pennings et al. 2002, p.93). A study by Brown et al. (2005) shows that high tolerance for food-born risks (e.g., *E.coli*, salmonella bacteria) lowers consumer willingness-to-pay for applications which aim at enhancing food safety. Past studies have provided evidence of a gap between consumers' perceptions of risks and scientific assessment of risks (Lewis and Tyshenko 2009, Hansen et al. 2003) and suggested that subjective knowledge is a better predictor of consumers' behaviors than objective knowledge (Flynn and Goldsmith 1999). In hindsight, the lack of attention to public sentiments towards a new technology, such as genetic modification in Europe, caused negative reactions that overshadowed positive aspects offered by this new technology (Ferber, 1999; National Academy of Sciences, 2000; Cobb and Macoubrie, 2004; Frewer and Shepherd 1995; Gaskell et al. 1999, 2004). In this light, assessing consumers' acceptance of food nanotechnology applications that could enhance food safety implies better understanding of consumers' perceptions towards nanotechnology and its applications to the food sector.

It is important to point out that polls show that the majority of the US public is uninformed about nanotechnology and its applications to the food sector with approximately 70% of respondents saying that they know nothing at all or very little about nanotechnology, while studies find no trend of increased familiarity and knowledge between 2004-2012 in the US (IFIC 2012; Duncan 2011; Cobb and Macoubrie 2004).

Given the low consumer awareness of nanotechnology, a large number of studies have focused on understanding what drives and shapes consumer perceptions and attitudes towards nanotechnology. These studies show that consumers' perceptions for nanotechnology applications are driven by a variety of demographic, psychometric or cultural factors. A common finding in this research is that when people lack information, as is the case with nanotechnology, or do not have enough time to assess information, they use heuristics (shortcuts) to form perceptions and attitudes (Kahan et al. 2007, 2009, 2011; Satterfield et al. 2009). Among the most important heuristics were affect, where people's perceptions about nanotechnology mirror their emotional appraisals of it (Kahan et al. 2007), trust in the industry, government and/or scientists, attitudes towards other more familiar technologies (Cobb and Macoubrie 2004; Siegrist et al. 2007; Siegrist 2008, Vandermoere et al. 2010, 2011), religious orientation (Scheufele et al. 2008), and cultural values which influence both where information about nanotechnology is sought and how it is processed (Kahan et al. 2008, 2009; Satterfield et al. 2009). Psychometric parameters, which include whether nanotechnology is perceived as being involuntarily imposed, unfamiliar, invisible, unequally distributed, beyond one's control or unnatural (Siegrist et al. 2007, 2008; Siegrist 2008) and attitudinal predispositions such as political leanings and intuitive toxicology are also shown to influence nanotechnology perceptions and attitudes (Kahan et al. 2007, 2009; Satterfield et al. 2009). Kahan et al. (2007), (2009) provide evidence that male, white, well-educated and high income earners are more likely to view nanotechnology risks as lower than those in all other demographic categories.

Risk and benefit perceptions were also found to be application-specific. For instance, sche et al. (2013) find that French consumers were willing to pay more for nano-packaging applications (nano-based orange juice bottle) than for nanofood applications (juice fortified with vitamin C) while German consumers exhibited the opposite preference. In another survey, Swiss respondents preferred nano-packed products (nano-outside) to nanofood products (nano-inside) (Siegrist et al. 2007).

Interestingly, research shows that, despite lack of knowledge and understanding of nanotechnology, the public has, nevertheless, opinions as to its potential benefits and risks. While in the US the public currently views the benefits of nanotechnology as outweighing potential risks, the EU public is not as optimistic[3] (Satterfield et al. 2009) in a meta-analysis of 22 studies). However, a large minority (44%) is unsure, which indicates that perceptions are malleable (Pidgeon et al. 2009; Satterfield et al. 2009). This raises the question as to how perceptions and attitudes are likely to evolve as the public becomes more familiar with nanotechnology. The familiarity hypothesis which posits that the more familiar/informed the public becomes, the more positive their views will become has been rejected in a number of studies. Kahan et al. (2007) show that the provision of balanced information about nanotechnology led to 'polarization and biased assimilation' along cultural lines, gender, race and political affiliation. Their research shows that individuals process information in a biased way that confirms their priors. Their findings are in line with research that also shows that individuals search harder for information that confirms their priors than information that challenges them (Scheufele and Lewenstein 2005; Kahan et al. 2010). In addition, research shows that both the source and the framing of information matter (Kahan et al. 2008; 2010). In Kahan et al. (2009) framing nanotechnology as risk abating had the paradoxical effect of causing one to view nanotechnology itself as risky.

[3] Bieberstein at al. (2013) find that French and German consumers weigh the applications of nanotechnology as being more risky than beneficial and are willing to pay a premium (either for food produced by conventional or organic methods, or food labels) to avoid food safety risks.

The main objective of this study is to shed light on the US public's perceptions of, and willingness to pay (WTP) for, food nanotechnology applications that could enhance food safety (e.g., packaging that can kill harmful food bacteria). In this context, we examine the trade-off consumers face: on one hand food nanotechnology can mitigate certain known food safety risks and on the other hand the technology itself may pose new, unfamiliar risks. Furthermore, we seek to understand how balanced information that is not attributed to identifiable advocates and information framings that emphasize the potential to mitigate food safety risks influence public perceptions, attitudes and WTP for food nanotechnology applications that could mitigate certain, known food safety risks. Specifically, we examine and contrast the effect of loss and gain information framings and investigate whether the framing increased acceptance and WTP by emphasizing the enhanced attributes of nanotechnology or whether instead it produced anxiety that spilled over to nanotechnology, crowding out the message that nanotechnology can abate certain known food risks as suggested by Kahan (2009). The rest of the paper is structured as follows: section II discusses the study design and the data collection process and provides descriptive statistics, section III provides the data analysis and the empirical results while section IV concludes the study.

II. Study design, data collection and descriptive statistics

A survey instrument was developed to examine our study objectives: (1) analyze the relationships between benefit and risk perceptions of food nanotechnology (the term "risk tolerance for food nanotechnology" is interchangeably used, henceforth) and consumers' WTP for nano-based packaged ground beef, (2) investigate the effects of the provision of balanced information and information framings on (i) risk and benefit perceptions of food nanotechnology applications and (ii) consumer WTP for nano-based packaged ground beef.

