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Recall information heterogeneity and perceived health risk: The impact of food recall on fresh meat market in the U.S.☆

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ABSTRACT

This paper examines the heterogeneous impact of various recall information on consumers' perceived health risks and quantifies the overall impact of food recalls on demand. Using the fresh meat market as a case study, this paper formulates a structural random coefficient discrete choice model of consumer demand. Among various characteristics of food recalls, our focuses are the number of recalls and the volume of food recalled. In addition to the latest recall information, the historical recall information may also change consumers' perception of health risks and we include the interaction terms of the historical recall information and the latest recall information into the model. Results show that both the number of recalls and the volume of food recalled have negative and significant effects on the demand. Historical recalls are also important to mitigate the negative impact of the latest recalls on the market. To minimize the negative impact of recalls, the highest priority should be given to preventing large-scale recalls, Class I recalls, product contamination recalls, and recalls due to being produced without benefit of inspection or import violation. Food companies should take the initiative to recall when problems arise. Further, simulation results imply that the number of recalls plays a much larger role than the volume of food recalled in meat demand.

1. Introduction

Food safety issues are threatening consumers' health and life and have undergone an increasing trend over the past years (Houser et al., 2019). In 2011, the Centers for Disease Control and Prevention estimated that about 48 million Americans (nearly 1 in 6) get sick, 128,000 are hospitalized, and 3,000 die of foodborne diseases every year. According to the 2019 FoodNet data, the number of infections has increased by 32 % over the past three years.[1] Among the core topics related to food safety issues is food recall, which is an action taken to remove from the market the products that may present health risks to consumers due to adulteration, misbranding, or violation of laws administered by the Food and Drug Administration (FDA) or the United States Department of Agriculture (USDA). Consumers, food manufacturers, companies using the recalled products, other related companies, and regulatory agencies are all affected by a food recall (Roman & Moore, 2012). It was estimated that the average cost of a recall to a food company is $10 M (Tyco Integrated Security, 2012). Taking into account the total number of recalls, the total losses are estimated to account for 0.5 % of the total U.S. food sales in 2019.[2]

Food recall is a critical public health measure to protect the public from health and life threats due to food safety issues. The food safety system in the U.S., which is composed of government regulatory agencies at all levels, together with food companies can be regarded as risk assessors or risk makers once a food recall occurs (Charlebois & Watson, 2009). When a potential food safety risk is detected, they issue a

☆ Statements: a. Researcher(s) own analyses calculated (or derived) based in part on data from Nielsen Consumer LLC and marketing databases provided through the NielsenIQ Datasets at the Kilts Center for Marketing Data Center at The University of Chicago Booth School of Business. b. The conclusions drawn from the NielsenIQ data are those of the researcher(s) and do not reflect the views of NielsenIQ. NielsenIQ is not responsible for, had no role in, and was not involved in analyzing and preparing the results reported herein.

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[1] Please see https://www.cdc.gov/foodnet/reports/prelim-data-intro-2019.html.

[2] The number of recalls is 225 from the FDA and 124 from the USDA in 2019. See https://www.fda.gov/safety/recalls-market-withdrawals-safety-alerts and https://www.fsis.usda.gov/recalls. According to the USDA, total U.S. food sales at supermarkets, other grocery (except convenience) stores, warehouse clubs, and supercenters reached $653 billion in 2019. See https://www.ers.usda.gov/topics/food-markets-prices/retailing-wholesaling/retail-trends/.

