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Measuring changes in pork demand, welfare effects, and the role of information sources in the event of an African swine fever outbreak in the United States

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ABSTRACT

African swine fever (ASF) has never been detected in the U.S., but the current global outbreak threatens to change that. Although ASF poses no known risk to human health and is not a food safety concern, little is known about the response in U.S. consumer demand in case of an outbreak. We use an online survey experiment, following the one-and-one-half-bound dichotomous choice contingent valuation approach to estimate changes in consumers' willingness to pay for pork in case of an ASF outbreak. Using these estimates, we find that demand for unprocessed pork (processed pork) products in the U.S. is predicted to shift downward by approximately 32 % (30 %) in the case of an ASF outbreak. Overall, the total annual welfare loss is predicted to be $55.46 billion in the pork market. We find that those consumers who are unaware about ASF, perceive it to be a risk to human health, and eat pork infrequently have a relatively larger reduction in willingness to pay for pork following an outbreak. Further, about 23 % of the survey respondents would stop purchasing pork products altogether following an ASF outbreak. Results also indicate that government institutions are most trusted when it comes to sharing news about food safety, strongly suggesting the importance of public institutions in generating awareness prior to and during an ASF outbreak.

1. Introduction

African swine fever (ASF) is a highly contagious viral disease in pigs with close to 100 percent fatality (USDA APHIS, n.d.). It has been spreading across continents, with a growing number of outbreaks being reported in China, Southeast Asia, and countries in the European Union, raising the concern of it becoming a global pandemic in the domestic and feral swine population (WOAH, n.d.). High mortality rates, transmission, and lack of vaccines make ASF a serious threat to global well-being (Khanna, 2022), considering that pork is the largest consumed meat in the world after poultry (Shahbandeh, 2022a). These outbreaks, along with the report of ASF in domestic swine farms in both the Dominican Republic in July 2021 (Gonzales et al., 2021) and Haiti in September 2021 (USDA APHIS, 2021) have heightened the risk that the disease could spread to otherwise disease-free countries in the world, including the United States (U.S.).

The U.S. is the largest pork exporting country by volume and value globally, exporting close to a third of pork and pork products produced in the country (Shahbandeh, 2022b). As ASF is listed as 'notifiable' by the World Organisation for Animal Health (OIE), it is expected that exports of all pork products from the country will decline drastically and almost immediately in the event of an ASF outbreak, severely affecting producers (Berthe, 2020; Carriquiry et al., 2020; Costard et al., 2009; Halasa et al., 2016). Excess supply in the domestic market in the short run, resulting from a ban on exports, would push down domestic prices in order to clear the market for pork. Such an outcome would be in sharp contrast to the larger outbreaks in China and other Southeast Asian countries where the outbreak led to a shortage in the domestic pork supply, sharp increases in the price of pork, and increases in the price and demand for substitute commodities (Mason-D'Croz et al., 2020; You et al., 2021).

Despite being fatal for the swine population, ASF is non-zoonotic, poses no known threat to human health, and is not a food safety concern (USDA APHIS, n.d.). In addition to the loss of the export market and death of infected hogs, losses in the U.S. pork industry would be amplified if there is a simultaneous decline in domestic demand for pork.

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There is limited research on consumer awareness of ASF in the U.S. and the extent to which an outbreak might affect demand. Any downward (or inward) shift in demand resulting from consumers abstaining from consuming pork will impact welfare outcomes for the pork industry.

In this study, we examine U.S. pork consumers' perception of ASF vis-à-vis concerns of food safety, purchase decisions of pork products in the case of an outbreak of ASF, and the role played by different sources of information in informing purchase decisions. We then consider the welfare implications associated with a downward shift in demand resulting from the outbreak. More specifically, our study addresses three related research questions. First, to what extent does demand for pork shift downward following an ASF outbreak? Second, in the event of an ASF outbreak, is demand for pork affected differently by different news sources that inform consumers about ASF? Third, what are the welfare implications for pork consumers and producers following an outbreak of ASF?

We conduct an online survey experiment to examine perceptions of U.S. pork consumers towards food safety, frequency of consumption of pork products, and prior knowledge of ASF. We use the survey-based one-and-one-half-bound dichotomous choice contingent valuation approach, a stated preference methodology, to estimate changes in the consumers' mean willingness to pay in case of an outbreak of ASF in the U.S., separately for unprocessed and processed pork categories. By randomly exposing the respondents to information about ASF from different news sources, we examine its impact on purchase decisions following an announcement of the outbreak. Finally, we discuss the welfare implications resulting from changes in consumer demand for the different pork products.

We find that only about a fourth of the respondents are aware of ASF and believe that consuming pork following an outbreak is safe for human health. About 23 % of all respondents were unwilling to consume pork in the event of an ASF outbreak, irrespective of the discount offered. We also find that consumers who receive information about ASF from a government institution, as opposed to the news media or producers, are less likely to stop consumption of pork in case of an ASF outbreak. Results from the contingent valuation model show that consumers who are unaware about ASF, perceive it to be a risk to human health, and are infrequent pork consumers, have a relatively larger reduction in willingness to pay for pork following an ASF outbreak. When we account for the reported frequency of consumption of pork and consumers who are unwilling to purchase pork at any price, the resulting downward shift in demand is approximately 32 % (30 %) for unprocessed pork (processed pork). This results in a welfare loss of $24.11 billion for pork consumers and $35.35 billion for the producers in the pork market.

The findings from this study build on the work by Lee et al. (2023) and provide further insights into changes in preferences of U.S. pork consumers following an outbreak of ASF, a disease that to date has never been found in the U.S. Additionally, understanding if demand outcomes differ after being exposed to information about ASF from different news sources will be critical in approaching awareness strategies for an animal disease that is not a threat to food safety. Consumer awareness about ASF in the U.S. is limited, and proper communication prior to and during an outbreak could be critical in minimizing both food safety concerns in consumers and economic losses to the pork sector.

2. Background and review of literature

China, the world's largest producer, importer, and consumer of pork, suffered a devastating outbreak of ASF in 2018. Unofficial estimates suggest that about 150–225 million pigs either died or were culled due to the outbreak, representing about 25 % of the global pig population (Khanna, 2022; Mason-D'Croz et al., 2020; You et al., 2021). The U.S. on the other hand is the largest pork exporting country by volume as well as value globally (Shahbandeh, 2022b). In 2019, approximately 27.6 billion pounds of pork were produced in the US, representing about 11 % of the world's total pork production (Shahbandeh, 2022c). In the same year, total domestic consumption was estimated to be about 17.2 billion pounds (Shahbandeh, 2022d), with a per capita consumption of 52.4 lb (Shahbandeh, 2023). ASF is foreign to the U.S. and has never been reported in the country to date.

Carriquiry et al. (2020) assess the impact of an outbreak of ASF on U.S. agriculture, anticipating definite downsizing in production and losses in employment in the industry, and almost complete loss of the export market for pork. Their study focuses on industry losses and estimates that the domestic price of pork declines by 40–50 % to clear the market which now has excess supply of pork. For the analysis, they assume that consumer preferences remain unchanged and changes in equilibrium consumption are represented by movements along the demand curve. They estimate a loss of about $50 billion over a period of 10 years for the entire pork industry. An outbreak in the U.S. can therefore be devastating for the pork industry, and further impact the global pork market.

The Centers for Disease Control and Prevention estimates that pork consumption results in 525,000 illnesses, 2,900 hospitalizations, and 82 deaths every year. Food safety concerns, food recalls, and outbreak of diseases directly affect consumer demand, and there is a large body of literature that has extensively studied this relationship (e.g., Marsh et al., 2004; Piggott and Marsh, 2004; Yim and Katare, 2023). While ASF is highly contagious and fatal for the swine population, there is no evidence that it is a food safety concern (USDA APHIS, n.d.).

The incidence of food-borne illnesses continues to increase in the U.S. (Tack et al., 2020). Studies have shown that the psychological perception of risk rather than the factual risk itself is likely to affect consumer behavior (Ferrer and Klein, 2015; Liao et al., 2020; Taylor, 1974). Animal diseases have been shown to be an important factor affecting meat demand, both in the US and globally (Wang and de Beville, 2017). Research has also shown that people tend to respond in a uniform manner to different types of uncertainty concerning food safety, leading them to often overestimate risk when the actual risk may be low (Miles and Frewer, 2003; Miles et al., 2004). Lee et al. (2023) finds that 46 % of pork consumers would not purchase pork if there was an ASF outbreak in the U.S. despite it not being a food safety concern. Prior research has also found that a lack of knowledge about food quality and safety, and trust in the food supply chain impact consumers' intent to purchase food products (Franc-Dąbrowska et al., 2021; Robinson et al., 2020).

Media tools can play a major role in educating consumers about food safety and lead to behavioral changes that affect consumption decisions (Bolek, 2020). Attavanich, McCarl, and Bessler (2011) examined the market impact of media coverage of swine flu on the pork industry and estimated a sharp immediate decline in pork consumption in the US even after the WHO announced that pork was safe to eat. On the other hand, Mazzocchi et al. (2008) studied behavioral determinants of chicken consumption under the risk of salmonella in five European countries and found that their results differ significantly across the five countries. They hypothesized that cultural differences, social networks, media communications, and trust in institutions across the countries play important roles in determining consumption.

Our research takes a similar approach to Lee et al. (2023) to estimate changes in the willingness to pay for pork during an ASF outbreak in the U.S. Lee et al. (2023) use survey data from 2020 and contingent valuation methods to analyze whether consumers' perceptions of ASF and how the news about ASF is framed affects their purchase decisions for pork if an ASF outbreak occurs in the U.S. The willingness to pay estimates they obtain suggest that prior knowledge of the disease influences purchase decisions, and the nature of information framing (i.e., the connotation associated with the headline) has a greater effect on those who are less informed. Building on this research and prior studies on food safety issues and consumer behavior, we contribute to the literature by using the willingness to pay estimates to determine changes in pork demand in the domestic market and the resulting welfare outcomes. We obtain these results for disaggregated pork categories: unprocessed and

processed pork, thereby exploiting the variation between the two markets. Additionally, we examine whether informing consumers about ASF using different news sources is associated with their purchase decisions in the event of an ASF outbreak.

3. Analytical framework

We use an economic model of domestic and global demand and supply for pork produced in the U.S. to present different scenarios of an ASF outbreak in the U.S. We draw on the model presented by Paarlberg et al. (2003) that measures welfare impacts from an outbreak of FMD in the U.S. We begin with modeling the demand and supply of pork as a single commodity. Fig. 1(a) illustrates the domestic demand (D_0) and supply (S_0) of pork prior to an ASF outbreak in the U.S. Fig. 1(b) illustrates the demand and supply for pork produced in the U.S. in the global market, represented by D_x and S_x respectively, which determine the domestic price along with D_0 and S_0. Consumers in the U.S. purchase Q_D quantity of pork at price P_0, while a total of Q_T pork is produced.

We work with the scenario discussed by Carriquiry et al. (2020) who model the economic impacts of an outbreak of ASF in the U.S. where they consider a closure of international markets to pork produced in the U.S. An immediate impact of the ban on U.S. pork exports is that this quantity will now be available for sale in the domestic market, before producers and packing plants adjust to the change, leading to a sudden increase in the domestic supply of pork. Fig. 1(c) illustrates this change in domestic supply of pork as marked by an outward shift of the supply curve from S_0 to S_1. For the domestic market to clear, the price will fall to P_1. As a short-run outcome, we assume that the entire quantity of pork for the export market is now available in the domestic market, making Q_T the total pork available in the U.S. immediately after the outbreak occurs.

