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Consumers' Preferences for Nanotechnology in Food Packaging: A Discrete Choice Experiment

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Abstract

We examine consumers' preferences for chickens under different levels of food-borne health risk, animal welfare and pric attributes. We analyse how their preferences vary according to the risk reduction method. Our comparison is between risk reductions achieved by conventional improvements in the meat supply chain system (e.g. more stringent regulations and inspection regimes), and risk reductions achieved by food packaging nanosensors. Our comparison uses a two-treatment discrete choice experiment in which each treatment sample is only presented with one of the risk reductions: either nanotechnology or conventional methods. We also investigate heterogeneity in preferences for two consumer groups: (i) consumers who usually buy conventional raw, whole chickens, and (ii) consumers who usually buy niche, welfare-improved chickens, such as free-range and organic. Our results show evidence of heterogeneity in preferences and willingness- to-pay values of the both consumer groups. We find that consumers, on average, prefer raw, whole chicken with a lower risk of food poisoning, better animal welfare, and lower costs, regardless of the presence of nanosensors. Although consumers in general showed no strong preferences towards or resistance to nanotechnology, those who buy chickens with better animal welfare, on average, showed higher WTP for food risk reduction and animal welfare relative to conventional chicken consumers.

Keywords: *Animal welfare*; *discrete choice experiments*; *grids*; *health risks*; *nanosensors*; *nanotechnology*; *random parameter logit*; *UK*.

JEL classifications: *C33, C35, C51, D12*.

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Correction added on 5 June 2015 after original publication: the license terms have been amended.

1. Introduction

Food safety remains one of the key topics in the agri-food industry. Recent food contaminations and scandals have attracted considerable media interest and have prompted an increased concern among the public over food safety. According to the Food Standard Agency's foodborne disease strategy report (FSA, 2011), each year in the UK, around a million people suffer a foodborne illness, around 20,000 people receive hospital treatment and 500 die due to foodborne illnesses, and it has a total economic cost of around £2 billion.[2] Poultry meat is the most frequent source of foodborne illnesses, and accounts for around 20% of the illnesses (Gormley *et al.*, 2011). As a consequence, there is an increased demand for better safety practices and techniques ensuring the safety of foods in the entire supply chain. For example, high pressure treatments have been used to inactivate microbial activity to ensure food safety and retain food quality, freshness, as well as to extend the shelf life (Yang *et al.*, 2012).

There may be several benefits of novel food technologies in terms of: (i) providing more effective production techniques (e.g. increased yield), (ii) producing new tastes, textures, and flavours, and (iii) ensuring improved safety during shelf life of foods (Chaudhry *et al.*, 2008; FSA, 2012). Their acceptability and future uses, however, can obviously be affected by how they are perceived by consumers. When people have little information about the technology, the risk involved or the enhanced food safety consequent on novel technologies, they may be more suspicious of the new foods and technologies (Huotilainen and Tuorila, 2005; Siegrist, 2007). Ultimately, consumers determine acceptance of the new technologies (Moon *et al.*, 2007; Frewer *et al.*, 2011). The contentious history of genetically modified foods in the EU has shown that there can be strong reaction and opposition to new technologies.

This research investigates British consumers' preferences for raw whole chicken with different levels of food risk, animal welfare and price attributes. We investigate the effects of safety technologies on consumer preferences for raw, whole chicken. The technologies considered involve conventional improvements in the meat supply chain system (e.g. more stringent regulations and inspection regimes) and innovations in food packaging using nanotechnology. Nanotechnology was chosen as a method of providing risk reductions due to current contentious issues regarding its use in food production and packaging in the UK. 'Nanosensors' in meat packaging are capable of delivering quantifiable reductions in food poisoning risks, exhibited by a colour coded indicator to identify whether or not the food is safe to eat. The comparison of consumers' preferences and willingness-to-pay (WTP) for health risk reductions, attributable to raw whole chicken, delivered by these two methods is implemented by conducting a two-treatment discrete choice experiment. While the first treatment focuses on food poisoning risk reductions achieved by general improvements in the meat supply chain system, the second treatment focuses on risk reductions delivered by food packaging nanosensors that reveal whether or not the chicken contains unsafe pathogen levels. In the nano treatment group, the credence attributes of raw whole chicken (e.g. safety) turn into search attributes (e.g. appearance).

Due to the novelty of nanotechnology, there are limited studies on the public's view, knowledge and perception of it in food production and none have assessed the values consumers place on the risk reductions that might be achieved by the

[2] This includes NHS, lost earnings and other expenses, as well as pain and suffering.

nanotechnology. Thus, the research presented here contributes to the literature by filling this gap and sheds light on how people view this novel technology and value the benefits it might deliver using the discrete choice methodology. Additionally, this research investigates observed and unobserved sources of preference heterogeneity among consumers.

Overall the results show that, on average, consumers prefer chicken with a lower risk of food poisoning, better animal welfare and lower costs, regardless of the presence of nanosensors. The results also show the existence of heterogeneity in consumers' preferences for raw whole chickens that include nanosensors in packaging. Although consumers in general showed no strong preferences towards or resistance to nanotechnology, those who buy chickens with better animal welfare, on average, show a tendency to value food risk reduction and animal welfare more than those who usually buy conventional raw, whole chickens.

The remainder of this paper is structured as follows: section 2 reviews the literature on consumers' concerns, awareness and attitudes to nanotechnology. Section 3 explains the study design and data collection, and section 4 introduces the models employed to analyse the data. Section 5 contains the results, and the final section concludes.

2. A Novel Technology: Nanotechnology

Nanotechnology (creation and manipulation of materials at the nano (one billionth) scale) is currently receiving increased attention and is one of the emerging technologies identified by the UK Food Standards Agency (FSA) as requiring greater research on public perceptions (Lyndhurst, 2009). The potential application is expected to have a major impact on agriculture (e.g. nano-particles and nano-emulsions in pesticides), food safety e.g. nanosensors), new product development (e.g. formulation, packaging), and food processing technologies (e.g. nano-filters) (see Chaudhry *et al*., 2008; Marette *et al*., 2009; Stampfli *et al*., 2010; Bieberstein *et al*., 2013; Schnettler *et al*., 2014, for some recent applications).

Nanotechnology in food packaging is one of the potential applications that has attracted much recent attention (Stampfli *et al*., 2010; Bieberstein *et al*., 2013). Nanostructures (e.g. nanosensors) can be used in smart packages that sense the surrounding environment and allow consumers to know when contamination or a pathogen is detected (e.g. Gfeller *et al*., 2005; Yam *et al*., 2005; Augustin and Sanguansri, 2009; Schnettler *et al*., 2014).