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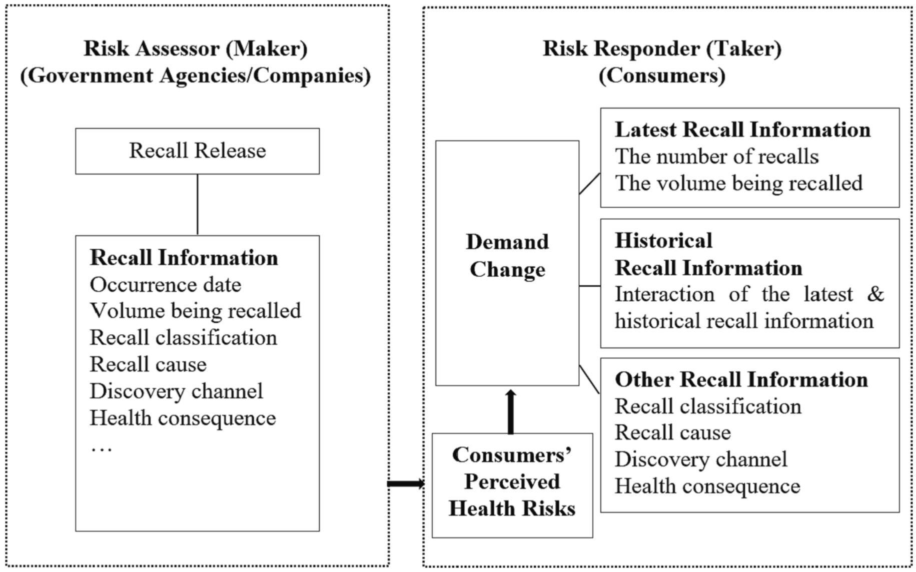

Fig. 1. Recall information and consumer choices.

food recall and release the recall information to the public through various channels, such as official websites, public media wire services, media outlets in areas that received recalled products, e-mail subscription services, and social media. The recalls of most meat, poultry, and some egg products are monitored by USDA, while the recalls of other food and beverages are supervised by FDA. FDA's recall release contains information on recall occurrence date, brand and company name, product description, the reason for the recall, discovery channels of recalls, etc. USDA's recall release provides additional information on the total volume being recalled, recall classification, and health consequences.

Given that the U.S. has a bifurcated food safety system with different recall release strategies, consumers, as the risk responders or the risk-takers, are exposed to various food recall information. This information may change consumers' perceived health risks of the underlying products and further affect their purchasing behaviors and food demand (see Fig. 1). Therefore, this study answers the following two questions. First, what's the impact of food recall on consumer demand? Second, how do consumers respond to recall information with heterogeneous characteristics?

A previous survey found that consumers are aware of the heterogeneity of recall information and respond differently to the various information (Cates et al., 2020). However, more empirical studies are still needed regarding the impact of food recalls on demand. First, previous studies focused more on a specific large-scale recall which caused larger losses and gained more attention from the public. For example, the 2003 BSE beef recall (Schlenker & Villas-Boas, 2009; Taylor et al., 2016), the 2007 peanut butter recall (Bakhtavoryan et al., 2012, 2014a, 2014b, 2018; Miller & Littlefield, 2010), and the 2010 egg recall (Li et al., 2017). As a result, the impact of smaller-scale recalls and the volume of food recalled are not fully studied. Second, previous literature focused on either the short-term effect (Bakhtavoryan et al., 2012; Schlenker & Villas-Boas, 2009; Toledo & Villas-Boas, 2019) or the long-term effect over time (Bakhtavoryan et al., 2014a, 2018; Houser et al., 2019) separately, instead of their interactive effects from a dynamic time perspective. Third, previous empirical studies that studied the characteristics of food recall either only covered a small set of characteristics of recalls (Batz et al., 2012; Shang & Tonsor, 2017) or focused on a specific pathogen and product type (Bakhtavoryan et al., 2012; Toledo & Villas-Boas, 2019). For example, Shang & Tonsor (2017) first provided evidence of heterogeneity in demand impacts across regions and products, however, the impact of more characteristics of recalls on demand has not been fully studied, such as the number of recalls, the volume of food recalled, recall classifications, recall causes, etc.