While Carriquiry et al. (2020) assume an unchanged demand curve, Lee et al. (2023) finds that 46 % of pork consumers may avoid consuming pork during an outbreak. The extent of a downward (or inward) shift in demand is not clearly known and some prior literature has dealt with this by making assumptions. For example, in analyzing the

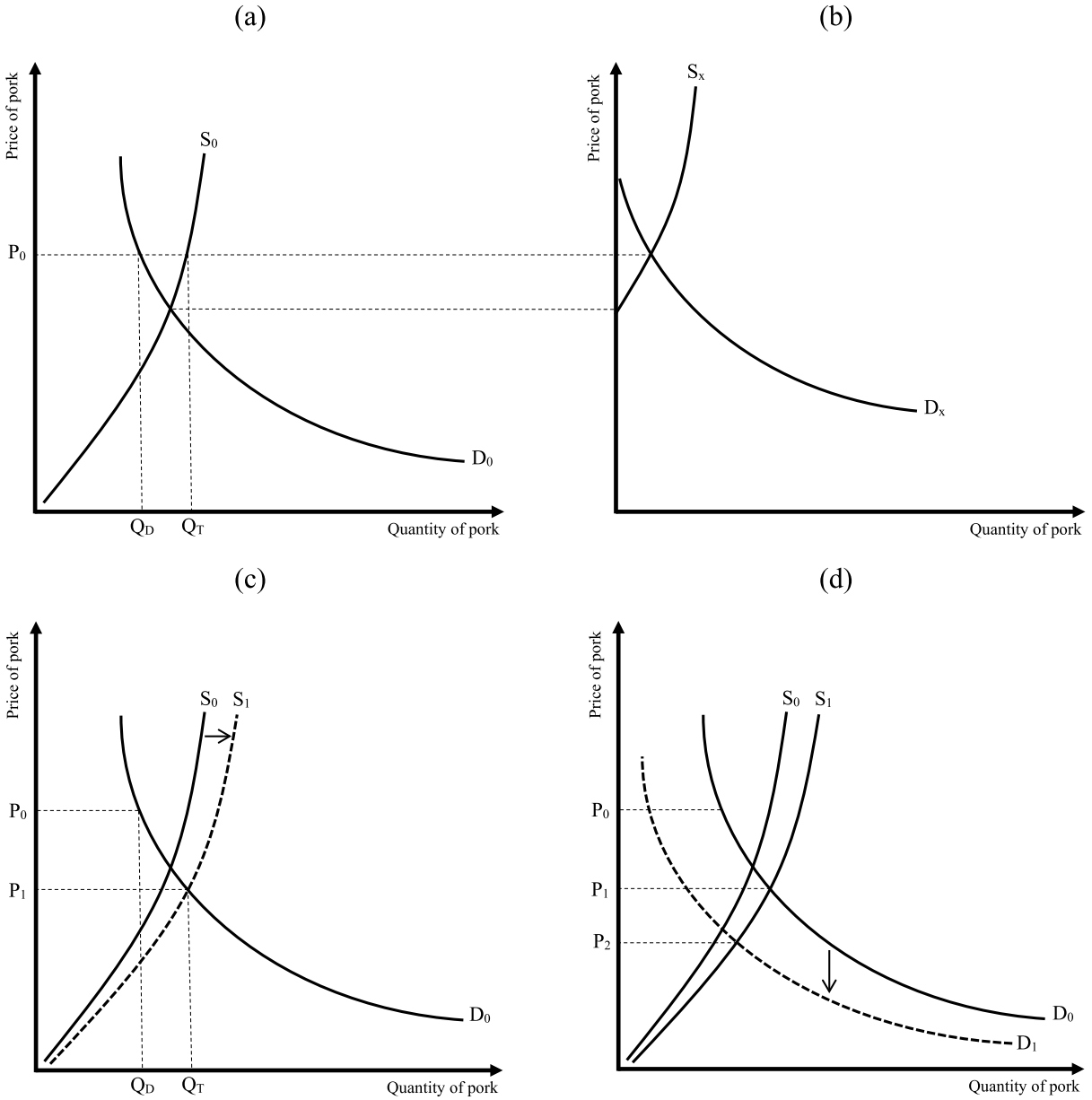

Fig. 1. Modeling the economic effects of ASF outbreak in the U.S. pork market.

potential outbreak of classical swine fever in the U.S., Paarlberg et al. (2009) assumes a fall in demand for pork by just 1 %, much lower than what the findings of Lee et al. (2023) suggest. Fig. 1(d) illustrates a downward shift in demand, from D_0 to D_1, representing a reduction in the willingness to pay for pork during an ASF outbreak, further pushing down the equilibrium price to P_2. We use this framework to estimate the reduction in demand resulting from the ASF outbreak and the associated welfare implication.

4. Survey design

We conduct a survey experiment to examine perceptions of U.S. pork consumers towards food safety, changes in their consumption behavior of pork after a hypothetical outbreak of ASF in the country, and whether different sources of information affect how consumers respond. We use a stated preference methodology to elicit responses from consumers for a hypothetical situation, which can only be done in a controlled environment. This allows us to use different sources of information as our treatment to inform consumers about the outbreak, something we cannot otherwise control in the respondents' real lives.

4.1. Survey and data collection

We developed an online survey to collect responses from pork consumers in the U.S. We programmed our survey on Qualtrics and used their panel of consumers to distribute the survey. We conducted a pretest of the survey by collecting 50 responses through Qualtrics, following which we conducted the survey from January 25, 2023, to January 31, 2023. The survey included a screening question to identify pork consumers. The incidence rate of the survey was 80.23 %, i.e., close to 20 % of the participants who initiated the survey were screened out because they did not consume pork. We collected 1,519 complete responses and this sample was balanced for gender, age, race, and region, closely following the U.S. Census of 2020. The survey is presented in the Appendix.

Responses to the survey included frequency of consumption for both unprocessed pork products (e.g., chops, loin, and ribs) and processed pork products (e.g., bacon, ham, and sausages). Disaggregating 'pork' into the two broad categories allowed us to consider the difference in own-price elasticities between the two categories and therefore evaluate changes in demand with more precision. The respondents were asked about their tradeoffs between food cost and food safety on a scale of 1–3, where 1 represented greater importance for food prices, and 3 represented a greater importance to food safety. Responses were also recorded for the occurrence of any food-borne illnesses within the last two years of taking the survey.

Next, to understand changes in pork consumption behavior during an outbreak of ASF, respondents were presented with a news article related to ASF. To investigate whether being informed about ASF from different news sources had any effect on consumers' pork consumption behavior after being told about the ASF outbreak, the respondents were randomly assigned the news from one of three sources. The three sources were: (i) U.S. Department of Agriculture's Animal and Plant Health inspection Service (USDA APHIS), (ii) National Pork Producers Council (NPCC), and (iii) National Public Radio (NPR), representing the government, pork producer, and media respectively. One news source was randomly presented to each survey participant.

The news announcements, that were between 100 and 125 words, contained similar information, each telling the respondents about the disease, its fatality in pigs, lack of any evidence of threat to food safety, and that it had not been reported in the U.S. to date. The information used in these announcements were exact words taken from the respective sources to resemble the language the respondent could expect to see from that source. Each news announcement cited the source and contained a link to the respective website for the respondents to verify and read the complete article if they wished to do so.

Following the news announcement, respondents were informed about a hypothetical outbreak of ASF in the U.S. The announcement was as follows:

Consider the following **hypothetical situation**:

Suppose there is a widespread outbreak of African Swine Fever (ASF) in the United States. Hog farms where the outbreak occurs report the death of their pigs and confirm the outbreak. The pork supply chain is likely to include meat from hogs that were infected with the virus.

The respondents were then asked about their willingness to pay for the two categories of pork products during the period of the outbreak of ASF. They are also asked whether they would substitute away from consuming pork, and if so, then what products would they purchase more of. We also obtained responses of their understanding of personal health risk associated with ASF and whether they had any knowledge of ASF prior to the survey.

Next, the respondents were presented with different sources of news from where they might receive information about food safety and diseases. The news sources included: television and radio news, social media, print media, Centers for Disease Control and Prevention, meat producers, academic sources, and word of mouth. For each source, they were asked about their perception of trustworthiness using a five-point Likert Scale. The survey concluded with questions on socio-demographic characteristics including gender, age, education, race, household income, number of household members, and whether there were children and/or older adults in the household.

4.2. The contingent valuation method

We utilize the one-and-one-half-bound (OOHB) dichotomous choice contingent valuation (CV) approach to analyze the survey responses and estimate the consumers' WTP for unprocessed and processed pork products. The OOHB CV model was proposed by Cooper et al. (2002) as a method with potentially lower response bias than the double-bounded models and more efficient estimates than the single-bound models. Contingent valuation methods are utility-based, stated preference models that have been extensively used to study consumer preferences for different food attributes and technologies. These include assessment of WTP for genetically modified foods (e.g., Delmond et al., 2018; McCluskey et al., 2003), issues related to animal welfare (e.g., Bennett and Blaney, 2003; Tonsor and Wolf, 2011), and food safety (Buzby, Skees, and Ready, 2019; Neill and Holcomb, 2019).

In this study, we take an approach that is similar to the one used in Delmond et al. (2018) which employed a modified OOHB model to estimate consumers' WTP for genetically modified bread in Russia. After the respondents were presented with the news announcement related to ASF and informed about a hypothetical outbreak in the U.S., they were asked whether they would be willing to purchase pork at the same price as before the outbreak. If they answered "yes", then they did not receive a follow-up question on pricing. If they answered "no", they received a follow-up question that asked whether they were willing to buy the same pork product at a discounted price. We used three discount levels: 25 %, 50 %, and 75 %. The respondents were presented with a discount that was chosen randomly and each discount was presented to one-third of the survey respondents. This set of questions was presented twice, once to elicit responses for unprocessed pork and once for processed pork. We disaggregated pork into two categories and estimate changes in demand separately for both as prior research has shown the two categories to have different own-price elasticity estimates (Tonsor and Lusk, 2021).

Despite being informed that ASF is not a food safety issue, we expect consumers to regard it as a credence attribute that reflects negatively on the quality of pork. Due to such an association, we do not expect consumers to be willing to pay a higher price for pork in the case of an outbreak of ASF. This justifies our choice of using the OOHB dichotomous choice method instead of a double-bound method. As a result, we did not ask a follow-up question to determine a price premium when the respondent answered "yes" to whether they were willing to purchase

pork at the same price as prior to the outbreak. Additionally, since we did not provide any initial retail price of pork to the respondents and instead asked whether they were willing to purchase pork "at the same price as before the ASF outbreak", we avoid having a starting point bias in the survey (Veronesi, Alberini, and Cooper, 2011).

Following the setup in Delmond et al. (2018), let$B_i^1 = 1$ represent the initial bid offered to individual i (i.e., "the same price as prior to the ASF outbreak"). Since we do not specify any prices, the initial bid is normalized to 1 and the follow-up discounted prices are with respect to this normalized price of pork. Let $B_i^2 = \{0.75, 0.5, 0.25\}$ represent the follow-up prices that are equivalent to receiving a discount of 25 %, 50 %, or 75 % respectively, conditional on the respondent answering "no" to the initial bid. Let C_i represent individual i's true willingness to pay, a value that is unobserved by the researcher. This setup of the modified OOHB model is illustrated in Fig. 2.