Although nanotechnology has promising applications in many sectors, there are concerns over its use in the food industry (Marette *et al*., 2009; Stampfli *et al*., 2010; Reisch *et al*., 2011; Coles and Frewer, 2013). Currently, there is a lack of information on the health and environmental impacts of such technologies. In the UK, it has been argued that nanotechnology implementation needs more research to ascertain the human toxicological impact of residue nano-materials in foods before being used in food production and packaging (House of Lords, Science and Technology Committee, 2010). This uncertainty has raised concern amongst the public. In a recent UK Food Safety Agency report on emergent technologies, Lyndhurst (2009) indicated that people have concerns about nanotechnologies in general. More specifically, they are anxious about the technology's effectiveness, long-term side-effects, its ability to ensure safety, and they question whether the use of this technology in food systems would be beneficial to them. The same report also mentioned that people have a low level of awareness of nanotechnologies in general, both in the UK and elsewhere. However, in a comparative study, Reisch *et al.* (2011) found that consumers' awareness of nanotechnology has recently risen slightly in Europe and the US. Notwithstanding this, there have still been concerns expressed over nanotechnologies in the UK (Reisch *et al.*, 2011; Matin *et al.*, 2012; Gupta *et al.*, 2013). In particular, the public's experience with previous technologies, such as genetic modification, suggests that caution is required regarding the introduction of nanotechnology. It is therefore very important to assess views and preferences held by the public with regard to nanotechnology and nano-foods.

Acceptability of nanotechnologies is an important determinant of their successful implementation (e.g. Gupta *et al.*, 2013; Frewer *et al.*, 2014). Consumers' willingness to accept nanotechnologies, however, depends on various factors, including consumers' knowledge and understanding of the technology and its applications, and perceptions of risks and benefits associated with such technologies. For example, it is found that consumers are more likely to accept the nanotechnology in food packaging than in food processing (Siegrist *et al.*, 2008; Stampfli *et al.*, 2010; Gupta *et al.*, 2013; Schnettler *et al.*, 2014). However, when there are health benefits associated with foods produced by nanotechnologies, the acceptability appears to increase (e.g. Roosen *et al.*, 2011; Bieberstein *et al.*, 2013), but consumers may not be necessarily willing to pay more (e.g. Marette *et al.*, 2009), especially when there are potential health risks involved in the technology (Roosen *et al.*, 2011). Such consumer attitudes and reduction in their willingness-to-pay (WTP) when food safety is achieved via a technology that involves uncertainties in its health and environmental impacts, seem to be common across various studies on different food technologies, such as genetic modification (e.g. Ison and Kontoleon, 2014), food irradiation (e.g. Huang *et al.*, 2007), vacuum packaging (e.g. Chen *et al.*, 2013), and high pressure processing (e.g. Olsen *et al.*, 2011).

3. Study Design and Data

The preferences towards nanotechnology in food packaging are investigated in a specific setting where nanosensors deliver a quantifiable reduction in food poisoning risk by showing a colour change when food is unsafe to eat.[3] The value of the risk reduction delivered in this way is measured against equivalent values delivered conventionally (e.g. more stringent regulations and inspection systems). This comparison is achieved by conducting a two-treatment web-based discrete choice experiment (DCE) in which each treatment sample is only presented with the risk reductions achieved by one of the means. Although we could have used the method of risk reduction as another attribute in the DCE survey to examine consumers' preferences for these risk reduction methods, in this paper, we investigate views and preferences for nanotechnology and for conventional methods separately using two treatments. The difference between two treatments gives us consumers' views in isolation, as well as differences in their preferences.

[3]We note that the reduction in food poisoning risk depends on sellers' and consumers' willingness to take action (i.e. not to sell or consume the product) when the nanosensors indicate the product is unsafe to consume.

Table 1
Product attributes and levels

Attribute	Levels
Level of food risk (FR)	10/10,000, 20/10,000, 40/10,000, 80/10000 (baseline)
Level of animal welfare (AW)	40 (baseline), 70, 100
Price (P)	0% (baseline), 5%, 10%, 25%, 50% increase

In the treatment that focuses on nanosensors, we provided respondents with information about nanotechnology and its use in food production and packaging prior to the choice experiment (see Appendix A in the online Supporting Information). In both treatments, we use raw, whole chickens due to the fact that the highest incidence of foodborne illnesses occurring in the UK are attributed to poultry (FSA, 2011). In fact, according to Gormley *et al.* (2011, p.691) 'poultry meat is the most frequently implicated food vehicle, accounting for around 20% of all foodborne outbreaks'. Due to it being a common source of food poisoning in the UK, the FSA has focussed on this issue and has led awareness campaigns across the supply chain. One of the recent campaigns, for example, has involved recommendations for consumers not to wash raw chicken, but instead to cook it properly to kill the bacteria (FSA, 2014).

Within the DCE surveys, respondents choose between whole chickens of identical appearance, taste and texture, but which differ in terms of three attributes: level of food risk, level of animal welfare and price. Table 1 summarises the attributes and attribute levels included in the choice experiment design.

There are a number of ways to present risk changes to respondents, such as via percentage terms, absolute terms and visual presentations like grids, charts and ladders. In this paper, we chose to present food risk levels using absolute numbers with a visual aid, i.e. risk grids, as used by some other studies (e.g. Krupnick *et al.*, 2002; Adamowicz *et al.*, 2011).[4] Figure 1 shows an example of a risk grid used in the choice tasks. The grids included 10,000 cells (100 by 100), each cell representing a person from the population of 10,000 individuals. The dark shaded cells[5] represent people who have food poisoning attributable to eating unfit chicken. Currently, approximately 80 people in every 10,000 get food poisoning annually. We calculated this baseline figure by using the estimates from Adak *et al.* (2005). The levels of food poisoning risks in the survey were 80, 40, 20 and 10 per 10,000, that is, reductions of 0%, 50%, 75% and 87.5% from the baseline value. These reductions are achieved by not consuming the contaminated products. The contamination can be due to various pathogens, such as *E. coli*, Salmonella, or Campylobacter. In our surveys, we did not specify the type of pathogens associated with the contamination, but explained before respondents took the survey, how the nanosensors work and inform consumers when the chicken is unsafe to eat (see Appendix A).

[4]We investigate the effects of alternative presentations of risk changes on respondents' choices in Erdem and Rigby (2011).

[5]We acknowledge that these shaded cells could be distributed in the risk grid differently or presented with a different colour. However, as our main focus is to present changes in risk levels, we feel that the current representation satisfies this purpose. This was also confirmed by our pilot surveys.