To examine the impact of various recall information on consumer response, this paper formulates a structural random coefficient discrete choice model of consumer demand using the fresh meat market as a case study. Among various characteristics of food recalls, our main focuses are the number of recalls and the volume of food recalled. In addition to the latest recall information, historical recall information may also change consumers' perception of the health risks of the underlying products. We further explore the heterogeneous impact of other recall information including recall classification, recall causes, discovery channels, and health consequences. To estimate our model, we use brand-level data on fresh meat from 2012 to 2016 across the contiguous United States. Combined with food recall data collected from the USDA Food Safety and Inspection Service (FSIS) website, we empirically assess how heterogeneous food recall information affects consumer preferences, estimate the value of food recall information, and compare the effects of alternative levels of the number and volume of food recalled on meat product demand by simulating the market outcomes over the sample periods under different scenarios.

Results in this paper show that both the number of recalls and the volume of food recalled have a negative and significant impact on meat demand. Further, simulation results suggest that frequent recalls of a smaller scale would probably cause larger losses than one recall with a higher volume. Historical recalls are also important to mitigate the negative impact of the latest recalls on the market. When there is no devastating recall occurring in the past six months and a new recall happens, the shocks to the demand are larger in markets with no recalls in the last six months than that with at least one recall. Class I recalls that have the highest health risks to consumers have a larger negative impact on demand than Class II and Class III recalls that have lower health risks. In addition, among all recall causes, consumers are most concerned with large food recalls caused by product contamination in the fresh meat market. As for discovery channels, recalls discovered by government agencies are more likely to cause a larger loss in meat demand, followed by food recalls discovered by illness reports, consumers' complaints, and companies' self-checking.

This paper contributes to the food safety literature. As far as we know, this paper is the first to include various recall information to empirically estimate its heterogeneous impact on meat demand. The framework in this study can also be generalized to other food markets other than the fresh meat market. Moreover, results from this study provide essential information to the fresh meat industry and shed light on government policies and market strategies aiming to reduce the negative effect of food recall on consumer demand. In particular, understanding the heterogeneity in the effects of recall information on the fresh meat market is important for firms to respond to the recall events and invest in food safety technologies and strategies accordingly.

The rest of the paper is organized as follows. Section 2 describes the data and summary statistics for market variables and recall information. Section 3 describes the method for demand estimation. Section 4 presents the estimation results. Section 5 introduces the design of the counterfactual analysis and gives the simulation results. Section 6 concludes and discusses the implications for theory and practice.

2. Data

2.1. The fresh meat market

In this study, we use the fresh meat market as a case study to examine the impact of heterogenous food recall information on food demand due to three reasons. First, meat recall has shown increasing trends in both the number of recalls and the volume of food recalled. According to FSIS, the number of meat recalls has increased by over 50 % from 2012 to 2019, the pounds being recalled in 2019 is almost 6 times higher than that in 2012.[3] Moreover, the meat industry is the largest segment of the U.S. agricultural sector. Meat production totaled 52 billion pounds in 2017, and poultry production totaled 48 billion pounds in 2017. The U. S. meat and poultry industry account for $1.02 trillion in total economic output or 5.6 percent of gross domestic product (GDP). More importantly, the meat industry in the U.S. has suffered dramatic market losses due to recall events (Schlenker & Villas-Boas, 2009; Taylor et al., 2016; Thomsen & McKenzie, 2001).

2.2. Summary statistics

The main data used in this study is Nielsen Retail Scanner Data from 2012 to 2016, which covers more than half the total sales volume of U.S. grocery and drug stores and more than 30 percent of all U.S. mass merchandiser sales volume.[4] It collects dollar sales, volume sales, prices, and detailed information on product characteristics (e.g. brand names, container sizes, package sizes, etc.), marketing (e.g. price and in-store displays), location, and time of sales. In this analysis, we use brand-level data on fresh meat across the contiguous United States. Data for market shares and prices used are aggregated at the product-month-state level. Following Cohen (2008), we calculate the market share of each meat product in our sample as a share of the maximum potential market size in the market. Specifically, we define market share for product j, in state s, at time t as:

$$s_{jst} = \frac{Volume_{jst}}{Max_t \sum_j Volume_{jst}} \tag{1}$$

The denominator, market size, is the maximum monthly volumes ever observed over the entire period in each market. We examined the total meat consumption in each state during the sample period. It is reasonable to use the maximum over the periods to define a saturation point for meat sales, when the market size is assumed to be proportional to the largest market volume in the state, regardless of time.