The responses to these close-ended CV questions therefore produce three possible discrete outcomes. First, the respondent is willing to purchase the pork at the initial price, and is not offered a discounted price (i.e., "yes"). Second, the respondent is unwilling to purchase pork at the initial price but is willing to purchase at the discounted price (i.e., "no-yes"). Third, the respondent is not willing to purchase pork at the initial price and is neither willing to purchase at the discounted price (i.e., "no-no"). According to the random utility framework, C_i is a random variable and its cumulative distribution function can be specified as $G(C_i;\theta)$, where θ represents the parameters of the distribution. Thus, under the OOHB approach, we can write the response probabilities π_i^y, π_i^{ny}, and π_i^{nn} for "yes", "no-yes", and "no-no" respectively as:

$$\pi_i^y(B_i^1) = \Pr(B_i^1 \le C_i) = 1 - G(B_i^1;\theta) \tag{1}$$

$$\pi_i^{ny}(B_i^1, B_i^2) = \Pr(B_i^1 \ge C_i \ge B_i^2) = G(B_i^1;\theta) - G(B_i^2;\theta) \tag{2}$$

$$\pi_i^{nn}(B_i^1, B_i^2) = \Pr(B_i^1 > C_i \cap B_i^2 > C_i) = G(B_i^2;\theta) \tag{3}$$

Then the corresponding log-likelihood function can be expressed as:

$$lnL^{OOHB}(\theta) = \sum_{i=1}^{N} \{d_i^y ln\, \pi_i^y(B_i^1) + d_i^{ny} ln\, \pi_i^{ny}(B_i^1, B_i^2) + d_i^{nn} ln\, \pi_i^{nn}(B_i^1, B_i^2) \tag{4}$$

where d_i^y, d_i^{ny}, and d_i^{nn} are dummy variables equal to 1 when the responses are "yes", "no-yes", and "no-no" respectively, and 0 otherwise. The model assumes a logistic cumulative distribution function for $G(C_i;\theta)$, and given the bids, this is specified as:

$$G(B) = \left[1 + e^{\alpha - \rho B}\right]^{-1} \tag{5}$$

where $\theta = \{\alpha, \rho\}$ are the parameters of the logistic function and B represents the bids. The maximum likelihood estimation method is used to obtain consistent and asymptotically efficient estimates, $\widehat{\alpha}$ and $\widehat{\rho}$, as functions of the bids. Using these estimates, we can obtain the mean and median relative WTP for pork, that are both given by $-\alpha/\rho$, in a model without any additional covariates. To estimate the relative WTP in a model with additional covariates, X, the standard logistic cumulative distribution function with mean zero and variance $\sigma^2/3$ is used, i.e., $G(B;X) = \left[1 + e^{\alpha - \rho B + \beta X}\right]^{-1}$. The mean relative WTP is now given by $(-1/\widehat{\rho})(\widehat{\alpha} + \widehat{\beta}\overline{X})$.

However, this WTP formulation is not constrained to be a non-negative random variable and the estimated area below the fitted function lies between negative and positive infinity. This creates a possibility for the estimated mean WTP to be negative, which in our case would imply a discount that exceeds 100 %. Hanemann (1989) discusses that the choice of employing CV models with the possibility of negative WTP values must depend on whether they are meaningful in the study context and provides a formulation to estimate the mean WTP that is constrained to be non-negative and bound at a maximum positive bid amount. The mean relative WTP, constrained to be between zero and the maximum bid B^{max} is given by:

$$E[WTP] = (-1/\widehat{\rho})\, ln\left(\frac{1 + e^{\widehat{\alpha}}}{1 + e^{\widehat{\alpha} - \widehat{\rho} B^{max}}}\right) \tag{6}$$

We estimate and report the WTP estimates obtained using equation (6) since we are interested in obtaining a non-negative WTP for purchasing pork (i.e., a discount that does not exceed 100 %) and relative to the original bid of unity that we start with. We interpret the relative WTP as the discount that the mean consumer must receive to be willing to consume pork during an outbreak of ASF. For example, an estimate of 0.65 would mean that the mean consumer is willing to purchase pork after being offered a discount of 35 % (i.e., 1 minus 0.65) during the ASF outbreak. Further, we estimate the influence of different information treatments on the choice responses, as well as the associations with the different covariates of interest in the model.

In addition to the response outcomes obtained to set up the OOHB model, the respondents who chose "no" for the first bid were also asked whether they would prefer not to purchase pork at any price. Spike models have been used in the literature to modify the log likelihood function with a spike at zero to incorporate this outcome (e.g., Lee et al., 2023). However, given the manner in which our model is set up, we do not use the spike model since we observe a spike in the data at two points; one for the set of respondent unwilling to buy at any price (i.e., equivalent to the response outcome "no-no" at a discount of 100 %), and second for the respondents who are willing to purchase at the price prior to the outbreak (i.e., equivalent to the response outcome "yes" or receiving a 0 % discount).

In estimating the mean WTP for the two categories of pork using the OOHB model described above, the response outcome "no-no" includes the respondents who are unwilling to purchase pork at any price. This is likely to bias the WTP estimates by underestimating the discount for the mean respondent. We account for this bias in estimating the resulting downward shift in demand for pork by separately weighting the respondents who are unwilling to consume pork at any price during the ASF outbreak, as discussed in the next subsection. Additionally, we analyze the characteristics of these respondents separately and determine whether the decision to stop purchasing pork is affected by the source of information describing ASF.

4.3. Estimating shift in demand

Consumers who are unwilling to purchase pork at any price represent a true zero WTP, i.e., they would choose "no-no" even when offered a

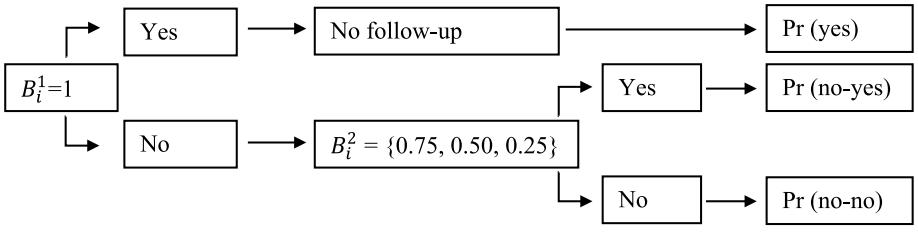

Fig. 2. Method of presenting bids and the possible response probabilities in the one-and-one-half-bound dichotomous choice contingent valuation model.

discount of 100 %, considering the non-negative WTP formulation in equation (6). When we estimate the mean relative WTP for the whole sample, it gives us the most conservative estimate of the change in WTP given that it ignores the fact that some individuals in the sample have a zero WTP. To account for this additional information, we obtain a modified estimate for the mean relative WTP in two steps. First, we estimate the WTP as a discount from the original price using equation (6) for the sub-sample of respondents that excludes those who have a zero WTP for pork following the ASF outbreak. Next, we assign a discount of 100 % (equivalent to a WTP of zero) to the respondents who indicated that they were unwilling to purchase pork at any price following the ASF outbreak. Finally, we obtain the weighted average WTP for the complete sample using these two estimates which now accounts explicitly for the case of zero WTP.

Furthermore, respondents who consume pork more frequently have a greater potential to influence changes in market demand, making the mean relative WTP for the pork market sensitive to frequency of consumption. Thus, to estimate changes in market demand for pork following an ASF outbreak, we use the survey responses of frequency of consumption to calculate weighted measures of changes in WTP. We aggregate the survey responses 'at least once a day' and 'at least once a week' to represent a 'high' frequency of consumption. Similarly, we aggregate the responses 'about once a month' and 'less than once a month' to represent a 'low' frequency of consumption. We estimate the mean relative WTP separately for the sub-samples of 'high' and 'low' consumption frequency respondents to obtain WTP_{high} and WTP_{low} respectively.

To obtain an aggregate weighted estimate for mean WTP, we generate weights for WTP_{high} and WTP_{low}. We create a numeric scale for the four categories of frequency of consumption by assigning each with a number that approximately represents 'times consumed in a month (four weeks)'. Accordingly, the weights assigned for 'less than once a month' is '0.5', 'about once a month' is '1', 'at least once a week' is '4', and 'at least once a day' is '28'. These weights are informed estimates and can be varied to test the sensitivity of the WTP estimates.

Using the relative proportions of consumption within 'high' and 'low' frequencies (see Table 2), and the numeric scale for the four responses of frequency, we obtain weights represented by $freq_i$ where $i = \{unprocessed, processed\}$. $freq_{unprocessed}$ is 6.4 and $freq_{processed}$ is 14.6 for those reporting 'high' frequency of consumption relative to the weight of '1' assigned to 'low' frequency of consumption. We assign WTP_{high} and WTP_{low} to the respective respondents and aggregate the estimates using weights for 'high' and 'low' to obtain WTP_{con_i}, the weighted estimate for mean relative WTP based on the reported frequency of consumption represented by equation (7). The number of respondents reporting high and low frequencies of consumption are represented by n_{high} and n_{low} respectively.

$$WTP_{con_i} = \frac{freq_i\,(n_{high})\,(WTP_{high}) + (n_{low})(WTP_{low})}{freq_i(n_{high}) + (n_{low})} \tag{7}$$

Lastly, we combine the reported frequency of consumption with zero WTP to obtain estimates for the shift in demand. As discussed above, we first estimate $WTP_{high}^{non-zero}$ and $WTP_{low}^{non-zero}$ for the respective sub sample of respondents who report a positive WTP following the ASF outbreak. We modify equation (7) by adding WTP_{zero} (equivalent to a discount of 100 %) to both the 'high' and 'low' categories. We estimate equation (8) to obtain WTP_i that represent the extent of the downward shift in demand for the respective pork categories resulting from the ASF outbreak. The number of respondents who report a non-zero WTP for pork, and high and low frequencies of consumption are represented by $n_{high}^{non-zero}$ and $n_{low}^{non-zero}$ respectively. The number of respondents who report a zero WTP for pork, and high and low frequencies of consumption are represented by n_{high}^{zero} and n_{low}^{zero} respectively.

$$WTP_i = \frac{freq_i\left[\left(n_{high}^{non-zero}\right)\left(WTP_{high}^{non-zero}\right) + \left(n_{high}^{zero}\right)(100\%)\right] + \left[\left(n_{low}^{non-zero}\right)\left(WTP_{low}^{non-zero}\right) + \left(n_{low}^{zero}\right)(100\%)\right]}{freq_i\left(n_{high}^{non-zero} + n_{high}^{zero}\right) + \left(n_{low}^{non-zero} + n_{low}^{zero}\right)} \tag{8}$$

It is important to note that each of the WTP estimates in equations (7) and (8) are in the form of discounts that the mean consumer will be offered to purchase pork during the ASF outbreak. For example, $WTP_{high}^{non-zero}$ and $WTP_{low}^{non-zero}$ could be discounts of 18 % and 25 % respectively, whereas the discount of 100 % represents WTP_{zero}.

5. Survey data and descriptive statistics

Among the 1,519 respondents to the survey, 51.61 % were female, the mean annual household income was about $63 thousand, and had a mean household size of 2.7. The mean age was about 47 years, which lies in the median range of age in the data (45–54 years), and about 46 % of the respondents lived in households that did not contain children (under 18 years of age) or older adults (over 65 years of age). About 34 % of the respondents had a bachelor's degree or higher, and while about 60 % of the respondents were "White", 18.5 % were "Black", and 15.2 % were "Hispanic or Latino". See Table 1 for a description of the socio-demographic data, complete summary statistics, and comparison with the U.S. Census of 2020 where available. While the socio-demographics of U.S. pork consumers may differ from larger population statistics, our sample is representative of the U.S. population in terms of gender, income, and household size.

Table 2 presents the summary statistics for respondents' consumption preferences, prior awareness of ASF, and perceived impact of ASF on personal health. While less than 10 % of the respondents reported consuming pork daily (4.61 % for unprocessed pork and 9.28 % for processed pork), the majority of them report consuming pork at least once a week (40.82 % for unprocessed pork and 53.20 % for processed pork). When it comes to choosing between food price and food safety, 58.2 % respondents weigh them equally while purchasing food, whereas 32.06 % consider food safety as a more important parameter, and 9.74 % consider food price as being more important. Most of the respondents (82.49 %) did not report any incident of sickness from food-borne diseases in the last two years.

Close to three-quarters of the respondents (72.28 %) were uninformed or had a very limited knowledge about ASF prior to the survey. Despite the news announcement in the survey containing information about food safety, only 26.27 % of the respondents perceived ASF as not being a risk to personal health, whereas the others perceived some amount of risk or were uncertain. Lee et al. (2023) had found that even fewer respondents (16 %) were aware of ASF and did not believe that it was a threat to human health. The majority of respondents would substitute pork with beef and poultry during the ASF outbreak, in line with the findings of Tonsor and Lusk (2021), followed by seafood and non-meat food products.

Table 3 shows a summary of the three response outcomes from the survey, as well as respondents who are not willing to purchase pork at any price after an ASF outbreak. To purchase unprocessed pork, about a third of all respondents (33.71 %) were willing to pay the same price as

Table 1
Summary statistics for respondents' socio-demographic variables (N = 1,519).