To investigate the effects of the provision of balanced information and gain and loss information framings on consumers' risk and benefit perceptions regarding food nanotechnology and their WTP for food safety enhancing applications, we assigned the sample to one of the following four conditions: minimal information about nanotechnology (Condition 1), minimal information about nanotechnology and additional balanced information about risks and benefits of food nanotechnology (Condition 2), minimal information about nanotechnology, additional balanced information about risks and benefits of food nanotechnology and a gain-framed message about the benefits of nanofoods (Condition 3) and minimal information about nanotechnology, additional balanced information about risks and benefits of food nanotechnology and a loss-framed message about the benefits of nanofoods (Condition 4) (see Figure 1). By design, the questionnaires are the same for each treatment except for the nature of information provided and the sample size is approximately 300 subjects for each condition. To avoid ordering effects, the order in which benefits and risks information appeared under Conditions 2, 3 and 4 was randomized. The details of each treatment are given in Table 1.

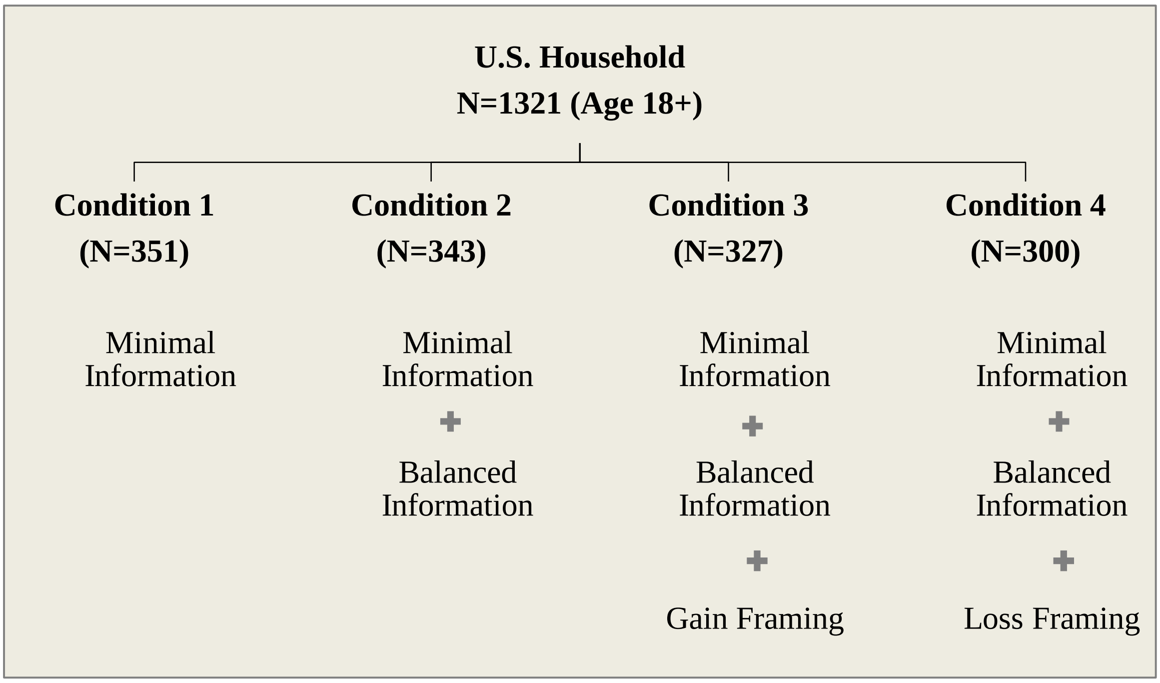

Figure 1. Survey design

Table 1. Information provided under the four treatment conditions.

Condition 1: Minimal information about nanotechnology.

Nanotechnology is science, engineering and technology that takes place at an extremely small scale (nanoscale) which is the level of atoms and molecules. Nanotechnology can be used to create new and unique products and applications. It has been used in cosmetics, computers, pharmaceuticals, medical devices, energy production, national security and defense and in agriculture and food production.

Condition 2: Additional balanced information about food nanotechnology.

Potential benefits of the use of nanotechnology in agriculture and the food sector include the following:

- The use of nanosensors to monitor crop growth and pest control and detect animal and plant diseases;
- The use of nano-additives and nano-ingredients that allow for changes in food texture, taste, processability and quality;
- Packaging material that is more durable, light, can repair tears, can respond to environmental conditions and improve food safety by signaling whether food is contaminated or spoiled or release preservatives that can extend food shelf life.

Research on the potential risks of nanotechnology is ongoing and has not been conclusive thus far. The main concern is that some nanoparticles could potentially be toxic to humans and/or the environment. It is also thought that nanoparticles may be inhaled by humans during their production or escape from engineered structures into food or the environment.

Condition 3: Gain Framing

When we consume food we face some risk of contracting harmful bacteria. When you choose to consume food packaged in nanotechnology-based packaging, you reduce your risk of contracting harmful bacteria.

Condition 4: Loss Framing

When we consume food we face some risk of contracting harmful bacteria. When you choose to consume food that is not packaged in nanotechnology-based packaging, you increase your risk of contracting harmful bacteria, compared to when nanotechnology-based packaging is chosen.

We used GfK Global[4] to field the survey and collect the data. After a pilot survey, the survey instrument was electronically sent to 2,182 US households between

[4] GfK Global is a leading online survey firm. GfK recruited participants from its probability based on-line survey research panel (KnowledgePanel®) that ensures representativeness of the US population. For more information see http://www.knowledgenetworks.com/ganp/.

March 24th and April 4th 2015 and 1,321 surveys were completed for a response rate of 60.5%. Participants were selected using the probability-based web sampling and sampling weights were used to correct non-response and under-or-over coverage of the US population. Key demographic and attitudinal characteristics of the sample are provided in Table 2.

Table 2. Demographic and attitudinal characteristics

	Sample	**Weighted Sample**
Gender		
Male	50.6%	48.2%
Female	49.4%	51.8%
Age (in years)	50.07	46.94
Education (mode)	High School	High School
Number of Children	0.46	0.5
Political Affiliations		
Republican	46.9%	43.4%
Independent	3.8%	4.3%
Democrat	49.3%	52.3%
Political Tendency		
Conservative	37.9%	35.3%
Moderate	35.2%	37.2%
Liberal	26.9%	27.5%
Religious Orientation		
Believer in God	67.9%	67.9%
Believer in a spirit/life force	12.9%	13.1%
Non-believer	8.2%	7.9%
Rather not say	11.0%	11.1%
Race		
White and Non-Hispanic	74.3%	65.5%
Black and Non-Hispanic	8.0%	11.5%
Others	17.7%	23.0%
Income		
Under $25k	15.6%	17.9%
From $25k to <$50k	21.4%	22.5%
From $50k to <$75k	19.7%	18.4%
More than $75k	43.3%	41.2%

III. Data analysis

1. Public awareness of and benefit-risk perceptions towards nanotechnology and food nanotechnology

A number of questions were designed to capture public awareness (Q13, 14 and 15 in Appendix A.1)[5] and benefit-risk perceptions of food nanotechnology (Q16). Consistent with previous studies, we find that the US public is generally unaware of nanotechnology with approximately 79% of our survey respondents reporting hearing nothing or a little about nanotechnology before the study. Furthermore, when asked about their familiarity with nanotechnology and food nanotechnology, 70.9% admit being "not at all familiar", 26.1% "somewhat familiar" with nanotechnology while the numbers for food nanotechnology are 88.7% and 10.6%, respectively.