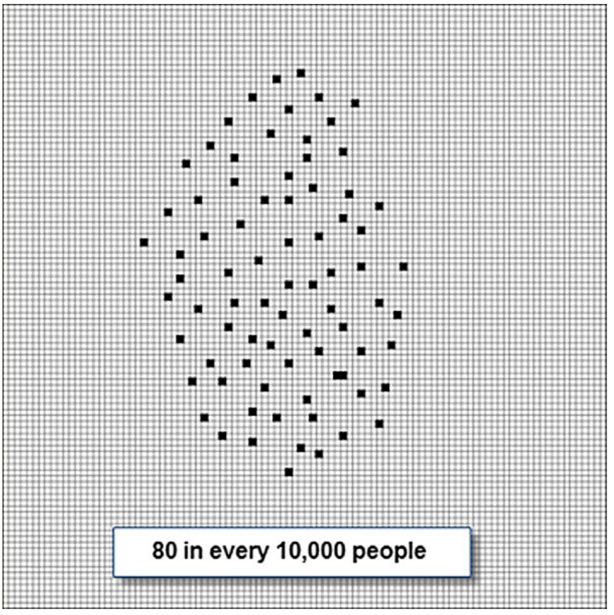

Figure 1. An example of risk grid used in the surveys

Animal welfare is included as one of the chicken attributes due to it increasingly being seen as an important ethical issue among consumers (Bennett *et al*., 2002; Institute of Grocery Distribution, 2007; Nocella *et al*., 2010). Another reason for its inclusion was that we could explore whether animal welfare is used as a signal for healthier and safer chicken by some consumers. The level of animal welfare is presented via an indicator, which is adopted from Kehlbacher *et al*. (2012) in which animal welfare is measured on a scale (0–100) that reflects the extent to which the needs and wants of the animal are met. A score of zero denotes extreme suffering, whereas a score of 100 denotes the highest level of welfare possible. This scale is based on a welfare index developed by the Welfare Quality® Project (Welfare Quality, 2009). Two important features of the index are that it reflects the views of both animal welfare scientists and the general public, and allows comparison of the welfare of animals on different farms with different animal husbandry systems. Rather than focussing on a particular welfare criterion (e.g. organic or free-range), the index is composed of a wide range of measures, such as ease of movement, absence of injuries, plumage cleanliness and thermal comfort. Details on how animal welfare is measured and how scores are calculated in Welfare Quality*reg* can be found in INRA (2011). In the survey, we consider three levels of animal welfare scores: 40 represents a 'legal minimum', a score of 70 represents a 'good life', and a score of 100 represents 'the best welfare possible', as presented in Kehlbacher *et al*. (2012). We present the levels of animal welfare and their descriptions to survey participants using a visual scale, as in Figure 2.[6]

As for the price attribute, it has five levels ranging from no change in price to a 50% increase from the respondents' typical current price, captured in an earlier survey

[6]We recognise that the welfare indicator may be interpreted differently among respondents. However, feedback from our pilot studies did not show this to be an issue.

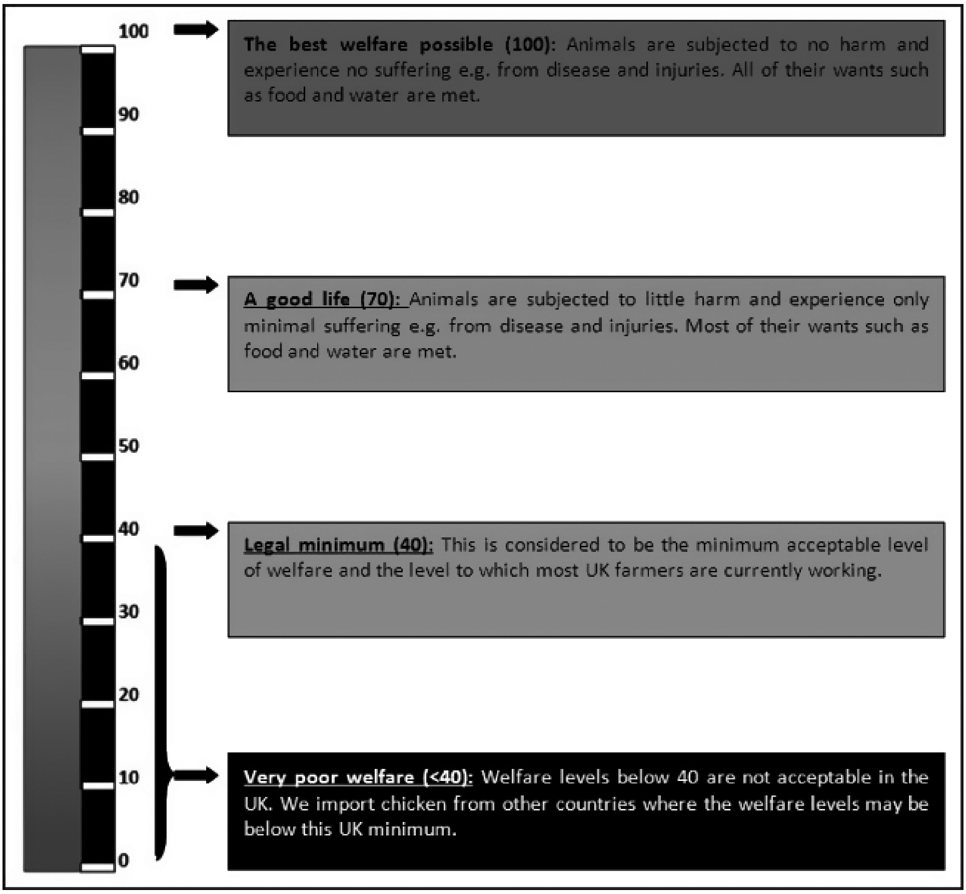

Figure 2. Animal welfare indicator used in the surveys

question (see below). The actual price was set at a respondent-specific base according to their individual responses to a question about how much they would usually pay. This is particularly important as people may pay different amounts for a whole chicken at different sizes. For example, people who usually buy medium sized organic chickens pay more than those who typically buy the same size conventional chickens. Thus, the price levels used in DCE tasks should be meaningful to them. Hence, the design was specified in percentage changes in prices but prices were presented in absolute terms within the choice sets.[7]

The surveys included eight DCE tasks and each task included three chicken options and the respondent's status quo. Providing a realistic and accurate choice set and status quo option is important. As nanosensors have not been used in the UK, the status

[7]Although it would have been possible to present price attribute as percentage changes from individuals' usual option, evidence reveals that people perceive percentages differently (e.g. Gigerenzer and Hoffrage, 1995; Visschers *et al.*, 2009). Thus, rather than using percentage changes, we preferred using monetary values of chicken alternatives calculated by taking incremental changes from individuals' reference points.

quo option had no nanosensors in its packaging. The other attributes of the status quo, however, vary with individuals' purchasing behaviour. For example, some people may typically buy free-range, organic or freedom-food chickens, while some usually buy conventional chickens. In this case, assuming the same (absolute) baseline levels for everyone does not reflect reality. Therefore, we used a pivot experimental design (also called 'customised, reference' design) to take this variation into account. In this design, the attribute-levels shown to respondents are pivoted from reference attribute levels (i.e. baselines) of each respondent, which we identified prior to DCE tasks via screening questions (see Appendix B, in the online Supporting Information).[8] After determining individuals' reference levels, the non-reference alternatives are described using deviations from their references. For example, assuming an individual usually pays £4 for a medium sized whole chicken, then the price levels for non-reference alternatives presented to this individual can take the values of £4 and £5, if price attribute levels are to vary by 0% and +25% from the reference level.