Variable	Categories	Statistics		U.S. Census 2020
Gender	Female		51.61 %	50.5 %
	Male		48.39 %	49.5 %
Education (highest completed)	Some high school or less		3.22 %	
	High school		25.74 %	
	Some college		24.09 %	
	Associates or technical degree		13.17 %	
	Bachelor's degree		23.51 %	
	Graduate or professional degree		10.27 %	
Race	White		60.17 %	75.8 %
	Black		18.50 %	13.6 %
	Asian		3.49 %	6.1 %
	Hispanic or Latino		15.21 %	18.9 %
	Other		2.63 %	
Children and/or old adults in the household	Only children		28.24 %	
	Only older adults		22.38 %	
	Children and older adults		3.36 %	
	Neither children nor older adults		46.02 %	
Annual household income ($)		Mean	63,028	69,021
		S.D.	41,258	
Age		Mean	47.23	38.5 (median)
		S.D.	17.97	
Household size		Mean	2.69	2.6 (median)
		S.D.	1.48	

they did before the ASF outbreak. Only 7.24 % of respondents were willing to purchase pork at the discounted price. The majority (59.05 %) of the respondents were unwilling to purchase pork even when some were being offered a discount of up to 75 %. Additionally, close to 23 % of all respondents (or 34 % of those who chose "no-no") did not want to continue purchasing unprocessed pork, irrespective of the price.

On the other hand, to purchase processed pork, a relatively higher number of respondents (42.86 %) were willing to pay the same price as they did before the ASF outbreak. Another 7.37 % were willing to purchase pork when offered a discount and the remaining 49.77 % declined to purchase pork even after being offered a discount. Similar to the case of unprocessed pork, 22.58 % of all respondents were not willing to purchase processed pork at any price in case of an ASF outbreak. The proportion of consumers unwilling to purchase pork at any price in our survey is considerably smaller than the figure of 46 % reported by Lee et al. (2023) from their survey in May 2020.

Table 2
Description and summary statistics for respondents' consumption preferences, prior awareness of ASF, perceived impact of ASF on personal health, and substitutes for pork.

Variable	Categories	Statistics
Frequency of consumption of unprocessed pork	At least once a day	4.61 %
	At least once a week	40.82 %
	About once a month	36.73 %
	Less than once a month	17.84 %
Frequency of consumption of processed pork	At least once a day	9.28 %
	At least once a week	53.20 %
	About once a month	26.92 %
	Less than once a month	10.60 %
Price vs. food safety	Lower food price is most important	9.74 %
	Food price and safety equally important	58.20 %
	Food safety is most important	32.06 %
Food-borne illness in past two years	Yes	12.78 %
	No	82.49 %
	Cannot say	4.73 %
Understanding of personal health risk associated with ASF	High risk	15.73 %
	Some risk	35.55 %
	No risk	26.27 %
	Uncertain	22.45 %
Knowledge of ASF prior to the survey	Very knowledgeable	8.30 %
	Moderately knowledgeable	19.42 %
	Limited knowledge	33.57 %
	Not informed	38.71 %
Substitute for pork following ASF outbreak	Beef	44.50 %
	Poultry	45.82 %
	Lamb	9.74 %
	Seafood	36.21 %
	Non-meat food product	19.03 %
	Not purchase more of anything	18.89 %
	Other	3.16 %

Table 3
Percent of respondents for the three response outcomes and those who are not willing to purchase pork at any price following the ASF outbreak.

Response to bids	Percent respondents	
	Unprocessed pork	Processed pork
Yes	33.71	42.86
No-yes	7.24	7.37
No-no	59.05	49.77
Total	100	100
Do not purchase at any price	22.71	22.58

Note: The response outcome "no-no" includes those who responded as not willing to purchase at any price.

6. Results, discussion and policy implications

First, we discuss whether learning about ASF from different news sources affects consumption of pork in an outbreak. Next, we present the coefficient estimates from the OOHB contingent valuation analysis and the estimated mean relative WTP for unprocessed and processed pork. Finally, we factor in the frequency of consumption and the respondents unwilling to pay to purchase pork following an ASF outbreak to estimate

the shift in demand and the resulting welfare implications. We discuss policy implications for the results in each of the following subsections considering that an ASF outbreak in the U.S. is likely to have implications for pork producers, consumers, as well as associated sectors.

6.1. Impact of news sources

We use a probit model to test whether receiving information about ASF from different news sources has a significant effect on consumers' decision to continue purchasing pork at the same price as well as their decision to stop purchasing pork during an ASF outbreak. We regress the binary choice of 'yes' (i.e., continue to purchase pork at the same price) on the three news sources, one of which was randomly assigned to each respondent in the survey. We repeat the exercise with the binary choice of 'not purchase at any price'.

Results in Table 4(a) show that consumers are 5.1 % less likely to continue purchasing unprocessed pork at the same price during the ASF outbreak if they hear about the disease from producers as opposed to from the government, statistically significant at the 10 % level. The marginal effects for both media and producer provided information are negative for processed pork, but not statistically significant. Results in Table 4(b) show that consumers of unprocessed pork (processed pork) are 7.7 % (6.9 %) more likely to stop purchase of pork if they receive the information about ASF from producers as opposed to from the government, statistically significant at the 1 % level. While the marginal effects for the information from the news media source are also positive, neither is statistically significant.

While the reduction in WTP for pork underscores the need for efforts to grow awareness of ASF and messages of food safety, results in Table 4 provide insights into the efficacy of different news sources in doing so. If the pork market fails to consider awareness of ASF, something that can be considered a public good, then considering the resulting market failure and the associated welfare loss, the government has incentives to intervene and provide the necessary knowledge.

Our results show that knowledge sharing by the public sector is likely to benefit the pork market and minimize losses for the producers. In the survey, we had asked the respondents to indicate their trustworthiness for various news sources for information about food safety and food diseases. The responses are presented in Fig. 3 and show that compared to other news sources like television news and social media, the respondents trust the Centers for Disease Control and Prevention (CDC) with news about food safety and food diseases. The findings make the case for public sector institutions like the CDC to strengthen collaborations with pork producers as well as other news sources to garner the trust of consumers, tackle the mistrust, and prevent the spread of misinformation.

Reductions in pork consumption may be larger than what we estimate if changes in demand are driven by misinformation. Such an outcome reiterates policy implications for information dissemination to pork consumers as well as for consideration of spillover effects into substitute markets like beef and poultry. However, the public intervention programs themselves may result in unwanted outcomes in the pork market considering the potential for misperception of risks by consumers (Salanié and Treich, 2009). Findings from Salanié and Treich (2009) would imply that risk misperceptions regarding ASF would justify increased prevention efforts for consumers, which might reduce the government's ability to adequately respond to the actual risk associated with the outbreak, thereby creating ambiguity in social welfare outcomes.

Table 4
Marginal effects of news sources on purchase decision of pork following an ASF outbreak.

News Sources	Unprocessed Pork	Processed Pork
(a) Binary choice of purchasing pork at the same price		
Media	−0.033	−0.008
	(−0.092, 0.025)	(−0.069, 0.053)
Producer	−0.051*	−0.048
	(−0.109, 0.007)	(−0.109, 0.013)
Government (reference category)		
(b) Binary choice of not purchasing pork at any price		
Media	0.035	0.009
	(−0.015, 0.085)	(−0.040, 0.059)
Producer	0.077***	0.069***
	(0.026, 0.129)	(0.017, 0.121)
Government (reference category)		
Observations[a]	1,519 (345)	1,519 (343)

Note: *** and * represent coefficients statistically different from 0 at the 1 % and 10 % significance level respectively. Confidence intervals for the marginal effects in parentheses.

[a] Total observations, and the number of respondents who chose 'not purchase at any price' in parentheses.

6.2. Change in willingness to pay

We estimate two model specifications for each pork category. We estimate Models 1 and 3 by including the three randomly assigned news sources as explanatory variables in addition to the bids. We estimate Models 2 and 4 by including variables representing consumption behavior and awareness of ASF in addition to the news sources and bids. In all four specifications, we use the complete sample of 1,519 respondents. The results are presented in Table 5.

Consistent across all model specifications, the bid is negatively associated with WTP and statistically significant at the one percent level. Thus, as the discount offered to consumers increases (i.e., the relative price of pork decreases), the likelihood of a consumer purchasing pork following the ASF outbreak increases. The estimated mean relative WTP in Model 1 (3) is 0.4560 (0.5257), i.e., the mean respondent must receive a discount of 54.40 % (47.43 %) relative to the price of unprocessed pork (processed pork) products before the outbreak of ASF to be willing to consume pork in case of an outbreak.

The additional covariates in Models 2 and 4 account for the observable (stated) differences across the respondents that include having experienced food-borne illnesses in the past, perceived personal health risk from ASF, knowledge of ASF prior to the survey, frequency of consumption of pork, and preference between price of food and food safety. The estimated mean relative WTP for pork in Model 2 (4) is 0.6642 (0.7402), i.e., the mean respondent must receive a discount of 33.58 % (25.98 %) relative to the price of unprocessed pork (processed pork) products before the outbreak of ASF.

We interpret the sign (direction) of the estimated coefficients of the covariates in Models 2 and 4 as these are not marginal effects and cannot be interpreted directly. A positive sign implies that the variable has a positive correlation with the likelihood of answering 'yes' to the given bid, i.e., it is associated with a higher WTP for pork during the ASF outbreak relative to the price of pork prior to the outbreak. Coefficient estimates for news sources in Models 1 and 3 show that receiving the information about ASF from the media or from a producer is associated with a lower mean relative WTP as compared to receiving news from the government, although the coefficients are not statistically different from zero.

Coefficient estimates in Models 2 and 4 show that consumers who have experienced food-borne illness within the two years preceding the survey or are unsure of it do not have an effect that is significantly different from those who did not experience any such illness. Relative to consumers who do not perceive ASF to be a health risk, those that consider it to be of high risk, or having some amount of risk, or are uncertain about their belief of the risk are likely to have a significantly lower WTP for pork during the outbreak.

Consumers who are highly or moderately knowledgeable about ASF are likely to pay a relatively higher price for pork compared to

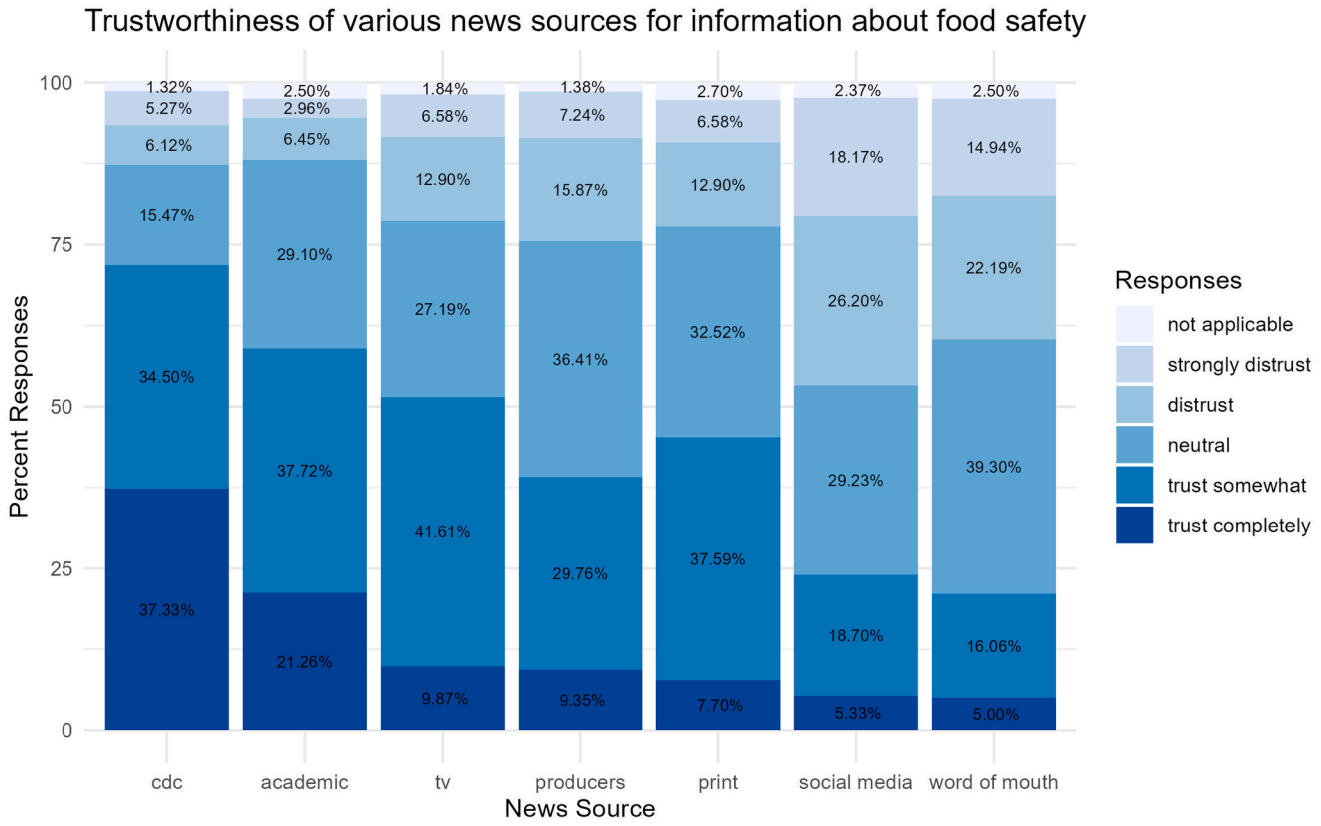

Fig. 3. Responses for trustworthiness of various news sources for information about food safety.