Overall, more than half of the respondents (62.2%) claim that they are neutral about the benefits and risks of food nanotechnology. There is a slightly greater proportion of respondents who perceive the benefits as outweighing the risks than the opposite (19.4% vs. 18.4%). Our results also support earlier findings by Kahan et al. (2007, 2009) that women tend to be more concerned about the risks of nanotechnology than men. In our study, a greater proportion of the female population is in disagreement with the statement "Overall, the benefits of food nanotechnology are greater than the risks" and female respondents give a lower average rating on that question (2.92 for female vs. 3.06 for male on a 5-point rating scale, $p = 0.002$).[6] The more familiar consumers claimed to be with nanotechnology and/or food

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[5] See Appendix A.1 for the survey instrument. Note that all questions up to Q15 appear before subjects are exposed to the information treatments.

[6] We run Levene's Test for Equality of Variances to determine if the variances for two subsamples (male vs. female) are equal and then carry out the t-test for Equality of Means, given the (un)equal variances, to test if the difference of two means is statistically significant.

nanotechnology, the more likely they were to rate food nanotechnology as being more beneficial than risky $(p = 0.015)$.

In addition, consumers' risk perceptions of nanotechnology applications that could enhance food safety differ between condition 1 (minimal information) and the other information conditions in a statistically significant manner, capturing the effects of the provision of different information content on consumers' perceptions. Specifically, consumers who were provided with minimal information about nanotechnology gave a .23-point $(p = 0)$ higher rating of the benefits of nanofood applications than the group which receives additional balanced information without framing about food nanotechnology and a .37-point $(p = 0.01)$ higher rating of the benefits of nanofood applications than any other groups that receive additional information with or without framing about food nanotechnology. This suggests that (1) greater exposure to information intensifies risk perceptions of food nanotechnology, which is in line with previous studies that reject the familiarity hypothesis and (2) the provision of gain and loss framed information reinforces the effects of balanced information on consumers' benefit-risk perceptions of food nanotechnology. Moreover, information framing effects are found to be significant (see the mean comparisons: 2 vs. 3 and 2 vs. 4 in Table 3). Specifically, consumers provided with a gain-framed message rated 5 points $(p = 0.01)$ on benefit/risk perceptions lower than those who were not exposed to information framing and consumers provided with a loss-framed message rated 18 points $(p = 0.003)$ higher than those who were not exposed to information framing. Our findings are different than Kahan et al. (2007) who find that the provision of balanced information about nanotechnology had, on average, no effect on benefit/risk perceptions. In their study, information effects were detected only when the subjects were divided in subgroups.

Table 3 also provides the average values of consumers' risk perceptions of food-borne bacteria, namely *E.coli* and Salmonella (captured by Q7), across the four treatment conditions. On average, consumers rate their perceived risks of *E.coli* and Salmonella bacteria as 2.49 and 2.5 on a 4-point scale. The other risk-related variable is consumers' risk tolerance towards other food technologies. We create this construct using Confirmatory Factor Analysis of responses to a set of questions which reflect the respondents' level of acceptance for each of the following production practices: genetic modification, use of chemicals/pesticides and animal cloning. The construct is measured by three items on a 7-Likert rating scale (from *Totally unacceptable* to *Perfectly acceptable*) (Q4) and one item on a 5-Likert scale (from *Strongly disagree* to *Strongly agree*) (Q5). The four items measuring risk perceptions of food production practices form a reliable composite as shown by the Cronbach's *alpha* internal reliability coefficient of .85. The one-factor model fitting these four items is shown to be satisfactorily valid with the model fit indices being p-value (Chi-square) = 0.069, RMSEA=0.036, CFI=0.999 and TLI=0.996.

Table 3: Mean difference of risk-related variables across information conditions and tests of equality of means

	Means and Standard Deviations					Mean Differences(4) and Standard Deviations							
	Full Sample	Cond.1	Cond.2	Cond.3	Cond.4	1 vs. Avg(2,3,4)	1 vs. 2	1 vs. 3	1 vs.4	2 vs. Avg(3,4)	2 vs. 3	2 vs. 4	3 vs. 4
Risk perception of food-borne bacteria:													
Risk perception of E.coli bacteria(1)	2.49 (.97)	2.45 (.96)	2.57 (.96)	2.46 (1.01)	2.48 (0.93)								
Risk perception of Salmonella bacteria(1)	2.5 (.98)	2.57 (.96)	2.49 (.99)	2.53 (.92)	2.52 (.96)								
Risk tolerance for food technologies:													
Risk tolerance for other food production methods(2)	.00 (1.00)	.10 (1.11)	-.07 (1.08)	-.03 (1.02)	-.01 (1.03)								
Risk tolerance for food nanotechnology(3)	2.97 (.80)	3.07 (.67)	2.84 (.85)	2.98 (.82)	3.00 (.84)	.37** (.01)	.23*** (.06)	.08 (.06)	.05 (.39	-.33*** (.10)	.15** (.06)	-.18*** (.06)	-.03 (.06)

(1): Averages on a 4-point scale from "Almost no risk" to "High risk"
(2) Standardized values for the risk perception construct. The higher is the value, the more beneficial (or the less risky) is the technology perceived.
(3) Averages on a 5-point scale from "Strongly Disagree" to "Strong Agree". The higher is the value, the more beneficial (or the less risky) is the technology perceived.
(4) Mean difference = Mean of the first group – Mean of the second group.
Significance codes: '***' $p< 0.001$ '**' $p<0.05$ '*' $p<0.10$

Table 4. Mean differences of consumers' WTP across information conditions and tests of equality of means