Part A of Table 1 provides summary statistics on prices, sales volume, and market shares by meat types. In general, non-ground meat has relatively higher prices than ground meat. The price is the highest for lamb and the lowest for chicken. In addition, beef, turkey, and chicken account for most of the sales volumes and market shares in the U.S. fresh meat market.

Table 1
Summary statistics for main variables across meat types.

Panel A. Market information

Meat type	Price($/pound)		Total volume (pounds)		Market share (%)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Whole sample	4.22	2.17	29,286	116,605	1.72	4.66
Ground beef	4.25	1.42	79,450	234,709	4.32	9.07
Ground chicken	3.50	1.44	9,216	16,979	0.73	1.22
Ground lamb	7.09	1.06	1,288	2,454	0.10	0.18
Ground pork	3.25	0.68	4,528	8,887	0.30	0.44
Ground turkey	3.63	1.09	40,195	99,126	2.49	3.43
Non-Ground beef	6.78	4.05	14,905	41,890	0.71	1.33
Non-Ground chicken	3.02	1.95	24,849	62,441	1.56	3.02
Non-Ground lamb	7.18	1.45	120	168	0.00	0.01
Non-Ground pork	4.97	1.97	4,270	9,085	0.29	0.51
Non-Ground turkey	4.10	0.93	17,525	70,986	1.20	2.99

Panel B. Latest recall information in the last month

Meat type	The number of recalls (10ˆ-2)		The volume recalled (pounds)	
	Mean	Std. Dev.	Mean	Std. Dev.
Whole sample	3.25	19.02	23,392.68	368,551.87
Ground beef	9.10	28.76	34,962.00	233,011.08
Ground chicken	0.00	0.00	0.00	0.00
Ground lamb	0.04	1.94	0.03	1.59
Ground pork	0.00	0.00	0.00	0.00
Ground turkey	0.03	1.86	0.09	4.68
Non-Ground beef	5.97	24.33	152,629.69	1,098,734.40
Non-Ground chicken	11.45	37.44	31,167.09	188,261.99
Non-Ground lamb	0.00	0.00	0.00	0.00
Non-Ground pork	2.46	15.72	3,404.38	63,922.33
Non-Ground turkey	0.45	6.69	37.37	1,124.92

Panel C. Historical recall information in the last six months

Meat type	The number of recalls (10ˆ-2)		The volume recalled (pounds)	
	Mean	Std. Dev.	Mean	Std. Dev.
Whole sample	20.83	50.97	149,298.02	926,785.80
Ground beef	59.13	63.86	251,450.72	586,239.86
Ground chicken	0.00	0.00	0.00	0.00
Ground lamb	0.13	3.56	0.10	2.92
Ground pork	0.00	0.00	0.00	0.00
Ground turkey	0.25	4.99	0.63	12.52
Non-Ground beef	37.91	64.14	973,199.62	2,645,735.90
Non-Ground chicken	72.27	84.21	179,649.91	418,250.04
Non-Ground lamb	0.00	0.00	0.00	0.00
Non-Ground pork	15.64	37.64	9,381.16	100,624.96
Non-Ground turkey	2.78	16.44	168.03	2,013.69

Note: 1) For market data information, the mean is the average for each product in each month in each state. 2) For recall information, the mean is the average for each meat type in each month in each state. 4) The number of observations is 81,545 for Panel A and Panel B, and 69,298 for Panel C.

[3] The number of meat recalls is 82 for 2012, and 124 for 2019; the volume of food recalled is 3,475,115 pounds for 2012, and 20,427,455 pounds for 2019.

[4] See https://www.chicagobooth.edu/research/kilts/datasets/nielsenIQ-nielsen.