consumers who are uninformed about the disease. Additionally, we see that those who report a higher frequency of consumption of pork products are more likely to pay a higher price for pork during the ASF outbreak as compared to those who report infrequent consumption. Lastly, consumers who prioritize food safety over price are willing to pay a lower price for pork during the outbreak.

These findings have important implications for pork consumers and producers, based on the assumption that our survey data is representative of the U.S. population. In the event of an outbreak of ASF in the U.S., the average pork consumer would only purchase pork when it is offered at a discounted price despite ASF not being a threat to food safety. The findings are in line with Lee et al. (2023) but contrary to the consumer response discussed by Carriquiry et al. (2020). In the short term, an outbreak of ASF in the U.S. could be highly damaging for pork producers if they lose their export market and possibly animals in their herd. Their situation would worsen with a reduction in the domestic demand for pork, which could be driven to some extent by the lack of awareness of ASF and perceived concerns of food safety.

The majority of respondents in our survey had little or no knowledge about ASF despite there being a global outbreak, findings mirrored by Lee et al. (2023) and the KSU Meat Demand Monitor.[1] Additionally, the majority of pork consumers also perceive ASF to be a risk to personal health, reaffirming the lack of awareness about the disease. Both low awareness and perceived health risk of ASF adversely affect pork demand and would hurt producers in the case of an outbreak in the U.S. However, both these issues can be mitigated to a large extent through strategic information campaigns. These findings provide an insight into consumer beliefs and responses pertaining to ASF and can aid in developing measures to inform consumers about the disease, both prior to and during the outbreak. Policy that supports communication efforts about food safety will be key in minimizing adverse impacts of ASF for pork producers, as well as potentially allowing consumers to make informed decisions about pork consumption rather than being driven by lack of knowledge about the disease.

From the socio-demographic variables, only gender has a statistically significant effect on WTP. For both the unprocessed and processed pork categories, female consumers have a larger decrease in WTP than male consumers in case of an ASF outbreak. The other demographic variables include log(income), age, education, household size, and whether the household has either children, older adults, both or neither. The estimates suggest that these variables do not have a statistically significant effect on the mean relative WTP for pork. Complete results for both unprocessed and processed pork are presented in the Appendix.

Empirical results from the OOHB models for both unprocessed and processed pork show that a certain proportion of consumers would be willing to purchase pork only when offered at discounted prices, while some are willing to purchase at the same price as they did before the outbreak or not purchase at all. Overall, this will result in a downward shift of the demand curve in the domestic pork market when there is an outbreak of ASF. Next, we discuss the sensitivity of the extent of the demand shift followed by the resulting changes in welfare.

6.3. *Estimates for the shift in demand*

In order to obtain WTP estimates that reflect the consumption pattern of the consumers, we estimate the mean relative WTP for both unprocessed and processed pork for sub-samples divided by the reported frequencies of consumption. Findings from the OOHB models in Table 5 show that respondents with a relatively higher frequency of consumption of pork are willing to pay a higher price following the outbreak. While the WTP estimates in Table 5 represent unweighted mean changes, we argued in Section 4.3 that consumers with a relatively

[1] https://www.agmanager.info/livestock-meat/meat-demand/monthly-meat-demand-monitor-survey-data.

Table 5
Coefficient estimates of the explanatory variables on mean relative willingness to pay for unprocessed and processed pork from the one-and-one-half bound model.

Variables	Unprocessed Pork		Processed Pork	
	Model 1	Model 2	Model 3	Model 4
Constant	−1.608***	−0.343	−1.219***	−0.026
	(0.241)	(0.335)	(0.202)	(0.320)
Bid	−2.807***	−2.178***	−2.675***	−2.365***
	(0.275)	(0.244)	(0.235)	(0.230)
News source				
Media	−0.163	−0.165	−0.032	−0.038
	(0.146)	(0.148)	(0.138)	(0.142)
Producer	−0.105	−0.050	−0.126	−0.024
	(0.148)	(0.150)	(0.139)	(0.145)
Government (reference category)				
Prior food-borne illness				
Yes		0.213		0.179
		(0.183)		(0.181)
No (reference category)				
Unsure		0.060		0.014
		(0.291)		(0.274)
Perceived health risk				
High risk		−1.488***		−1.590***
		(0.227)		(0.212)
Some risk		−0.677***		−0.705***
		(0.156)		(0.152)
No risk (reference category)				
Uncertain		−0.763***		−0.980***
		(0.175)		(0.171)
Prior ASF knowledge				
Very knowledgeable		1.437***		1.250***
		(0.258)		(0.251)
Moderately knowledgeable		0.590***		0.501***
		(0.179)		(0.172)
Limited knowledge		0.065		0.115
		(0.151)		(0.143)
Not informed (reference category)				
Frequency of consumption				
High		0.536***		0.325***
		(0.123)		(0.122)
Low (reference category)				
Price vs safety[a]		−0.326***		−0.331***
		(0.101)		(0.098)
Mean relative willingness to pay[b]	0.4560	0.6642	0.5257	0.7402
Observations	1,519	1,519	1,519	1,519

Note: ***, **, and * represent coefficients statistically different from 0 at the 1%, 5%, and 10% significance level, respectively. Standard errors in parentheses. For the description and summary statistics of the variables, see Table 2.

[a] Continuous variable, increasing in preference for food safety over price of food.

[b] Estimates obtained using equation (6).

higher frequency of pork consumption would have a greater impact on changes in market demand.

We estimate changes in the mean WTP for respondents reporting non-zero WTP and high frequency of consumption ($WTP_{high}^{non-zero}$), non-zero WTP and low frequency of consumption ($WTP_{low}^{non-zero}$), and zero WTP (WTP_{zero}) for pork following the disease outbreak. These results along with coefficient estimates of the model covariates are presented in Table 6. These results show covariate relationships and the change in mean WTP for consumers belonging to different segments of the market based on their consumption frequency as well as type of pork product. While we controlled for the reported frequency of consumption in Models 2 and 4, we do not do so in estimating $WTP_{high}^{non-zero}$ and $WTP_{low}^{non-zero}$ since we are dividing the sample itself by the respective frequencies.

Results in Table 6 show that respondents who consume both categories of pork products more frequently would be willing to pay a higher price as compared to respondents who consume pork less often, on average, following an ASF outbreak. We exploit this difference to obtain a more nuanced measure for change in market demand as opposed to using the mean value for the complete sample. The direction and association of the covariates with the mean WTP is similar across the two categories of pork products and consumers with high and low frequency of consumption.

Table 7 presents collectively the mean relative WTP for both pork categories for respondents reporting non-zero WTP, and high and low frequencies of consumption, as well as for the complete sample. For unprocessed pork, while the change in WTP is a 33.58 % discount for the full sample, it is 15.51 % and 31.90 % for respondents with high and low frequencies of consumption respectively. For processed pork, the mean WTP during an outbreak is a 25.98 % discount for the full sample, and 12.69 % and 23.40 % for respondents with high and low frequencies of consumption respectively. WTP_{zero} is equivalent to a discount of 100 %.

Table 8 shows the extent of reduction in demand for both categories of pork for two scenarios. The reduction in demand is analogous to a downward shift in demand resulting from a decrease in the WTP for pork products. The first scenario reflects the unweighted WTP estimates which do not consider the differences in frequency of consumption across consumers, or the fact that some consumers would be unwilling to purchase pork at any price in the event of an outbreak and are likely either over- or under-estimating the extent of the shift. The second scenario reflects the reduction in demand that explicitly accounts for consumers who drop out of the pork market following the ASF outbreak. The resulting downward shift in demand, estimated using equation (8) is 32.31 % (30.38 %) for unprocessed (processed) pork.

When we include weights for the frequency of consumption, the mean discount for processed pork increases compared to the first scenario. We observe this change because among those who are willing to purchase pork at a relatively higher discount (or not willing to consume at all), the reported frequency of consumption is relatively higher for processed pork consumers. As a result, the reduction in demand for processed pork is amplified when we account for frequency of consumption. We do not see as much of a change in the case of unprocessed pork.

6.4. Welfare implications

In this section, we evaluate the changes in economic welfare outcomes for consumers and producers of pork associated with the outbreak of ASF in the U.S. using the single-sector partial equilibrium model set up in Fig. 1. We have estimated that at any given price, the demand for pork shifts downward, which is in addition to an increase in domestic supply of pork. Consumers stand to gain from the resulting reduction in price, thus experiencing an increase in welfare, whereas producers experience a loss in welfare. These represent changes in consumer and producer surplus respectively, and their net aggregate represents the total welfare effect. While our welfare analysis does not capture the economic effects associated with the ASF outbreak on the pork sector and associated sectors fully, it provides insights into the potential welfare implications for pork consumers and producers resulting from shifts in supply and demand for pork.

We represent the welfare effects resulting from changes in the pork market equilibrium in Fig. 4. First consider the scenario where the domestic supply of pork increases from S_0 to S_1 following the ASF outbreak but the demand remains unchanged at D_0, like the case discussed in Fig. 1(c). The change in consumer surplus is given by $\Delta CS = CS_1 - CS_0 = A + B + C + D$. The respective change in producer surplus is given by $\Delta PS = PS_1 - PS_0 = H + I + K + L - R - A - B - C$. The change in total surplus is given by $\Delta TS_1 = \Delta CS + \Delta PS = D + H + I + K + L - R$.

Table 6
Coefficient estimates from the one-and-one-half bound model of the explanatory variables on mean relative willingness to pay (WTP) for respondents reporting non-zero WTP for pork, and high and low frequencies of pork consumption.