	Means and Standard Deviations					Mean Differences[1] and Standard Deviations							
	Full Sample	**Cond.1**	**Cond.2**	**Cond.3**	**Cond.4**	**1 vs. Avg(2,3,4)**	**1 vs. 2**	**1 vs. 3**	**1 vs.4**	**2 vs. Avg(3,4)**	**2 vs. 3**	**2 vs. 4**	**3 vs. 4**
Preferred Ground Beef (WTP_1)	3.64 (1.94)	3.61 (1.85)	3.77 (2.04)	3.61 (1.97)	3.53 (1.89)								
Preferred Ground Beef, Packaged In Safer Packaging (WTP_2)	3.74 (2.19)	3.62 (2.15)	3.95 (2.21)	3.64 (2.13)	3.75 (2.28)								
Packaging that could reduce bacteria (WTP_s=WTP_2 - WTP_1)	0.12 (1.27)	0.02 (1.32)	0.20 (1.24)	0.04 (1.36)	0.23 (1.10)								
Preferred Ground Beef, Packaged In Nano-Based Packaging That Can Reduce Harmful Bacteria (WTP_3)	2.94 (2.44)	3.08 (2.36)	2.90 (2.52)	2.85 (2.40)	2.90 (2.47)	.65 (.44)	.22 (.18)	.24 (.18)	.19 (.19)	-.002 (.27)	.02 (.18)	-.02 (.19)	-.05 (.19)
Consumer valuation for nanotechnology process (WTP_n=WTP_3 - WTP_2)	-0.82 (2.08)	-0.54 (2.02)	-1.06 (2.23)	-0.82 (1.97)	-0.87 (2.05)	1.19** (.38)	.52*** (.15)	.31** (.16)	.36** (.16)	-.38 (.27)	-.22 (.16)	-.16 (.16)	.05 (.16)

(1) Mean difference = Mean of the first group – Mean of the second group.

(2) Significance codes: '***' $p< 0.001$ '**' $p<0.05$ '*' $p<0.10$

2. Consumers' WTP for applications that could enhance food safety

We assess both consumer perceptions of the application (i.e., the packaging that can substantially reduce bacteria by 99.9%) and their perception of the technology that is used to produce it (i.e., nanotechnology). To capture consumer evaluation for each one, we ask participants the three following WTP questions:

Q10- [truncated] What is the highest (max) price you would pay for 1 pound of <u>your preferred type</u> of ground beef? Please use the list of prices below to make your selection.

Q11- [truncated] What is the highest (max) price you would pay for 1 pound of <u>your preferred type</u> of ground beef, packaged in packaging that ***can substantially reduce*** *(up to 99.99%) harmful bacteria? Please use the list of prices below to make your selection.*

Q17- [truncated] What is the highest (max) price you would pay for 1 pound of <u>your preferred type</u> of ground beef, packaged in ***nanotechnology-based*** *packaging that* ***can substantially reduce*** *(up to 99.99%) harmful bacteria? Please use the list of prices below to make your selection.*

Question Q10 captures consumers' WTP for their preferred type of ground beef (WTP_1) and serves as a benchmark and question Q11 captures their WTP for their preferred type of ground beef packaged in packaging that can reduce harmful bacteria (WTP_2) while question Q17 captures consumer WTP for ground beef packaged in nano-based packaging that can reduce harmful bacteria (WTP_3). WTP_1, WTP_2 and WTP_3 are elicited through the revised multiple price list (MPL) method where respondents are asked to select the price that reflects their highest valuation for the products (see Anderson et al. (2007) for details of the MPL method). In each of the above questions, consumers can select the option '$0; I would not buy'; otherwise, they choose among prices which start at $2 and go up to $10 in ten cents increments.

When respondents are exposed to questions Q10 and Q11 they have not yet seen any reference to nanotechnology and they have not been exposed to the information treatments. Thus, a comparison of the two WTP measures gives consumers' WTP for packaging that could improve food safety, that is, $WTP_s = WTP_2 - WTP_1$. Question Q17 is asked after the respondent are exposed to the information treatments. In this manner, consumers' valuation of nanotechnology, $\boldsymbol{WTP_n}$, can be derived by subtracting consumers' WTP for their preferred type of ground beef packaged in packaging that could improve food safety from their WTP for their preferred type of ground beef packaged in nano-based packaging, that is $WTP_n = WTP_3 - WTP_2$. Thus, we are able to disentangle consumers' valuations for the enhanced attributes offered by nanotechnology (i.e., packaging that can improve food safety) and the technology that is used to generate it (i.e., nanotechnology).

As can be seen in Table 4, consumers are, on average, willing to pay $.12 for packaging that could improve food safety for ground beef. Exposure to new information about food nanotechnology, albeit a balanced one, decreases consumers' valuation for the nanotechnology process. Consumers under Condition 2 discount the use of food nanotechnology almost as twice as do those under Condition 1 ($1.06 vs. $0.54, $p < .001$). In the following sections we shall identify factors underlying such differences.

3. Effects of consumer perceptions and information provision on WTP for ground beef packaged in nano-based packaging that can reduce harmful bacteria (WTP_3)

a. Econometric Model Specification and Estimation Strategies

We model consumer WTP for ground beef packaged in nano-based packaging that can reduce harmful bacteria (WTP_3) in two stages: the first stage is to model the decision to purchase the nanofood product and the second stage is to model the 'amount' decision, that is, how much to pay for the product. Due to the binary nature of the participation decision, a Probit analysis of the first stage is conducted. As can be seen in Figure 2 which depicts the Q-Q plots and histograms of the WTP_3 variable and its logarithm against those of a normally distributed random variable, $\log(WTP_3)$ follows a normal distribution but WTP_3 does not. Hence, in the second stage, we perform an OLS estimation of $\log(WTP_3)$ instead of WTP_3.