Figure 3(a) and 3(b) illustrate examples of choice tasks asked to people who buy conventional chicken and welfare-improved chickens (e.g. free-range), respectively. The conventional chicken is assumed to have the legal minimum level of animal welfare described above (a score of 40). For free range, organic and freedom-food chicken, the animal welfare is higher than the minimum level. We, therefore, used a score of 70, representing 'a good life', for the welfare-improved chickens. As illustrated in Figure 3, the choice tasks for the two treatments were the same except for the inclusion of the nanosensor information for the nanotechnology treatment.

For each DCE treatment, a sequential experimental design was created in NGENE (Rose *et al.*, 2009) using priors from pilot surveys. For the pilot surveys, a pivot design minimising D-error was generated using priors of zero for the marginal utility of all attributes. Choice models estimated from the pilot data provided new estimates of the marginal utilities. These point estimates and their standard errors were used as priors in a new Bayesian efficient design (see Ferrini and Scarpa, 2007) for the main survey to improve the accuracy of the information (Scarpa *et al.*, 2007). Each respondent was assigned randomly to a treatment.

Using a web-based survey, a total of 3,554 observations for model estimation were gathered from a sample of 449 consumers in the UK in 2010 via a survey research company, who is compliant with ESOMAR regulations.[9] The sample is equally split between the nano treatment (225 consumers) and no-nano group (224 consumers). In both treatment groups, just over half of the respondents were female (55%), 32% were in full-time employment, 29% had education until at least 18 years -old. The average age of the sample fell within the 30–45 years age band. The average annual household income was about £25,000. A comparison with 2011 UK Census data showed that the respondents in our nano and no-nano treatment groups were similar to the general UK population with respect to age, gender, income, and employment status.[10]

[8]More details on pivot-design can be found in Rose *et al.* (2009).

[9]See http://www.esomar.org for further details on the ESOMAR regulations.

[10]We also checked the raw data to discover whether there were any respondents who always clicked on the same option or provided inconsistent responses, such as unreasonable prices for raw, whole chickens. This did not seem to be a relevant concern for this dataset.

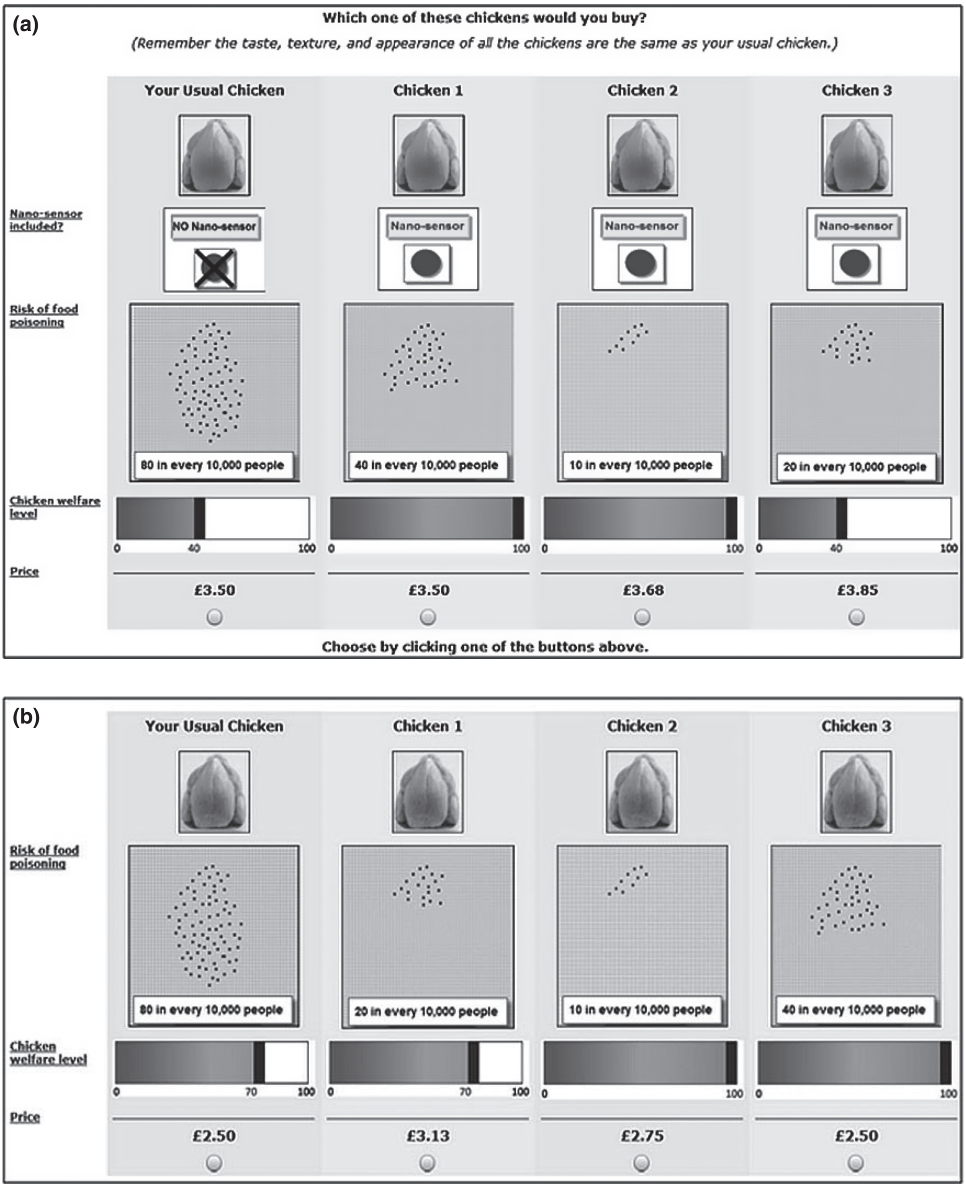

Figure 3. Sample DCE tasks. (a) DCE task when health risk reductions are delivered via nanotechnology. (b) DCE task when health risk reductions are delivered via conventional methods

4. The Models

Analysis of the DCE data is based on random utility theory (RUT), initiated by Thurstone (1927) and generalised by McFadden (1974). The utility that individual n derives from an alternative i, among J alternatives can be written as the following:

$$U_{ni} = V_{ni} + \varepsilon_{ni}, \tag{1}$$

where ε_{ni} is the stochastic (random) component, which is *iid* over alternatives, and V_{ni} is the observed component of the utility.