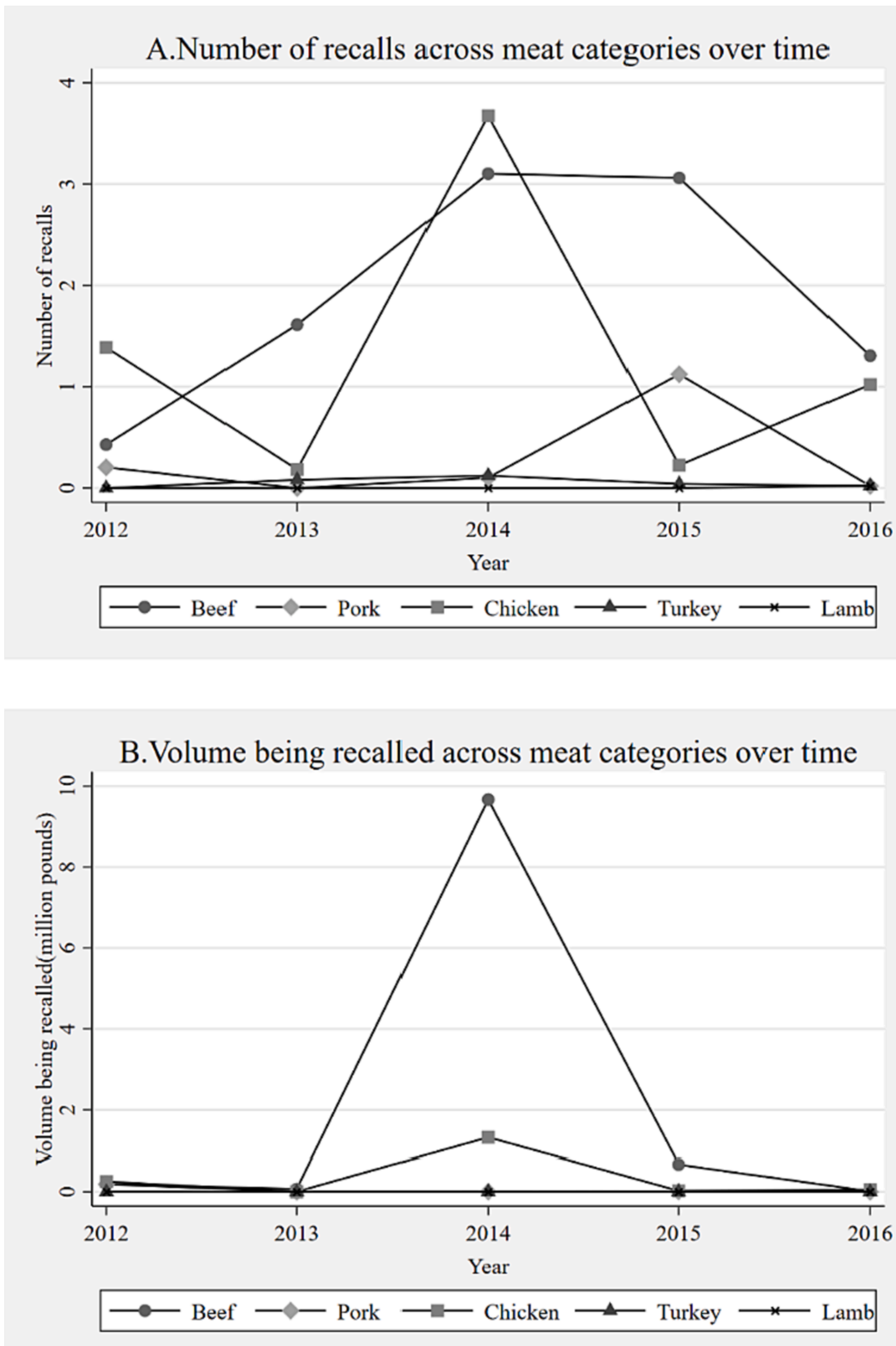

Fig. 2. The average number of recalls and volume recalled in a month in a state across meat categories over time.