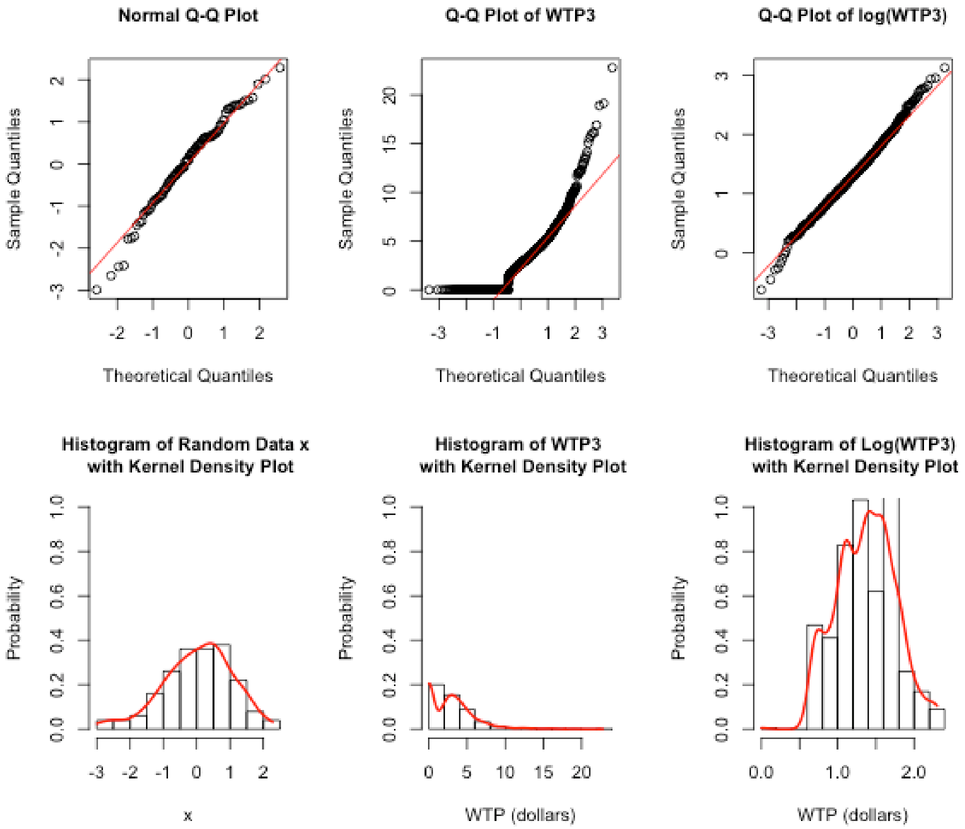

Figure 2. Q-Q plot of consumers' WTP for ground beef packaged in nanotechnology-based packaging that can reduce harmful bacteria (WTP_3)

The above modeling is a brief characterization of Cragg (1971) Lognormal Hurdle Model (LH). Following Wooldridge (2010), the Cragg population model can be written in as:

$$y = sw^* = 1[X\gamma + v > 0]\exp(X\beta + u) \tag{1}$$

where y is the observable variable which captures consumers' WTP for nano-based ground beef, s the binary participation indicator which determines whether y is zero or strictly positive, w^* the continuously distributed, non-negative latent variable which is only observed when $s=1$, and X the matrix of covariates which include risk perception variables, demographic variables (e.g., age, income, gender, education, work status) and other exogenous variables.

An important assumption for the above model is that the disturbances u and v are independent of X and each other. This assumption is relaxed in the Exponential Type II Tobit model which allows correlations between the models in two stages and is most effective when the covariates in the 'amount' model (Hurdle 2) are a subset of those in the 'participation' model (Hurdle 1) (Wooldridge 2010). In our estimation results (Table 5), the correlations between the two models $(corr12)$ are shown to be statistically insignificant at $\alpha = 0.05$ and, thus, the Lognormal Hurdle model is sufficient.

Conditional on the covariates X, v follows a standard normal distribution, i.e., $v \mid X \sim N(0,1)$ while u has a normal distribution with mean zero and variance σ^2, i.e., $u \mid X \sim N(0,\sigma^2)$. Given the lognormal distribution of $w^* = \exp(X\beta + v)$ and the independence of u and v, the amount decision $y = sw^*$ is lognormally distributed conditional on $y > 0$.

In the first hurdle, we estimate the determinants of consumers' decision as to whether they want to buy the product. The Probit model of the first hurdle has the form of

$$P(s \mid X) = P(y > 0 \mid X) = \Phi(X\gamma) \quad (2)$$

where $\Phi(.)$ is the cumulative density function of a normal distribution. Given the maximum likelihood estimated parameters, γ, the marginal probability effect of an explanatory variable X_j equals to $\frac{\partial \Phi(X'\hat{\gamma})}{\partial X_j} = \hat{\gamma}\,\phi(X'\hat{\gamma})$, where $\phi(.)$ is the standard normal probability density function if X_j is continuous or equals to $\Phi_{X_j=1}(X'\hat{\gamma}) - \Phi_{X_j=0}(X'\hat{\gamma})$ if X_j is binary (or categorical).

In the second hurdle, we are interested in estimating $E(y \mid X)$, the effects of risk perceptions and other characteristics on consumers' WTP for ground beef packaged in nano-based packaging that can reduce harmful bacteria. We can integrate the conditional expected value of y, $E(y \mid X, y>0) = E(w^* \mid X, s=1) = \exp(X\beta + \frac{\sigma^2}{2})$ over $y>0$ to obtain the unconditional expected value as in equation (3).

$$E(y \mid X) = \int_{y>0} E(y \mid X, y>0)dy = \Phi(X\gamma)\exp(X\beta + \frac{\sigma^2}{2}) \quad (3)$$

Since $f(y \mid X) = \left[1-\Phi(X\gamma)\right]^{1[y=0]} \left[\frac{1}{\sigma y}\Phi(X\gamma)\phi\left(\frac{\log(y)-X\beta}{\sigma}\right)\right]^{1[y=1]}$, for a random observation $i = 1, 2, ..., \mathrm{N}$, the log-likelihood function can be derived as

$$l(\theta) = 1[y_i = 0]\log\left[1-\Phi(X_i\gamma)\right]$$
$$+1[y_i > 0]\left\{\log\left[\Phi(X_i\gamma)\right] + \log\left[\phi\left(\frac{\log(y_i)-X_i\beta}{\sigma}\right)\right] - \log\sigma - \log y_i\right\}$$

Then we can regress an OLS of $\log y_i$ on X_i to obtain the estimator of β, $\hat{\beta}$. It follows that the semi-elasticity[7] of $E(\mathrm{y} \mid \mathrm{X})$ relative to X_j equals to

$100 * \left[\hat{\gamma}_j\lambda(X\hat{\gamma}) + \hat{\beta}_j\right]$, where $\lambda(.)$ is the inverse Mills ratio.[8]

b. Results

Results for the Cragg Lognormal Hurdle model are shown in Table 5. Risk Tolerance For Food Nanotechnology is the only variable that has a statistically significant positive impact on both the likelihood of buying a nano-based packaged food product and consumer WTP for the product. Given the coefficient of 0.082 in the Probit model, we can estimate the marginal effects of risk tolerance on the likelihood $P(s \mid X)$ at mean values of other variables is 0.03. This means that a one-unit increase in risk tolerance for food nanotechnology would increase the expected probability of

[7] Semi-elasticity is the percentage change in a function relative to an absolute change in a parameter.