The multinomial logit (MNL) model has been the basic model used for analysing stated preference choice data. A shortcoming of this model is the assumption of homogeneous preferences for all respondents (DeShazo and Fermo, 2002; Louviere *et al.*, 2002; Hensher *et al.*, 1999), unless interaction terms are used to reveal some differences. Alternatively, heterogeneity in preferences can be explored using random parameter logit (RPL) models, which allow random taste variation (see Train, 2009), for an overview). In this paper, we investigate the heterogeneity using two model specifications. The first one is the standard MNL model addressing observed sources of preference heterogeneity by exploring differences in preferences for chickens due to the presence of nanosensors, as well as consumers' different purchasing behaviour via interaction terms. The MNL model with 'nano' and 'consumer type' interactions provides differences in preferences of subsample of respondents in both nano and no-nano treatment groups and between those who usually purchase conventional and welfare-improved chickens, respectively. However, it is based on the assumption that preferences within each subsample are homogenous, which may not be a realistic assumption. Therefore, by using an RPL specification, we further explore how preferences within each subsample are distributed, as well as how the moments of the distributions vary by the presence of nanosensors and consumers' purchasing behaviour.

In the MNL specification, the indirect utility, V_{ni}, can be expressed as the following:

$$\begin{aligned} V_{ni} =& (\beta_{\mathrm{SQ}} + \zeta_{\mathrm{SQ}_{\mathrm{nano}}}\delta_{\mathrm{nano}} + \zeta_{\mathrm{SQ}_{\mathrm{welf-cons}}}\delta_{\mathrm{welf-cons}}) \\ &+ (\beta_{\mathrm{FR}} + \zeta_{\mathrm{FR}_{\mathrm{nano}}}\delta_{\mathrm{nano}} + \zeta_{\mathrm{FR}_{\mathrm{welf-cons}}}\delta_{\mathrm{welf-cons}})x_{\mathrm{FR}_{ni}} \\ &+ (\beta_{\mathrm{AW}} + \zeta_{\mathrm{AW}_{\mathrm{nano}}}\delta_{\mathrm{nano}} + \zeta_{\mathrm{AW}_{\mathrm{welf-cons}}}\delta_{\mathrm{welf-cons}})x_{\mathrm{AW}_{ni}} \\ &+ (\beta_{\mathrm{P}} + \zeta_{\mathrm{P}_{\mathrm{nano}}}\delta_{\mathrm{nano}} + \zeta_{\mathrm{P}_{\mathrm{welf-cons}}}\delta_{\mathrm{welf-cons}})x_{\mathrm{P}_{ni}} \\ &+ (\beta_{\mathrm{FR*AW}} + \zeta_{\mathrm{FR*AW}_{\mathrm{nano}}}\delta_{\mathrm{nano}} + \zeta_{\mathrm{FR*AW}_{\mathrm{welf-cons}}}\delta_{\mathrm{welf-cons}})x_{\mathrm{FR*AW}_{ni}}, \end{aligned} \tag{2a}$$

where β_{SQ} is an alternative specific constant for the status quo (SQ); β_{FR}, β_{AW}, β_{P} are the parameters for food risk, animal welfare and price attributes, respectively; δ_{nano} and $\delta_{\text{welf-cons}}$ are dummy variables taking a value of 1 for respondents whose sets included nanosensors in packaging, and who usually purchase welfare-improved chickens, respectively. The parameters ζ_{nano} and $\zeta_{\text{welf-cons}}$ are interactions, or shifters, to capture the effects of nanosensors and purchasing behaviour (purchasing welfare-improved chickens or not) on marginal utilities, respectively. If $\zeta_{\mathrm{nano}} = \zeta_{\text{welf-cons}} = 0$, then neither the presence of nanosensors in packaging nor the consumers' purchasing behaviour (i.e. whether the consumer buys welfare-improved chickens) have an impact on marginal utilities and WTPs. The last interaction term on the food risk and animal welfare is added to the indirect utility to investigate whether there is any perceived relationship between these two attributes,[11] as found in the literature (e.g. Kehlbacher *et al.*, 2012; Miele *et al.*, 2013).

[11]The interaction is based on the best level of animal welfare (i.e. 100 score) and the best level of food safety (i.e. 87.5% reduction in risks). This is to see the perceived relationship between these two attributes when they are at their best possible levels. We acknowledge that it is possible to investigate a perceived link between AW and FP when different levels of risk reduction and animal welfare are achieved.

We can write the equation (2a) as the following reduced form:[12]

$$V_{ni} = \sum_{k=1}^{K} (\beta_{\mathrm{k}} + \zeta_{\mathrm{k}_{\mathrm{nano}}} \delta_{\mathrm{nano}} + \zeta_{\mathrm{k}_{\mathrm{welf-cons}}} \delta_{\mathrm{welf-cons}}) x_{\mathrm{k}_{ni}}. \tag{2b}$$

In the RPL specification, we assume that all parameters, apart from the price and the interaction terms, are random with a normal distribution.[13] The expression for the random parameters takes the following form:

$$\beta_{nk} = \mu_k + \sigma_k \upsilon_{k_n}, \tag{3a}$$

where μ_k and σ_k are, respectively, the mean and standard deviation of the random parameter for attribute k; and, υ_n is a standard normal deviate. In the case where sources of heterogeneity around the means and standard deviations are captured, we can define μ_k and σ_k as the following:

$$\begin{aligned} \mu_k &= \mu + \zeta_{k_{\mu_{\mathrm{nano}}}} \delta_{\mathrm{nano}} + \zeta_{k_{\mu_{\mathrm{welf-cons}}}} \delta_{\mathrm{welf-cons}}, \\ \sigma_k &= \sigma + \zeta_{k_{\sigma_{\mathrm{nano}}}} \delta_{\mathrm{nano}} + \zeta_{k_{\sigma_{\mathrm{welf-cons}}}} \delta_{\mathrm{welf-cons}}, \end{aligned} \tag{3b}$$

where μ and σ are the mean and standard deviation of the distributions without 'nano' for consumers who usually buy conventional raw whole chickens (i.e. 'reference' case); $\zeta_{\mu_{\mathrm{nano}}}$ and $\zeta_{\mu_{\mathrm{welf-cons}}}$ are the shifters around the means, and $\zeta_{\sigma_{\mathrm{nano}}}$ and $\zeta_{\sigma_{\mathrm{welf-cons}}}$ are the shifters around the standard deviations of the distributions of the reference case due to the presence of nanosensors (i.e. nano treatment) and consumers' purchasing behaviour.[14] The indirect utility can be rewritten as:

$$\begin{aligned} V_{ni} = \sum_{k=1}^{K} \Big[\Big(\mu + \zeta_{k_{\mu_{\mathrm{nano}}}} \delta_{\mathrm{nano}} + \zeta_{k_{\mu_{\mathrm{welf-cons}}}} \delta_{\mathrm{welf-cons}} \Big) \\ + \Big(\sigma + \zeta_{k_{\sigma_{\mathrm{nano}}}} \delta_{\mathrm{nano}} + \zeta_{k_{\sigma_{\mathrm{welf-cons}}}} \delta_{\mathrm{welf-cons}} \Big) \upsilon_{k_n} \Big] x_{\mathrm{k}_{ni}}. \end{aligned} \tag{4}$$

The conditional probability of choosing alternative i from a total of J alternatives on choice occasion t for individual n can be expressed as the following:

$$P(i_n | x_n, \beta_n) = \frac{\exp(V_{nit})}{\sum_{j=1}^{J} \exp(V_{njt})}. \tag{5}$$

The conditional probability of observing a sequence of choices, $y_n = \langle j_{n1}, j_{n2}, \ldots, j_{nT_n} \rangle$, over the T_n choice occasions for respondent n is the product of

[12]Note that for the sake of brevity we combined the alternative specific constant for the status quo in this expression. The multiplication with $x_{\mathrm{FR}_{ni}}$ does not apply for this constant, as shown in equation (2a).