Variables	Unprocessed Pork		Processed Pork	
	High Frequency of Consumption	Low Frequency of Consumption	High Frequency of Consumption	Low Frequency of Consumption
Bid	−0.854***	−2.429***	−1.085***	−2.291***
	(0.301)	(0.415)	(0.272)	(0.433)
News source				
Media	−0.168	0.025	0.059	−0.220
	(0.207)	(0.232)	(0.186)	(0.259)
Producer	0.146	−0.126	0.087	−0.193
	(0.213)	(0.240)	(0.188)	(0.277)
Government (reference category)				
Perceived health risk				
High risk	−1.409***	−1.721***	−1.443***	−1.741***
	(0.289)	(0.426)	(0.255)	(0.471)
Some risk	−0.527**	−0.680***	−0.466**	−0.635**
	(0.222)	(0.243)	(0.202)	(0.282)
No risk (reference category)				
Uncertain	−0.536**	−0.896***	−0.901***	−0.753**
	(0.267)	(0.264)	(0.227)	(0.306)
Prior ASF knowledge				
Very knowledgeable	1.651***	1.061**	1.224***	1.230**
	(0.348)	(0.496)	(0.323)	(0.583)
Moderately knowledgeable	0.574**	0.045	0.253	0.220
	(0.247)	(0.292)	(0.218)	(0.325)
Limited knowledge	0.195	−0.157	0.074	−0.125
	(0.228)	(0.231)	(0.193)	(0.259)
Not informed (reference category)				
Mean relative willingness to pay[a]	0.8449	0.6810	0.8731	0.7660
Observations	582	592	763	413

Note: ***, **, and * represent coefficients statistically different from 0 at the 1%, 5%, and 10% significance level, respectively. Standard errors in parentheses. For the summary statistics of the variables, see Table 2. The variables 'prior food-borne illness' and 'price vs safety', and constant excluded for brevity.
[a] Estimates obtained using equation (7), modified to include respondents with non-zero willingness to pay.

Table 7
Estimates of mean willingness to pay (in percentage discount from initial price) by sub-samples based on frequency of consumption.

Category	Mean Relative Willingness to Pay (Observations)	
	Unprocessed pork	Processed pork
(a) WTP	33.58 % discount (1,519)	25.98 % discount (1,519)
(b) $WTP_{high}^{non-zero}$	15.51 % discount (582)	12.69 % discount (763)
(c) $WTP_{low}^{non-zero}$	31.90 % discount (592)	23.40 % discount (413)
(d) WTP_{zero}	100 % discount (345)	100 % discount (343)

Note: WTP estimates for (a) are obtained from Model 2 and Model 4 respectively, presented in Table 5. Coefficient estimates from the one-and-one-half bound models for (b) and (c) are presented in Table 6.

Table 8
Estimates of mean reduction in market demand for pork following an outbreak of ASF.

	Scenario	Unprocessed pork	Processed pork
i.	Reduction along price, unweighted	33.58 %	25.98 %
ii.	Reduction along price; weighted and explicitly accounting for respondents unwilling to consume at any price[a]	32.31 %	30.38 %

[a] Estimates obtained using equation (8).

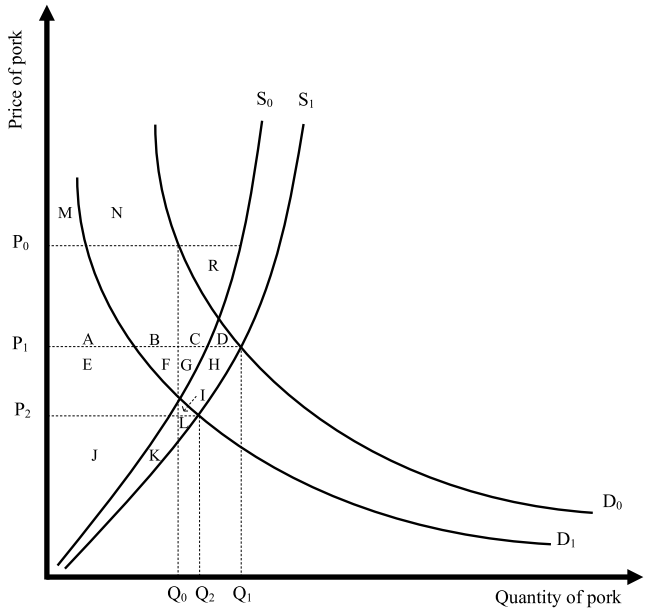

Fig. 4. Welfare implications associated with an increase in supply and reduction in demand for pork following an outbreak of ASF in the U.S.

Consider next, the simultaneous reduction in demand for pork and its implications on welfare outcomes. The change in consumer surplus resulting from the ASF outbreak is now given by $\Delta CS = I + E + A - N$, whereas the change in producer surplus in now $\Delta PS = K + L - R - A - B - C - E - F - G$. The change in total surplus is $\Delta TS_2 = \Delta CS + \Delta PS = I + K + L - R - B - C - F - G - N$. Accounting for a reduction in demand for pork results in an outcome ΔTS_2 that can represent a net welfare loss in the pork market, an outcome significantly different from ΔTS_1.

To estimate welfare changes resulting from a downward shift in the demand curve, we compute the demand and supply functions for pork. We obtain own-price demand elasticity and supply elasticity of pork from the literature. The elasticity estimates will determine the share of welfare loss between the consumers and producers of pork. We use a demand elasticity (η_d) of −1.2, that we obtain by taking the mean of the estimates of Okrent and Alston (2012), Tamim Rahman et al. (2019), and Tonsor and Lusk (2021) and a supply elasticity (η_s) of 0.165, that we obtain by taking the mean of the estimates of Suh and Moss (2017) and Kaiser (2022) to compute the demand and supply functions respectively and to perform the welfare analysis. We assume constant elasticity demand and supply curves, with the functional forms $Q = a_d P^{\eta_d}$ and $Q = a_s P^{\eta_s}$ respectively.

We use data for average pork sale price and volume to calibrate the values of a_d and a_s, which are 110.55 (for D_0) and 18.29 (for S_0) respectively. At the time of the survey (January 2023), the composite retail price of pork was $4.76 per pound (NPCC, 2023). In 2022, the per capita consumption of pork in the U.S. stood at about 51 lb per year (Shahbandeh, 2023), equivalent to a total of approximately 17 billion pounds per year. About 25 % of the U.S. pork production was exported in 2021 (Cook and Schulz, 2022), representing approximately 6.6 billion pounds of the pork produced in 2022. We use this data to calculate the demand and supply functions, as well as the prices and quantities that would be realized if there is an ASF outbreak.

We had estimated that following an ASF outbreak, the demand for unprocessed pork (processed pork) would shift downward along the price axis by 32.31 % (30.38 %), as shown in Table 8. For estimating welfare implications for the composite pork market, we use a reduction in demand of 31.35 %, an average of the two estimates. In calculating the shift in the demand and supply curves, we assume that the elasticity estimates remain unchanged, and that as an immediate impact of the outbreak, the entire quantity that was being exported is now available in the domestic market. This allows us to calculate the change in consumer, producer, and total surplus resulting from an ASF outbreak. The estimates of the welfare implications associated with an increase in supply and reduction in demand for pork following an ASF outbreak is presented in Table 9.

In the first scenario, where the domestic supply of pork increases following an ASF outbreak and demand remains unchanged, consumer surplus increases by $23.01 billion and producer surplus decreases by $23.37 billion. Therefore, the total surplus decreases by $0.36 billion. In the second scenario, where the demand for pork decreases in addition to the increase in the domestic supply of pork, consumer surplus decreases by $24.11 billion and producer surplus decreases by $31.35 billion. Therefore, the total surplus decreases by $55.46 billion. Although there is a decrease in total surplus in both scenarios, it is significantly larger in the scenario that accounts for a reduction in demand.

Though the welfare loss for pork consumers is large in the second scenario, this can be considered as the gross welfare effect limited to the pork market since this is a partial equilibrium analysis. Pork consumers can be expected to substitute to other markets like beef and poultry, which will attenuate their overall loss of consumer surplus. Similarly, some producers may benefit from higher prices in markets that represent substitutes for pork. On the other hand, welfare losses for producers could be even greater if ASF infections cause an increase in pig mortality and culling to prevent the spread of the infection, an outcome that we do not consider in this study. Such an outcome is likely to make the recovery of the pork sector even more challenging. Larger than expected losses for pork producers may also prompt policymakers to allocate more resources to strengthen biosecurity measures and response preparedness.

Particular regions in the U.S. may be more adversely impacted since pork production is concentrated within the states of Iowa, Minnesota, and North Carolina (USDA NASS, 2023). The number of hog operations have decreased in the last two decades alongside an increase in farm size, with over 90 % of all hogs being raised on farms with 2000 or more hogs (NPCC, n.d.). This could have distributional impacts for producers in terms of the losses associated with an ASF outbreak, with implications for government agencies in implementing regulations and inspections to prevent and control the outbreak. Further, this may result in supply chain disruptions and have further impact on international trade.

The welfare loss that we estimate is based on the assumption that the entire quantity for export would be available in the domestic market and that both the upward shift in supply and the downward shift in demand would be observed over a one-year period. But both the extent and duration of the drop in U.S. pork meat exports after an ASF outbreak are subject to uncertainty. A discovery of a single reported case of BSE in the United States was confirmed on December 23, 2003. Many governments imposed import bans on U.S. beef exports, causing a sharp decline of 83 percent from December 2003 to January 2004. But the United States only surpassed the pre-BSE exports levels of beef meat and beef offal for the first time in 2011 (Taha and Hahn, 2014).

It is also important to note that these welfare estimates are sensitive to the parameters of the demand and supply functions as well as the respective elasticities. Research suggests that the own-price demand elasticity estimates vary significantly across pork products (Tonsor and Lusk, 2021). Tonsor and Lusk (2021) find elasticity estimates for bacon (−0.87), breakfast sausage (−3.29), loin (−1.145), and ribs (−2.516), and report that they vary significantly across the U.S. states. This suggests that welfare implications from an ASF outbreak would differ within the unprocessed and processed pork markets as well as across states in the U.S. Our estimates for welfare changes provide a benchmark that incorporates demand changes for both unprocessed and processed pork consumers and is representative of the U.S. population.

Table 9
Estimates of welfare implications for the pork market associated with an outbreak of ASF.

	Scenario	Price ($/lb)	ΔCS	ΔPS	ΔTS
(1)	$S_0 \rightarrow S_1 D_0$ *unchanged*	$P_0 = 4.76 P_1 = 3.61$	23.01	−23.37	−0.36
(2)	$S_0 \rightarrow S_1 D_0 \rightarrow D_1$	$P_0 = 4.76 P_2 = 3.27$	−24.11	−31.35	−55.46

Note: ΔCS, ΔPS, and ΔTS are reported in billion dollars.

7. Conclusion

The recent global outbreak of ASF has grown to become the largest animal disease outbreak in the world and have raised the risk of outbreaks in countries like the U.S. which have otherwise been disease-free. An immediate impact of an ASF outbreak in the U.S., the largest pork exporting country globally, would be a reduction of export, thereby increasing domestic pork supply and pushing down prices in the short run. While ASF is almost completely fatal for the swine population, it is not a food safety concern and consumption of pork products following an outbreak is completely safe. However, given consumers' concerns of food safety and limited awareness of ASF in the U.S., in this research we examine whether the ASF outbreak would lead to a downward shift in demand for pork and the welfare implications such a shift may have on the pork market. Additionally, we examine the awareness of ASF in the U.S. pork consumers and whether learning about the disease from different news sources affects their consumption behavior in the event of an outbreak.

We conducted an online survey in January 2023 that was representative of the U.S. population to collect data on pork consumption preferences in the U.S. We observed that about three-quarters of pork consumers were largely unaware about ASF and believed that it posed a risk to human health. Additionally, about a fourth of the survey respondents would not be willing to purchase pork at any price if there is an ASF outbreak. We find that consumers who receive the news about ASF from a government institution (e.g., CDC), as opposed to from the

news media or producers, are less likely to stop consumption of pork following an ASF outbreak. Using the one-and-one-half-bound dichotomous choice contingent valuation approach, we find that the ASF outbreak results in a downward shift in demand by 32.31 % (30.38 %) for unprocessed pork (processed pork) products. The resulting welfare loss is $24.11 billion for pork consumers and $35.35 billion for the producers.

Findings from this study have important implications for the pork sector pertaining to awareness about ASF and concerns of food safety. While some prior research have estimated the impacts of an ASF outbreak in the U.S. pork sector that is largely driven by impacts to producers, our results suggest that the estimated economic losses are likely underestimated if the possible reduction in demand is not considered. Considering that the average U.S. pork consumers is likely unaware about ASF, proper communication about the disease and related messages of food safety would be critical in minimizing concerns of food safety and rumors in consumers as well as losses to the pork sector.