[8] $\lambda(X\gamma) = \frac{\phi(X\gamma)}{\Phi(X\gamma)}$

buying a nanofood product by 3 percent. Likewise, the .13 and .17 marginal probability effects for risk tolerance for other food production methods and consumption frequency imply an increase of 13 percent and 17 percent in the likelihood of purchase due to one-unit change in each of these two variables, respectively.

Consumers' WTP for ground beef packaged in a nano-based packaging is affected by their risk tolerance for food nanotechnology, risk perceptions of *E.coli* bacteria, income and work status. Specifically, a one-unit increase in their risk tolerance for food nanotechnology increases their WTP for nano-based ground beef by 47 percent. Consumers who feel more threatened by the risks posed by *E.coli* are willing to pay 22 percent more for the nanofood product. Having higher income increases consumer WTP while being without a job lowers their WTP.

In both hurdles, we do not observe information effects as the coefficient estimates for the categorical variable "Cond." are not statistically significant at a 95% (or even 90%) confidence level. This result is expected given the mean difference of the pair 1 vs. Avg (2, 3 and 4) is insignificant as shown in Table 4. Likewise, consumers' levels of familiarity with food nanotechnology (i.e., self-assessed familiarity) and involvement with food safety issues have no significant impacts on their WTPs for nano-based ground beef.

Table 5. The Cragg Lognormal Hurdle regression results

Dependent Variable	*WTP for for ground beef packaged in nano-based packaging that can reduce harmful bacteria*	
	Hurdle 1 (Probit)	**Hurdle 2 (OLS)**
Explanatory Variables		
Risk Perception of *E.coli*	-0.014	0.092**
Risk Perception of Salmonella	0.115	-0.050
Risk Tolerance for Food Nanotechnology (B>R)	0.455***	0.070**
Risk Tolerance for Other Food Technologies	0.082**	-0.017
Consumption Frequency	0.346***	0.014
Trust in Industry	0.029	0.010
Independent vs. Republican	0.068	-0.114
Democrat vs. Republican	0.062	0.023
Age	0.002	0.000
Education	0.004	0.008
Female vs. Male	-0.100	0.037
Child	0.091*	-0.007
Income: From $25k to <$50k	-0.043	0.086*
Income: From $50k to <$75k	0.119	0.104**
Income: $75k+	0.112	0.195***
Not Working	-0.007	-0.075**
Familiarity with Food Nanotechnology	0.052	-0.047
Condition 2	-0.036	-0.052
Condition 3	-0.122	-0.051
Condition 4	-0.099	-0.040
Involvement	-0.013	-0.033
Condition 2 x Involvement	-0.022	0.018
Condition 3 x Involvement	-0.015	0.013
Condition 4 x Involvement	-0.028	0.000
corr12[(a)]		0.024
(Intercept)	-2.365***	0.919***

Significance codes: '***' p< 0.001 '**' p<0.05 '*' p<0.10
Log-Likelihood: -2171.9 on 52 Df
R^2: Coefficient of determination: 0.16123 Likelihood ratio index: 0.063602
[(a)] Correlation between Hurdle 1 and Hurdle 2

4. Effects of consumer perceptions and information provision on WTP for packaging that can reduce harmful bacteria (WTP_s) and for use of food nanotechnology in food packaging (WTP_n)

a. Econometric Model Specifications and Estimation Strategies

We model WTP_s which captures consumers' valuation of packaging that can reduce harmful bacteria in ground beef when consumers receive no information about the process that is used to generate it. A 3-level categorical variable is created indicating whether consumers are willing to pay less (A), the same (B) or more (C) for such packaging. We use the Multinomial Logit Model (MNLM) to understand what choices consumers make given their demographic characteristics and risk perceptions.

Following Long (1997), let y define the dependent outcome variable, j the j^{th} category of the outcome variable y (i.e., $j = A, B$ or C) with the subsample size N_j, J be the reference or base category. Given the covariates X, the odds of the outcome category j versus the reference outcome category J is

$$\Omega_{j|J} = \frac{P(y = j \mid X)}{P(y = J \mid X)} = e^{\beta_{0,\mathrm{j|J}} + X'\beta_{\mathrm{j|J}}} \tag{4}$$

Taking the logarithm of both sides of equation (4) gives us

$$\ln \frac{P(y = j \mid X)}{P(y = J \mid X)} = \beta_{0,\mathrm{j|J}} + X'\beta_{\mathrm{j|J}} \tag{5}$$

Since the probabilities of all categories of the outcome variable must add up to 1, the log-odds of having the outcome falling into category A relative to category C can be written as:

$$\ln \frac{P(y = A \mid X)}{P(y = C \mid X)} = \ln \frac{P(y = A \mid X)}{P(y = B \mid X)} + \ln \frac{P(y = B \mid X)}{P(y = C \mid X)} \tag{6}$$

It follows that $\beta_{A|C} = \beta_{A|\mathrm{B}} + \beta_{\mathrm{B}|C}$ and we can easily obtain a coefficient for any comparison knowing the other two coefficients.

Due to the difficulty in interpretability, the estimated coefficients of an MNLM are normally transformed to their exponentiations, the odds-ratio $OR_{j|J,k} = e^{\beta_{0,j|J} + X'\beta_{j|J}}$ where k is the k^{th} explanatory variable.[9] The odds ratio of > 1 implies that the risk of the outcome falling in the j outcome category relative to the risk of the outcome falling in the J outcome category increases as x_k increases, holding all other variables constant. The odds ratio of 1 implies no association between the outcome variable and explanatory variables.

One of the key assumptions for this model is the Independence of Irrelevant Alternatives (IIA) property, which states that the odds of choosing A over B, for example, are unaffected by other alternatives such as C. We would argue our data satisfy this IIA property since consumers' choice of "Pay More" Over "Pay The Same", for example, does not depend on the presence of the "Pay Less" option. Hausman and McFadden (1984) and Small and Hsiao tests are widely used for testing the IIA assumption. Another primary assumption is no multicollinearity, which requires the covariates in the model are not highly correlated. We tested this assumption using the "variance inflation factor (VIF)" values and evidence of multicollinearity is found in an acceptable range (VIF<10).