[13]Holding price constant is a convenient assumption as the distribution of willingness-to-pay (WTP) takes the form of the distribution of the attribute coefficient, which then allows easy derivation, and interpretation of the results. Depending on the choice of distributions for the coefficients, a ratio of two randomly distributed terms can lead to heavily skewed, and perhaps undefined moments. For more information, see Train (2009) and Daly *et al.* (2012). We acknowledge that our decision to specify price as a fixed parameters is a limitation.

[14]We note that we also accommodate the heterogeneity in the status quo effect. When estimating a status quo alternative specific constant, since only differences in utility matter, it is immaterial whether we add a zero-mean (normally distributed) error component to the two non-status quo alternatives or allow the status quo parameter to be normally distributed.

the form in equation (5). Under the RPL, where we assume βs are individual-specific, the unconditional choice probability is the integral of this product over all values of β weighted by their density $f(\beta|\theta)$, as in equation (6):

$$\Pr(y_n|x_n,\theta) = \int \left(\prod_{t=1}^{T} \frac{\exp(V_{nit})}{\sum_{j=1}^{J} \exp(V_{njt})} \right) f(\beta|\theta) d\beta \quad (6)$$

where $f(\beta|\theta)$ is the normal density with θ parameters of the distribution (i.e. mean and standard deviation). We then maximise the log-likelihood of equation (6), $LL_\theta = \sum_{n=1}^{N} \ln[\Pr(y_n|x_n,\theta)]$, using simulated maximum likelihood estimation with 1,000 Halton draws.[15] All models are estimated in OxMetrics (Doornik, 2009).

5. Results

In order to be able to explain and compare preferences of different consumer groups within nano and no-nano treatments, we pool the data from both subsamples and use shifters for the nano treatment (denoted by 'nano') and shifters for consumers' purchasing behaviour – i.e. whether the consumer buys welfare-improved chicken or not (denoted by 'welf-cons'). Before performing analysis on the pooled data, we tested whether the difference between the scales of the Gumbel errors in two treatments, namely nano and no-nano treatments, is different from zero. It is necessary to perform such a test in order to identify and make comparisons between parameter coefficients in these treatments. As Swait and Louviere (1993) highlighted, although the scale factor cannot be identified in any particular set of empirical data, the ratio of the scale factor of one data set relative to another can be identifiable. This is simply done by normalising the variance in one treatment by setting it to $\pi^2/6$ and then estimating the variance in the other treatment relative to that in the first. We then test whether the estimated variance is statistically significantly different from $\pi^2/6$.[16] This did not reveal a significant scale difference, therefore, we identify differences in preferences in terms of utility coefficients.

5.1. *Estimation results*

We present results from the analysis of the MNL and RPL models in Table 2.[17] The results from the analysis of the MNL model show that consumers prefer raw, whole chicken with a lower risk of food poisoning, better animal welfare, and lower costs,

[15]Integral in equation (6) is approximated through simulation, by taking draws from the density function, calculating conditional probabilities for each draw, and averaging the results. This average is the simulated probability. The simulated probabilities are inserted into the log-likelihood function to give a simulated log-likelihood, which is maximised to give θ estimates (i.e. means and standard deviations).

[16]For more information on scale issues, see Swait and Louviere (1993) and Train (2009).

[17]We also estimated models addressing the observed sources of heterogeneity either due to the presence of nanosensors or due to consumers' purchasing behaviour (or consumer types) separately. Here, we present the MNL and RPL models that are simultaneously exploring observed heterogeneity due to both the presence of nanosensors and consumers' purchasing behaviour. This is motivated by the need to explain preferences of different consumer groups within different treatments. The results from these models are available from the author upon request.

Table 2
Estimation results

	MNL		RPL	
	Estimate	t-rat	Estimate	t-rat
Mean				
$\hat{\mu}_{SQ}$	0.67***	3.38	−1.06***	−3.09
$\hat{\mu}_{AW}$	0.11***	5.12	0.20***	5.00
$\hat{\mu}_{FR}$	−0.41***	−10.38	−0.69***	−8.30
$\hat{\mu}_{FR*AW}$	0.45***	3.42	0.48***	2.61
$\hat{\mu}_{P}$	−1.47***	−16.03	−2.51***	−17.44
Mean shifters				
$\hat{\zeta}_{SQ_{nano}}$	0.21	0.82	−0.57	−1.23
$\hat{\zeta}_{AW_{nano}}$	−0.01	−0.17	0.01	0.21
$\hat{\zeta}_{FR_{nano}}$	0.05	1.06	0.00	0.03
$\hat{\zeta}_{FR*AW_{nano}}$	0.04	0.26	−0.10	−0.40
$\hat{\zeta}_{P_{nano}}$	0.33***	3.11	0.19	1.10
$\hat{\zeta}_{SQ_{welf-cons}}$	0.41	1.51	1.11**	2.33
$\hat{\zeta}_{AW_{welf-cons}}$	0.18***	5.13	0.44***	5.25
$\hat{\zeta}_{FR_{welf-cons}}$	0.00	−0.01	0.04	0.32
$\hat{\zeta}_{FR*AW_{welf-cons}}$	0.15	0.77	0.15	0.56
$\hat{\zeta}_{P_{welf-cons}}$	0.65***	6.10	1.31***	7.66
Std. dev				
$\hat{\sigma}_{SQ}$			1.47***	4.15
$\hat{\sigma}_{AW}$			0.29***	7.21
$\hat{\sigma}_{FR}$			0.79***	11.43
Std. dev shifters				
$\hat{\sigma}_{\zeta_{SQ_{nano}}}$			0.55	1.03
$\hat{\sigma}_{\zeta_{AW_{nano}}}$			0.08	1.39
$\hat{\sigma}_{\zeta_{FR_{nano}}}$			0.21**	2.10
$\hat{\sigma}_{\zeta_{SQ_{welf-cons}}}$			−0.16	−0.22
$\hat{\sigma}_{\zeta_{AW_{welf-cons}}}$			0.19**	2.29
$\hat{\sigma}_{\zeta_{FR_{welf-cons}}}$			−0.16	−1.39
$LL(\hat{\beta})$	−3,893.91		−2,950.09	
$\bar{\rho}^2$	0.21		0.40	
AIC	7,817.81		5,948.18	
BIC	7,910.45		6,096.40	
N(obs.)	3,554		3,554	
N(param.)	15		24	

Note: Due to rounding, some of the coefficients appear to be zero. **Parameter is significantly different from zero at the 5% level. ***Parameter is significantly different from zero at the 1% level.

regardless of the presence of nanosensors. Consumers are also more likely to choose their usual option (SQ), rather than a different chicken alternative. The results also show that the respondents perceive a positive relationship between animal welfare and food safety, which was also observed in other studies (Kehlbacher *et al.*, 2012; Miele *et al.*, 2013).