The findings from this study also emphasize the need for future research that examines in more detail the spillover effects of the reduction in pork demand to auxiliary industries like feed, processing, and transportation. Our model does not consider the possibility of an increase in demand for pork by consumers resulting from a decrease in the price, an outcome that can be further examined. Another avenue of further research that would have important implications for the pork sector would be to examine the duration of the reduction in demand and the time it might take for the demand to return to the pre-outbreak level. In estimating the welfare outcomes of an ASF outbreak, we have not considered the scenario where swine herds die or are culled because of infections. This would result in further welfare losses for the producers and could be examined through an inward shift of the supply curve.

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CRediT authorship contribution statement

Pratyoosh Kashyap: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jordan F. Suter:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Conceptualization. **Sophie C. McKee:** Writing – review & editing, Resources, Project administration, Conceptualization.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodpol.2024.102672.

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1. Appendix: Supplementary Material

Supplementary Material to 'Measuring Changes in Pork Demand, Welfare Effects, and the Role of Information Sources in the Event of an African Swine Fever Outbreak in the United States':

1. Survey Questions

1. Have you consumed pork (example: chops, ribs, bacon, ham) in the last year?

   (Survey instruction: This is a screening question. Only those who respond with a "yes" in this question will proceed with the survey.)

   - Yes
   - No

2. Over the past one year, how often did you consume un-processed pork products (example: chops, ribs, loin)?

   - At least once a day
   - At least once a week
   - About once a month
   - Less than once a month
   - Never

3. Over the past one year, how often did you consume processed pork products (example: bacon, ham, sausages)?

   - At least once a day
   - At least once a week
   - About once a month
   - Less than once a month
   - Never

4. How important for you is lower cost versus improved food safety while purchasing food? Please mark, on a scale of 1 to 3, where **1 means lower prices of food is most important** and **3 means food safety is most important**.
    - 1 - Lower food prices is most important
    - 2 - Food price and safety equally important
    - 3 - Food safety is most important
5. Have you had any incidents of sickness from food-borne illness in the last two years?
    - Yes
    - No
    - Cannot say

The next section of the survey will discuss African Swine Fever, which is a disease that affects pigs.

6. (Survey instruction: Below are three separate news announcements. Present each announcement to one-third of the respondents in a random order):
    - Please read the following announcement related to African Swine Fever:

      African Swine Fever (ASF)

      African swine fever is a highly contagious and deadly viral disease affecting both domestic and feral swine of all ages. ASF is not a threat to human health and cannot be transmitted from pigs to humans. It is not a food safety issue.

      ASF is found in countries around the world. More recently, it has spread to the Dominican Republic and Haiti. ASF has also spread through China, Mongolia, and Vietnam, as well as within parts of the European Union. It has never been found in the United States – and we want to keep it that way.

      Source: U.S. Department of Agriculture, Animal and Plant Health Inspection Service (USDA APHIS)

      Learn more at: https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-

disease-information/swine-disease-information/african-swine-fever/seminar#:~:text=African%20swine%20fever%20is%20a,in%20countries%20around%20the%20world.

- Please read the following announcement related to African Swine Fever:

  African Swine Fever (ASF)

  The U.S. Department of Agriculture announced that the Dominican Republic (DR) has confirmed cases of African swine fever (ASF). The cases were confirmed as part of a cooperative surveillance program between the United States and the DR. The United States remains free of ASF – an animal disease affecting only pigs with no human health implications – and imports no pork, animal feed or other pork production-related products from the Dominican Republic.

  "The United States has significantly bolstered biosecurity to protect the U.S. swine herd since ASF broke in China nearly three years ago and began spreading to other parts of the world," said Liz Wagstrom, chief veterinarian with the National Pork Producers Council.

  Source: National Pork Producers Council (NPPC)

  Learn more at: https://www.nppc.org/asf

- Please read the following announcement related to African Swine Fever:

  African Swine Fever (ASF)

  Al has 28,000 pigs spread out across 16 sites in northeast Iowa. Biosecurity is top of mind for him and other pork producers after African Swine Fever, a highly contagious viral disease in pigs, was confirmed in Haiti and the Dominican Republic over the summer of 2021.

  The highly contagious and deadly disease affects both domestic and feral (wild) pigs and there is no treatment or vaccine available for it. USDA is monitoring the

recent outbreaks of ASF is Asia and Europe and has proactively taken steps to increase our safeguarding efforts to keep the disease out of the United States. African swine fever does not affect human health, and it is not a food safety issue. It cannot be transmitted from pigs to humans.

Source: NPR via Iowa Public Radio

Learn more at: https://www.kcur.org/2022-02-14/as-african-swine-fever-plagues-other-countries-the-u-s-works-to-keep-it-out

7. Consider the following **hypothetical situation**:

Suppose there is a widespread outbreak of African Swine Fever (ASF) in the United States. Hog farms where the outbreak occurs report the death of their pigs and confirm the outbreak. The pork supply chain is likely to include meat from hogs that were infected with the virus.

Please answer the following questions regarding your purchase of pork. Please try and answer as close as possible to your actual response that you anticipate in the case of an outbreak of ASF. Your responses continue to be anonymous.

8. For the two categories pork products listed next, please decide whether you are willing to pay the price that is indicated to purchase the product. The categories of pork include:
    - Un-processed pork products like chops, ribs, and loin.
    - Processed pork products like bacon and ham.
9. Would you be willing to purchase **un-processed pork products (example: chop, ribs, and loin)** during an outbreak of African Swine Fever if it is offered at the **same price as before** the outbreak?
    - Yes
    - No
10. (Survey instruction: For the respondents who select "No" in question 9, present each price discount to one-third of the respondents in a random order. There are a total of three discounts.):

- Would you be willing to purchase **un-processed pork products (example: chop, ribs, and loin)** during an outbreak of African Swine Fever if it is offered at a **price 25% lower** than before the outbreak?
    i. Yes
    ii. No
    iii. Not purchase pork at any price
- Would you be willing to purchase **un-processed pork products (example: chop, ribs, and loin)** during an outbreak of African Swine Fever if it is offered at a **price 50% lower** than before the outbreak?
    i. Yes
    ii. No
    iii. Not purchase pork at any price
- Would you be willing to purchase **un-processed pork products (example: chop, ribs, and loin)** during an outbreak of African Swine Fever if it is offered at a **price 75% lower** than before the outbreak?
    i. Yes
    ii. No
    iii. Not purchase pork at any price

11. Would you be willing to purchase **processed pork products (example: bacon, ham)** during an outbreak of African Swine Fever if it is offered at the **same price as before** the outbreak?
    - Yes
    - No

12. (Survey instruction: For the respondents who select “No” in question 11, present each price discount to one-third of the respondents in a random order. There are a total of three discounts.):

- Would you be willing to purchase **processed pork products (example: bacon, ham)** during an outbreak of African Swine Fever if it is offered at a **price 25% lower** than before the outbreak?
    i. Yes
    ii. No
    iii. Not purchase pork at any price
- Would you be willing to purchase **processed pork products (example: bacon, ham)** during an outbreak of African Swine Fever if it is offered at a **price 50% lower** than before the outbreak?
    i. Yes
    ii. No
    iii. Not purchase pork at any price
- Would you be willing to purchase **processed pork products (example: bacon, ham)** during an outbreak of African Swine Fever if it is offered at a **price 75% lower** than before the outbreak?
    i. Yes
    ii. No
    iii. Not purchase pork at any price

13. How would you describe your understanding of your personal health risk associated with African Swine Fever?

- High risk
- Some risk

- No risk
- Uncertain

14. What would you expect to purchase more of during an outbreak of African Swine Fever?

    Select all those that apply.

    - Would not purchase more of anything
    - Beef
    - Poultry
    - Lamb
    - Seafood
    - Non-meat food product
    - Other

15. How would you describe your knowledge about African Swine Fever prior to this survey?

    - Very knowledgeable
    - Moderately knowledgeable
    - Limited knowledge
    - Not informed

16. Please indicate your perception of the trustworthiness of the various sources of news and information about food-safety, and food diseases provided below:

	Trust Completely	Trust Somewhat	Neutral	Distrust	Strongly Distrust	Not Applicable
Television and radio news	○	○	○	○	○	○
Social media	○	○	○	○	○	○
Print media	○	○	○	○	○	○
Centers for Disease Control and Prevention (CDC)	○	○	○	○	○	○
Meat producers	○	○	○	○	○	○
Academic sources	○	○	○	○	○	○
Word of mouth	○	○	○	○	○	○

17. How do you describe yourself?

- Male
- Female
- Non-binary / third gender
- Prefer to self-describe _____
- Prefer not to say

18. How old are you?

- 18-24 years old
- 25-34 years old
- 35-44 years old

- 45-54 years old
- 55-64 years old
- 65-74 years old
- 75+ years old

19. Including you, how many members do you have living in your household?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8+

20. Are there children under the age of 18 and/ or adults above the age of 65 in your household? Select all those that apply:

- Children under the age of 18
- Adults above the age of 65
- Neither children nor older adults

21. What is the highest level of education you have completed?

- Some high school or less
- High school diploma or GED
- Some college, but no degree
- Associates or technical degree
- Bachelor's degree
- Graduate or professional degree (MA, MS, MBA, PhD, JD, MD, DDS etc.)

- Prefer not to say

22. Which of the following best describes you?

- White or Caucasian
- Hispanic or Latino
- Black or African American
- Asian or Pacific Islander
- Native American or Alaskan Native
- Other
- Prefer not to say

23. What was your total household income before taxes during the past 12 months?

- Less than $25,000
- $25,000-$49,999
- $50,000-$74,999
- $75,000-$99,999
- $100,000-$149,999
- $150,000 or more
- Prefer not to say

(End of survey)

2. Examining Response Outcomes

We evaluate the three response outcomes “yes”, “no-yes”, and “no-no” based on categories of news sources, prior knowledge of ASF, perceived health risk from ASF, and frequency of consumption of pork. These are presented in Figure A1, with the cases for unprocessed pork in the left panel and for processed pork in the right. After the announcement of the hypothetical ASF outbreak, 36.5% of the respondents who received the news from the government were willing to purchase unprocessed pork at the same price as before the outbreak (i.e., the outcome “yes”), higher than the same outcome for media (33.2%) and producer (31.4%). This trend is similar for processed pork consumers with 44.7% of the respondents who received the news of ASF from the government were willing to purchase pork at the market price, greater than media (43.9%) and producer (39.9%), as illustrated in Figure A1(a) and (e).

On the other hand, while 55.7% of the respondents receiving the information about ASF from the government chose “no-no” for unprocessed pork, it was lower than the media (58.8%) and producer (62.7%). Again, the trend was similar for processed pork consumers with 46.7% respondents who learned about ASF from the government chose “no-no”, less than those learning about it from media (46.8%) and producer (53.8%). In assessing the change in willingness to pay for pork, we evaluate whether learning about ASF from these three different news sources had any effect on the responses following an outbreak and discuss the implications for communication about the disease.

When considering the responses based on their knowledge of ASF prior to the survey, as illustrated in Figure A1(b) and (f), the respondents choosing “no-no” were highest when they were least informed about ASF (64.1% and 55.4% for unprocessed and processed pork respectively). This proportion decreased with an increase in the reported knowledge of ASF for both categories of pork. Conversely, the proportion of respondents choosing “yes” was the highest among those who reported being ‘very knowledgeable’ about ASF (59.6% and 61.9% for unprocessed and processed pork respectively). This proportion declined with the decreasing knowledge of ASF, for both categories of pork, and was the lowest among those who were uninformed about ASF.

In Figure A1(c) and (g), we see that among the respondents who did not perceive ASF as a risk to their personal health, the proportion choosing “yes” was the highest (50.6% and 61.2% for unprocessed and processed pork respectively) when compared to those who believed otherwise, and the proportion choosing “no-no” was the lowest. The respondents who considered ASF to be of high risk to their personal health, the proportion choosing “no-no” was the highest (77.4% and 70.7% for unprocessed and processed pork respectively). We test whether prior knowledge of ASF and its perceived health risk affects the change in willingness to pay for pork since this will inform the need for communication about the disease before and during the outbreak.