The estimation procedure of consumers' valuation of the use of nanotechnology in food safety improvement, WTP_n, is analogous to that of consumers' valuation of packaging that can reduce bacteria in ground beef, WTP_s.

b. Results

Table 6 reports the estimation results of both models. [10] Preference for Organic Food Products[11] is positively associated with consumers' WTP for the application but negatively associated with consumers' WTP for the technology that is used to produce it. Specifically, the logit estimate for "Preference for Organic Food Products" of 0.168

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[9] $OR_{j|J,k} = e^{\beta_{0,j|J}}$ when all other variables are set to 0.

[10] See details about model fit in Appendices A.2 and A.3.

[11] The "Preference for Organic Food Products" variable is measured by consumers' 5-point rating which shows their agreement or disagreement to the question (Q3) "In my opinion, organic food products are healthier than other food products".

suggests that a one-unit increase in consumers' preference for organic foods would increase their log-odds of preferring "Pay More" to "Pay Less" for safer packaging (where the reference category is "Pay Less") by 0.168 unit, holding other variables constant at zeros $(p < 0.10)$.[12] We can use odds-ratios for an easier interpretation: since the odds-ratio for Preference for Organic Food Products is greater than one ($e^{\beta} = 1.183$), for a unit increase in consumers' preference for organic foods, the s odds of selecting "Pay More" over "Pay Less" for safer packaging is expected to increase by a factor of 1.183 $(p < 0.10)$. In contrast, the odds ratio of 0.732 implies that the odds of selecting "Pay More" over "Pay Less" for the use of food nanotechnology decrease by a factor of 0.732 $(p < 0.001)$. We also find that the more consumers feel that the food safety issues discussed in the survey are relevant to them, the more likely it is that they will be willing to "Pay More" as opposed to "Pay Less" for the use of nanotechnology but the less likely it is that they will be willing to pay more for packaging that can improve food safety risks.

The other variables that affect WTP_s and WTP_n in opposite ways are Race and Work Status. While White and Non-Hispanic consumers are more likely to pay more for the safer packaging, they pay less for the use of nanotechnology (i.e., when they find out that nanotechnology was used to produce it) as compared to Black and Non-Hispanic consumers. As compared to those without a job, consumers who are having one are willing to pay a premium for safer packaging but discount the nanotechnology process.

Unlike the above factors, Risk Perception of *E.coli*, Consumption Frequency, and Income are factors which affect WTP_s and WTP_n in a similar manner. Consumers

[12] The Wald test statistics are used to verify the significance of explanatory variables in discriminating pairs of outcome categories.

who are more concerned about the risk of *E.coli* are more likely to "Pay More" relative to "Pay Less" for both safer packaging and food nanotechnology. For a unit increase in consumers' risk perception of *E.coli*, the odds of preferring "Pay More" to "Pay Less" increase by a factor of 1.227 $(p < 0.10)$ for the packaging and by a factor of 1.215 $(p < 0.05)$ for food nanotechnology.

Earning more money makes it more likely for consumers to "Pay More" rather than "Pay Less". For example, for respondents in the <$25k income range, the odds of selecting "Pay More" over "Pay Less" for the safer packaging are expected to decrease by a factor of 0.402 $(p < 0.001)$ compared to respondents in the > $75k range. A similar interpretation is applied in comparing the $25k -$50k income group with the $75k+ income group. Finally, there is a statistically significant negative association between Consumption Frequency and consumers' choice to "Pay Less", "Pay The Same" or "Pay More" in Models 1 and 2. The odds ratio of 0.717 in Model 1, for example, suggests that the odds of consumers to "Pay The Same" relative to "Pay Less" decrease by a factor of 0.717 as consumption frequency increases. In other words, the more frequent is the consumption of ground beef, the lower is WTP for safer packaging and/or the use of nanotechnology in food packaging that enhances food safety. This finding may suggest that consumers who consumer ground beef more (less) frequently are less (more) concerned about food risks.

Socio-demographic variables such as Age, the Number of Children, Trust in the Industry and Political Affiliation are significant factors that determine consumers' WTP for packaging that can reduce harmful bacteria, but they do not affect consumers' WTP for the use of food nanotechnology. Specifically, being one-year older increases the odds of selecting "Pay More" relative to "Pay Less" for safer packaging by a factor of 1.018. Likewise, being one year older increases the odds of preferring "Pay The Same" to "Pay Less" by a factor of 1.008, holding all other variables constant at zeros ($p < 0.05$). The more children consumers have, the higher are the odds of selecting "Pay Less" over "Pay More" or "Pay The Same" ($p < 0.05$). Trust in the Industry is found to have a significant positive impact on consumers' choice to "Pay More". A unit increase in consumers' trust in the industry increases their odds of paying more for safer packaging as opposed to paying less by a factor of 1.283 ($p < 0.05$).

An Independent is less likely than a Democrat to prefer "Pay More" to "Pay Less" ($p < 0.05$). There is no significant difference between Republicans and Democrats in their choice of paying for safer packaging. Gender and Risk Tolerance for Other Food Production Methods do not significantly determine how much consumers are willing to pay for safer packaging or the use of nanotechnology in food packaging.

The regression results also show that consumers' WTP for the use of nanotechnology in packaging that can reduce bacteria is significantly determined by consumers' risks and benefits perception towards food nanotechnology. As expected, the more consumers value the benefits of food nanotechnology, the more they are willing to pay for the use of nanotechnology in food packaging. In particular, a one-unit increase in consumers' risk tolerance for food nanotechnology would result in an increase in the odds of "Pay The Same" and "Pay More" relative to "Pay Less" by a factor of 1.382 ($p < 0.001$) and 1.595 ($p < 0.001$), respectively.

We contrast condition 2 with condition 1 to examine the effects of the provision of information on WTP for the use of food nanotechnology and contrast condition 2 with the combined group of conditions 3 and 4 to explore the effects of information framing when balanced information is also provided. The odds ratio of 1.496 suggests that, relative to those in condition 2, consumers in condition 1 are more likely to prefer “Pay More” to “Pay Less” for the use of nanotechnology in food packaging. However, the effects of Cond. 3 and 4 on WTP_n are insignificant, indicating that if consumers are all exposed to balanced information about food nanotechnology, the effects of the provision of framing on consumers’ WTP might eventually vanish.