According to the results, all else being equal, there is no significant effect of nanosensors in packaging on marginal utilities of all non-price attributes. It is not surprising that the presence of nanosensors in packaging does not change the chickens' welfare as the nanosensor is a post-slaughter technology. Having a particular focus on the food risk, the results suggest no significant differences in consumers' preferences for food risk reductions achieved via the presence of nanosensors in packaging or by more conventional methods. This would also indicate that the presence of nanosensors in packaging does not seem to have a significant effect on consumers' likelihood of purchase when the level of food risk decreases.[18] However, the significant positive 'price' shifter ($\hat{\zeta}_{P_{nano}}$) suggests that consumers are prepared to pay a premium for chickens with nanosensors. Furthermore, as seen from significant and positive parameters of welfare-improved chicken consumers shifters, all else being equal, consumer who usually buy conventional chickens value animal welfare less than those who buy welfare-improved chickens. As also expected, the price these consumers are prepared to pay for a raw whole chicken is less than those who buy a niche product.

As we move from the MNL to the RPL model, we see dramatic improvements in the model fit (around 950 log-likelihood units in the expense of nine additional parameters) and observe significant standard deviations, suggesting the existence of unobserved sources of preference heterogeneity. This is also reflected in the significance of mean shifters.

While the results from the RPL model show some similarities to the MNL results, one of the differences between them is that the coefficient on status quo is statistically significant and negative, meaning that, all else being equal, consumers, on average, are more likely to purchase chickens different than their usual chickens, regardless of the presence of nanosensors in the packaging. Turning our attention to the heterogeneity around mean and standard deviation of the taste distributions, we note that the presence of nanosensors generally does not have any significant impact on the distributions, apart from the one for the food risk. Although there is a lack of a significant effect of nanosensors around the mean of FR distribution, the standard deviation of the distribution is higher in nano treatment than in the no-nano control group. This can be interpreted as consumers having more variation in their marginal utilities when food poisoning risks are reduced via nanosensors, as opposed to more conventional methods. This behaviour may be due to a number of reasons, such as unfamiliarity with nanotechnology and a lack of knowledge about it, uncertainty surrounding its possible health and environmental impact, and a lack of trust consumers may have in food system and the regulatory process watching over it. Another reason for having a higher standard deviation may be related to the survey design, such as the task complexity, in which case the status quo option may be seen as a safe refuge for the confused respondent.

The results of the RPL model also show that, unlike consumers who usually buy conventional chickens, consumers who buy welfare-improved chickens, all else being equal, on average, show significant preferences towards their usual chicken option, regardless of the presence of nanosensors. As expected, these consumers also tend to value animal welfare more than conventional chicken consumers, as indicated by significant positive $\hat{\zeta}_{\mathrm{AW}_{\mathrm{welf-cons}}}$. Looking at the standard deviations relative to the means

[18]The negative significant FR can be interpreted as the reducing probability of purchasing when the level of food risk increases.

Table 3
Marginal WTP estimates (£/chicken)

	Nano treatment		No-nano treatment	
	Conventional chicken cons.	Welfare-improved chicken cons.	Conventional chicken cons.	Welfare-improved chicken cons.
Marginal WTP estimates obtained from the estimation of MNL (£/chicken)				
WTP_{FR}	−0.31	−0.72	−0.28	−0.49
	(−0.37, −0.26)	(−0.96, −0.47)	(−0.32, −0.24)	(−0.62, −0.37)
WTP_{AW}	0.09	0.59	0.08	0.36
	(0.05, 0.13)	(0.35, 0.83)	(0.05, 0.11)	(0.24, 0.48)
Marginal WTP estimates obtained from the estimation of RPL (£/chicken)				
Mean				
WTP_{FR}	−0.30	−0.59	−0.30	−0.52
	(−0.37, −0.24)	(−0.88, −0.30)	(−0.37, −0.24)	(−0.72, −0.32)
WTP_{AW}	0.09	0.67	0.08	0.51
	(0.05, 0.13)	(0.44, 0.90)	(0.05, 0.11)	(0.35, 0.68)
Std. dev				
WTP_{FR}	0.36	0.86	0.36	0.57
	(0.29, 0.43)	(0.48, 1.24)	(0.29, 0.43)	(0.31, 0.83)
WTP_{AW}	0.16	0.50	0.12	0.43
	(0.12, 0.20)	(0.30, 0.71)	(0.09, 0.15)	(0.28, 0.59)

Notes: Figures in parentheses are 95% confidence intervals, obtained using the delta method. Approximately 30% of the respondents in each treatment are welfare-improved chicken consumers. An average price for a small chicken is around £3.

of attribute coefficients, we find that 90% of welfare-improved chicken consumers and 73% of the conventional consumers prefer better animal welfare.[19] Having particular focus on food risk, while we see no significant differences in the means of FR distributions for both welfare conscious groups and consumers who usually buy conventional chickens, regardless of the presence of nanosensors, the spread of the FR distribution in the nano treatment is significantly greater than the one observed for the no-nano control group, regardless of the consumer type. As in the MNL case, we also observe a tendency for consumers to associate improvement in animal welfare with food safety.

Overall, these results show the need to account for observed and unobserved sources of preference heterogeneity. While our results do not show a strong evidence of ‘nano’ effect on preferences, they highlight some important differences in preferences of different consumer groups.

5.2. Willingness-to-pay estimates

Table 3 compares the marginal WTP results derived under the MNL and RPL model. As can be seen, and as already deduced from the results in Table 2, irrespective of the treatments, consumers are willing to pay extra for improvements in the levels of

[19]These percentages are found by $\left[100 * \phi\left(-\frac{\text{mean}}{\text{std. dev}}\right)\right]$, where ϕ is the cumulative standard normal distribution.

animal welfare and food risk reduction. However, there are some variations in the marginal WTPs of consumers under each specification.

The marginal WTPs from the estimation of the MNL show some variations in nano and no-nano treatment groups. While conventional chicken consumers have similar marginal WTP for animal welfare in both treatment groups, welfare-improved chicken consumers value animal welfare more in the nano treatment. In fact, they are willing to pay approximately twice as much for better animal welfare when nanosensors are present in the packaging. That said, they are generally willing to pay around 4–6 times more for better animal welfare, compared to consumers who usually buy conventional chickens. They are also willing to pay more for food risk reductions achieved by nanosensors.