In assessing the response outcomes based on the reported frequencies of consumption, as illustrated in Figure A1(d) and (h), we see that the proportion of respondents who chose “yes” was highest among those who reported consuming pork at least once every day (67.2% and 59.6% for unprocessed and processed pork respectively). This proportion declined with the decrease in reported frequency of consumption. Those choosing “no-no” were the highest in proportion among the respondents who consumed the least amount of pork (less than once a month), for both unprocessed (80.8%) and processed pork (73.9%). This proportion declined with the increase in reported consumption. This distribution is likely to have an impact on changes in market demand since it tells us the characteristics of those who might lower or stop their consumption of pork during the outbreak. We consider the differences in frequency of consumption and the respective

choice outcomes in estimating the change in willingness to pay for both unprocessed and processed pork.

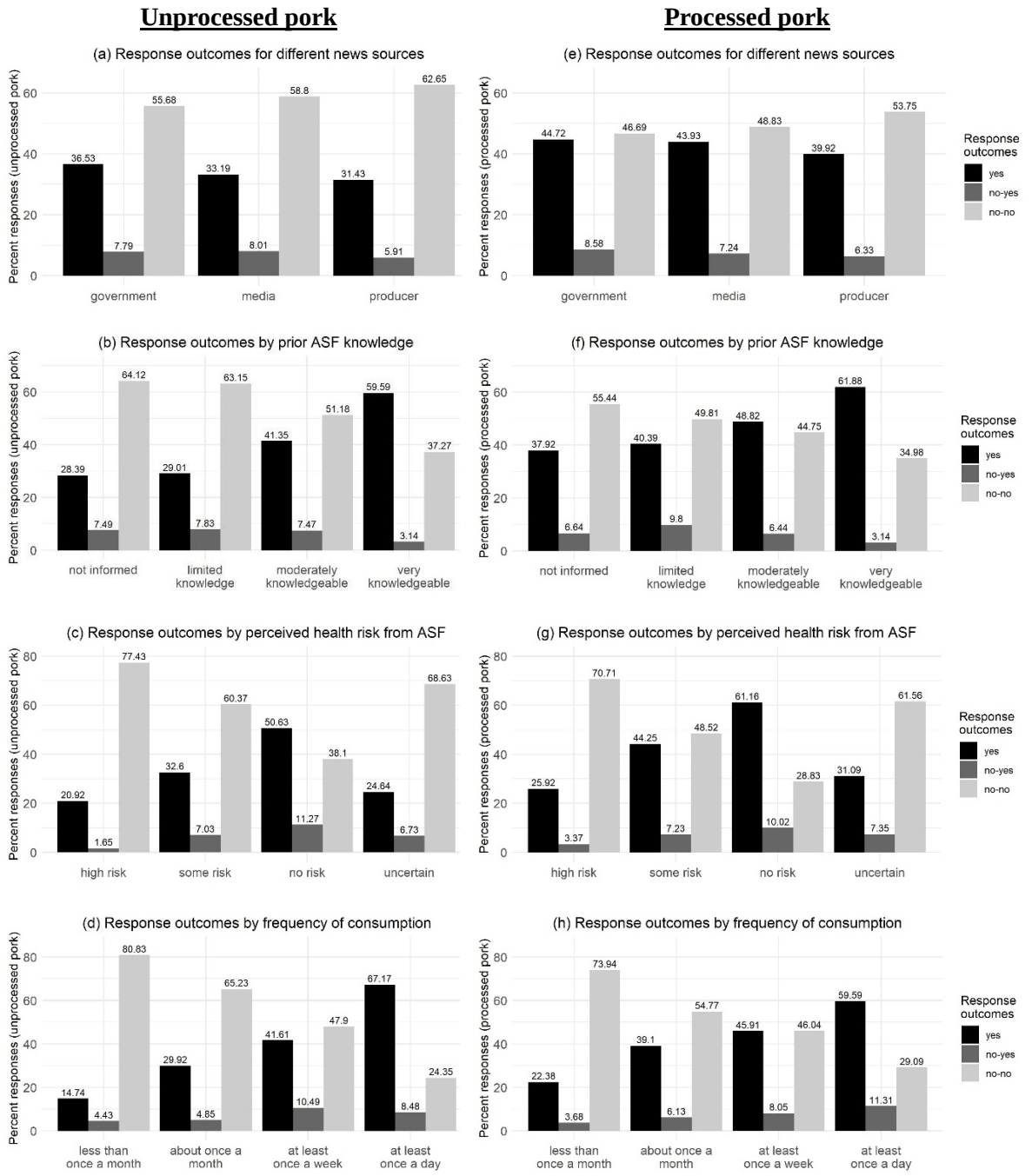

Figure A1. Response outcomes for unprocessed and processed pork, categorized by different survey responses.

Next, we evaluated differences across news sources, awareness of ASF, and frequency of consumption of pork of the respondents who were unwilling to purchase pork at any price in case of an ASF outbreak. Figure A2 illustrates these cases for both unprocessed and processed pork, in the left and right panels respectively. Among the consumers of unprocessed pork (processed pork) who received information about ASF from the government, 18.96% (19.96%) were unwilling to purchase

pork at any price, lower than the proportion of respondents receiving the news from the media and producer, as shown in Figure A2(a) and (e).

Figure A2(b) and (f) show that the consumers who were the least informed about ASF were most likely to stop purchasing pork during an outbreak. Among the respondents who reported being uninformed about ASF prior to the survey, 29.93% (28.57%) were unwilling to purchase unprocessed pork (processed pork) at any price. On the other hand, among those that reported being highly knowledgeable, 10.32% (13.49%) were unwilling to purchase unprocessed pork (processed pork) at any price.

Figure A2(c) and (f) show that after being presented with the information about ASF in the survey, consumers who were uncertain about personal health risk associated with ASF or perceived ASF to be of some risk, were more likely to stop purchasing pork during the outbreak. Among respondents who perceived ASF to be of high risk to them, 25.10% (28.03%) were unwilling to purchase unprocessed pork (processed pork) at any price, higher than the proportion of respondents who did not perceive ASF to be of any risk: 13.78% (12.03%). Figure A2(d) and (h) show that the majority of those willing to stop purchasing pork during the outbreak of ASF did not consume pork very frequently. 35.42% (33.54%) of the respondents who reported consuming pork less than once a month were unwilling to purchase unprocessed pork (processed pork) at any price. This was higher than the proportion of respondents who reported consuming pork at least once a day: 11.43% (10.64%).

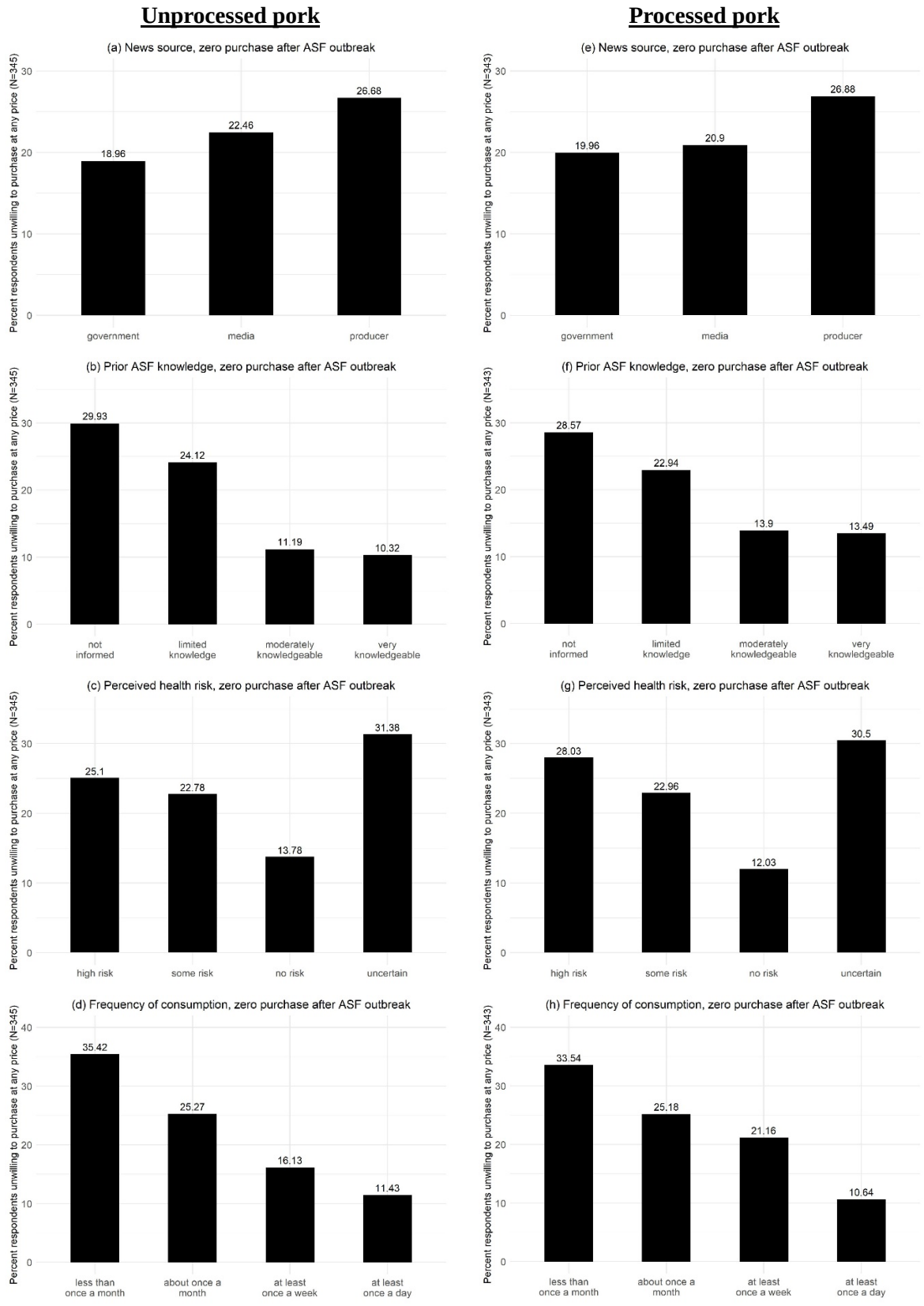

Figure A2. Respondents unwilling to purchase unprocessed and processed pork at any price, categorized by different survey responses.

3. Coefficient Estimates from the One-and-One-Half Bound Model

Table A1. Coefficient estimates of the socio-demographic variables on mean relative willingness to pay for unprocessed and processed pork from the one-and-one-half bound model.

Variables	Unprocessed Pork	Processed Pork
Constant	-2.156**	-1.892**
	(1.018)	(0.962)
Bid	-2.730***	-2.619***
	(0.272)	(0.235)
log(income)	0.091	0.062
	(0.096)	(0.091)
Age	0.001	0.001
	(0.004)	(0.004)
Education	0.020	0.054
	(0.048)	(0.045)
Household size	-0.082	-0.012
	(0.055)	(0.052)
Female	-0.504***	-0.429***
	(0.126)	(0.118)
Children and/or old adults at home		
Children	0.142	0.128
	(0.175)	(0.164)
Old adults	-0.161	-0.065
	(0.169)	(0.160)
Children and old adults	0.647	0.313
	(0.353)	(0.337)
Neither children nor old adults (reference category)		
News source		
Media	-0.167	-0.027
	(0.147)	(0.139)
Producer	-0.101	-0.102
	(0.149)	(0.141)
Government (reference category)		
Mean relative willingness to pay [a]	0.3337	0.3746
Observations	1,519	1,519

Note: *** and ** represent coefficients statistically different from 0 at the 1% and 5% significance level, respectively. Standard errors in parentheses. For the summary statistics of the variables, see Table 2.
[a] Estimates obtained using equation (6).