Table 6. The Multinomial Logit Model regression results

		Model 1		Model 2	
Dependent Variable:		**WTP for packaging that can reduce harmful bacteria**		**WTP for the use of nanotechnology in food packaging that reduces harmful bacteria**	
Reference category: Pay Less	Coef.	Pay The Same	Pay More	Pay The Same	Pay More
Intercept	β	3.481***	0.865	0.934	-2.019**
Age	β	0.008***	0.018**	-0.004	-0.004
	exp(β)	1.008	1.018	0.996	0.996
Number of Children	β	-0.275**	-0.197**	0.019	0.032
	exp(β)	0.759**	0.821**	1.02	1.032
Trust in the Industry	β	0.142	0.249**	-0.043	0.093
	exp(β)	1.153	1.283**	0.958	1.098
Consumption Frequency	β	-0.333**	-0.118	-0.308***	-0.034
	exp(β)	0.717**	0.888	0.735***	0.966
Involvement	β	-0.45***	-0.351**	0.02	0.273**
	exp(β)	0.638***	0.704**	1.02	1.314**
Risk Perception of E.coli	β	0.069	0.204*	0.035	0.194**
	exp(β)	1.071	1.227*	1.036	1.215**
Gender: Male vs. Female	β	-0.067	-0.08	0.206	0.231
	exp(β)	0.935	0.923	1.229	1.259
Political Affiliation Republican vs. Democrat	β	-0.001	-0.109	-0.229	-0.26
	exp(β)	0.999	0.897	0.795	0.771
Independent vs. Democrat	β	-0.536	-1.195**	-0.067	-0.544
	exp(β)	0.585	0.303**	0.935	0.58
Race Black and non-Hispanic vs. White and non-Hispanic	β	-0.933**	-0.808**	-0.18	0.663**
	exp(β)	0.394**	0.446**	0.835	1.941**
Other Races vs. White and non-Hispanic	β	-0.213	0.225	-0.443**	0.249
	exp(β)	0.808	1.252	0.642**	1.282
Income Under $25k vs. $75k +	β	-0.976***	-0.911**	-0.461**	-0.232
	exp(β)	0.377***	0.402**	0.631**	0.793
From $25k to <$50k vs. $75k +	β	-1.008***	-0.995***	-0.302*	-0.342
	exp(β)	0.365***	0.37***	0.74*	0.711
From $50k to <$75k vs. $75k +	β	-0.423	-0.509	-0.138	0.034
	exp(β)	0.655	0.601	0.871	1.034
Work Status: Working vs. Not Working	β	0.102	0.409*	-0.234*	-0.351*
	exp(β)	1.107	1.505*	0.791*	0.704*
Preference for Organic Food Products	β	0.071	0.168*	-0.062	-0.312***
	exp(β)	1.073	1.183*	0.94	0.732***
	β	-0.025	0.001	0.046	0.042

Risk Tolerance for Other Food Prod. Methods	exp(β)	0.975	1.001	1.047	1.043
Familiarity with Food Nanotechnology: *Low vs. High*	β			-0.012	-0.292
	exp(β)			0.988	0.747
Risk Tolerance for Food Nanotechnology	β			0.324***	0.467***
	exp(β)			1.382***	1.595***
Information Condition Cond.[(a)] 1 vs. Cond. 2	β			0.293	0.402*
	exp(β)			1.341	1.496*
Cond. 3,4 vs. Cond 2	β			0.059	0.215
	exp(β)			1.061	1.24

Significance codes: '***' p< 0.001 '**' p<0.05 '*' p<0.10
[(a)] Short for Condition

IV. Conclusions

In line with past studies, our survey results reveal that American consumers demonstrate low awareness of nanotechnology and its applications in the food sector and women are more concerned about the risk of food nanotechnology than men. However, unlike Kahan et al. (2007), we find that provision of balanced information causes consumers to interpret benefits and risks differently. Specifically, compared to those that receive minimal information about nanotechnology, those who receive balanced information about food nanotechnology view food nanotechnology as more harmful rather than beneficial. Gain and loss information framings reinforce the effects of the provision of balanced information.

Results from the Cragg Lognormal Hurdle Model show that a positive assessment of potential benefits and risks of food nanotechnology has a statistically significant positive effect on consumers' decision to buy the nanofood product and their willingness-to-pay for nanofood applications that provide food safety improvements. This result is in agreement with the findings of previous studies that demonstrate the importance of understanding consumers' risk perceptions in assessing the acceptance of new food products.

Consumers' risk tolerance of existing food technologies such as GMO, chemical use or animal cloning can be a good predictor of their decision to buy nanotechnology applications in the food sector although this factor may not be as useful in predicting how much they are willing to pay for it. In contrast to consumers' risk tolerance of existing food technologies, consumers' risk perception of food-borne pathogens, namely *E.coli*, is shown to be positively associated with the amount spent on the food safety enhancing application enabled by nanotechnology but not with the initial decision to buy or not to buy that product.

The survey instrument is designed in a way that allows us to disentangle consumers' valuation of the enhanced product attributes offered by nanotechnology from their valuation of the technology that is used to produce it. Our findings suggest that while consumers value the packaging that can reduce bacteria, they are averse to the use of nanotechnology in producing such product. On average, American consumers are willing to pay a premium of 12 cents for the packaging that has the potential to substantially reduce harmful bacteria while discounting by 84 cents the use of nanotechnology in food productions. A closer inspection of consumers' WTP for the use of nanotechnology across information treatments reveals that the nature of information is critical in determining how much consumers are willing to pay for nanotechnology. The group that is exposed to minimal information about nanotechnology has a higher WTP for the food nanotechnology application than any other group that receives additional information about food nanotechnology. Framing effects are not statistically significant when balanced information is also provided.

Risk perceptions of *E.coli*, Income and Consumption Frequency are positively associated with consumers' WTP for the enhanced packaging and the use of nanotechnology in food packaging. Preference for Organic Foods, Involvement, Black and non-Hispanic, Work Status are also significant determinants but have opposite effects on those two WTPs. Specifically, those who have greater preference for organic foods or feel less personally relevant to the questioned food issues are willing to pay higher for the packaging but lower for nanotechnology. Similarly, White and non-Hispanic respondents are more likely than Black and non-Hispanic respondents to pay a premium for the packaging but discount nanotechnology. So are consumers with jobs as compared to those without a job.

Age, the Number of Children, Trust in the Industry and Political Affiliation are significant factors that determine consumers' WTP for packaging that can reduce bacteria but do not affect consumers' WTP for the use of food nanotechnology. Benefit/risk perception of food nanotechnology, on the other hand, is strongly associated with consumer WTP for the use of food nanotechnology. Finally, it is interesting to note that while self-assessed familiarity with food nanotechnology appears to be positively correlated with consumers' benefit/risk perceptions of food nanotechnology, it has no significant effect on consumers' WTP for the use of food nanotechnology.

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