Turning our attention to the marginal WTP estimates obtained from the RPL model, we observe similar results: on average, consumers are willing to pay extra for better food safety and animal welfare. However, as seen from the statistically significant standard deviations, there is heterogeneity in their WTP values for product attributes.

Having a particular focus on food risk, the comparison of the mean marginal WTP values for food risk reductions reveals that consumers who prefer welfare-improved chicken tend to be more sensitive to the food risk, and therefore, they are, on average, willing to pay more for risk reductions. In fact, all other things being equal, these consumers are, on average, willing to pay approximately twice as much as conventional chicken consumers for a unit reduction in food risks in the nano treatment group, and slightly less than twice as much in the no-nano treatment group. This may be due to, *inter alia*, genuine sensitivity to food risks, 'perceived' positive association between food risk reduction and improved animal welfare, and increased food safety awareness when consumer are exposed to such technologies. This may also be due to differing views on the use of technology in meat packaging this consumer group might have.

Unlike consumers who prefer welfare-improved chicken, conventional chicken consumers, on average, tend to show lower WTP for risk reductions, and smaller variation in WTP values, regardless of the nanosensors. We also note that the confidence intervals are generally much tighter for these consumers, which implies that marginal WTPs are more precisely estimated than for the sample as a whole or for the welfare conscious group.

The difference between the WTPs in nano and no-nano treatments represents the implicit WTP to avoid nanotechnology. While conventional chicken consumers, on average, appeared to be indifferent to nanotechnology, consumers who buy welfare-improved chickens, on average, prefer nanotechnology.

As for the WTP for animal welfare (AW), consumers who usually buy value-added chicken, on average, are willing to pay approximately seven times more for better animal welfare than conventional chicken consumers, regardless of the use of nanosensors. This is substantial. However, the use of nanosensors in packaging does not have an impact on the level of animal welfare, thus we observe no significant differences between the mean marginal WTP under the nano treatment and no-nano control groups.

6. Conclusions and Discussion

Nanotechnology is one of the novel technologies currently receiving much attention in many countries. Its use in the food industry is limited due to the lack of information on the safety of such technologies and perceptions of anticipated consumer resistance to it. Using a two-treatment discrete choice experiment (DCE), we investigated UK consumers' preferences and acceptability of nanotechnology in food packaging. The first treatment explored improvements in the food system in general, while the second included nanosensors as part of the packaging to reveal whether or not the chicken contains unsafe pathogen levels by showing a change in colour. In addition to investigating differences in preferences between the nano treatment group and no-nano control group, we investigated how preferences show variations across the sample, especially for two consumer groups: consumers who usually buy conventional chickens, and consumers who usually buy welfare-improved chickens, such as free-range or organic. Our modelling approach addressed heterogeneity in preferences of these consumer groups in two ways: (i) using a MNL model with shifters (i.e. interactions) on the taste parameters, and (ii) using RPL models with shifters on the means and standard deviations of taste parameters.

Overall, the results from the estimation of all models are as expected. They show that, on average, consumers prefer chicken with a lower risk of food poisoning, better animal welfare, and lower costs, regardless of the presence of nanosensors. The results also show evidence of heterogeneity in consumers' preferences for raw, whole chickens. While our MNL model captures observed sources of heterogeneity the RPL model which concurrently addresses observed and unobserved heterogeneity, provides a better model fit and richer insight into consumers' preferences.

The results also show that although consumers in general display no strong attitudes towards or resistance to nanotechnology, those who buy chickens with better animal welfare, on average, show higher WTP for food risk reduction and animal welfare compared to conventional chicken consumers. In fact, the standard deviations of WTP distributions for food risk reductions are higher in the nano treatment group in particular than the no-nano treatment group (compared to differences in means of the distributions). Such behaviour may be due to various reasons, including the level of knowledge about the novel technology, confusions due to the survey design or context itself, lack of trust in institutions regulating the technology, perceived benefits and risks of nanosensors, and even previous experiences with other technologies, such as genetic modification. Another reason might be the limited sample size of the study.

Although some of our findings show a lack of a significant effect of nanosensors on choices consumers made, from the analysis of debriefing questions, it was found that more than half of the consumers (51%) indicated that the use of nanosensors in the packaging of chicken 'seems like a good idea'. The remaining 13% indicated that it 'does not bother them', 20% were 'a bit concerned but not greatly', 10% were 'concerned for themselves and their families', and 6% were 'more than concerned.' Among those who thought that the use of nanosensors seems like a good idea, only 5% opted-in to the status quo alternative and 95% chose chicken alternatives with nanosensors.

These results have important implications for the food industry and the regulators about the use of nanotechnology in food packaging (and possibly for production as well). The results, on average, do not provide strong evidence of positive preferences towards nano-technology or especially strong resistance to this technology, except amongst a minority group of consumers. The resistance to the technology amongst a minority group may be due to various reasons, including genuine disinterest, confusions respondents may have (and thus they may be simplifying their decision by being indifferent between nano and no-nano choices), or lack of knowledge regarding the nanotechnology and its health, environmental, and economic consequences. Thus, it is important for policy-makers to provide consumers with the best available information regarding the technology, any issues and uncertainties about the technology, and the future plans about its use in the food industry.

However, they showed heterogeneity in preferences and WTP values of different consumer groups. For example, while consumers who usually buy conventional chickens prefer chicken alternatives different than their usual option, those who buy welfare-improved chickens are more likely to choose their usual option. Failing to account for these variations may lead to unrealistic predictions of WTP, demand and market shares for value-added chicken products, as also reported by Campbell and Doherty (2013).

Our results suggest further research in the field. A key issue is whether preferences for nanotechnology differ with how the technology is used. For example, it would be interesting to see whether preferences change if the technology is used in food production which may cause nano-particle residues in foods, rather than in packaging, and how preferences vary with product type (e.g. meat vs. milk) and proposed use of the products (e.g. improved safety or enhanced taste). There is a lack of research on these issues, and the existing research has varying results. For example, Siegrist *et al*. (2008) found that the use of nano technologies in food packaging was viewed more favourably than their use in food production by Swedish consumers. Some studies, on the other hand, found that people are willing to buy foods produced using nano technologies (e.g. Cook and Fairweather, 2006). Although our results do not suggest differences in perceptions due to individuals' characteristics which may be related to our relatively small sample size, this is an interesting area for future research. Whilst the sample was representative of the general population with respect to gender, age, and economic characteristics, we acknowledge that our relatively small sample may prohibit the generalisation of our findings to the population. Nevertheless, our findings do give an indication of differences in consumers' preferences for nanotechnology, and this provides motivation for further work in this area.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix A. Information provided to the survey participants prior to the DCE tasks.

Appendix B. Screening questions on type, size and price of the chicken asked prior to the DCE tasks.

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