Data on recall information is obtained from the USDA FSIS website, where the recall occurrence date, the volume of food recalled, recalled products, recall classification, etc. are listed.

For each recall, the affected states and other characteristics are not directly listed and are hand collected. Ideally, we would like to match the recall information with the market data at the brand or firm level. Unfortunately, it is difficult to match the two types of data due to data limitations. There are many inconsistencies in the brand name and the information collection process between the FSIS recall data and Nielsen Retailer Scanner Data.[5] Therefore, we use the recall information at the meat type-state-month level, which reflects consumers' overall evaluation of health risks for a meat type.

Part B of Table 1 presents the summary statistics of the latest recall information, the number of recalls and the volume of food recalled in pounds in the last month, broken down by meat types.[6] There is significant variation in the number of recalls and the volume of food recalled across meat types, which partly motivates this paper and allows us to estimate the impact of food recall on consumer demand. For example, compared to non-ground beef, non-ground chicken is more frequently recalled with a larger number of recalls. However, its average volume being recalled is much smaller than beef. Furthermore, Fig. 2 illustrates the average number of recalls and the volume of food recalled in a month across meat categories from 2012 to 2016. Part C of Table 1 presents the summary statistics of the historical recall information, the number of recalls and the volume of food recalled in pounds in the last six months, broken down by meat types.

Table 2 provides monthly summary statistics on other characteristics of recalls. Recall classification directly reflects the severity of the recalls. A Class I recall indicates high or medium health risks, and it is a health hazard situation where there is a reasonable probability that the use of the product will cause serious, adverse health consequences or death. A Class II recall indicates low health risks and there is a remote probability of adverse health consequences from the use of the product. A Class III recall indicates marginal health risk, and it is a situation where the use of the product will not cause adverse health consequences. As can be seen, most of the recalls issued by the FSIS are Class I recalls, and the volume of food recalled for Class I is also much higher than for Class II and Class III recalls. Recall causes, discovery channels, and health consequences also reflect the severity of the recalls indirectly. Furthermore, most recalls in this paper were discovered after receiving consumer complaints and the average number of patients reported to have adverse health consequences is 0.0189 per recall.

3. Model

In this section, a random coefficient discrete choice model is implemented to estimate the demand for fresh meat products. Estimates from the demand system are then used to conduct counterfactual analysis. The data used in this paper is at the product-month-state level from 2012 to 2016.

3.1. The setup

The market is defined as a month and state combination. Suppose we observe $m = 1, \ldots, M$ markets, each with $i = 1, \cdots, I$ consumers. The contiguous United States (including 48 contiguous states and the District of Columbia)[7] and 59 months,[8] noted as s and t respectively, are included in the data, and M is 2891. A meat product is a combination of brand and meat type. This analysis covers five meat categories (beef, chicken, turkey, lamb, and pork) and each category is divided into two types: ground meat and non-ground meat. These categories cover over 90 % of volume sales in the fresh meat market in recent years and for each meat category, we include major brands that represent over 90 % of the volume sales of that category. The total number of products for all the markets,J, is 74 in this study.[9] $j = 0$ indicates the outside product, which means consumers may choose not to buy any of the fresh meat products.

Following Berry et al. (1995) (hereafter BLP), it is assumed that consumers choose a meat product among all available alternatives in a market to maximize the utility. The indirect utility for consumer i from purchasing meat product j in market m is given by:

$$U_{ijm} = \alpha_i p_{jm} + \beta_{1i} H_{jm} + \beta_{2i} X_j + \xi_{jm} + \varepsilon_{ijm}, i = 1, \cdots, I;\ j = 1, \cdots, J;\ m = 1, \cdots M \tag{2}$$

where H_{jm} is consumers' perceived health risks of the underlying product j in market t. The perceived health risk is a function of the characteristics of recalls and can be presented as

$$H_{jm} = H(recall\_info_{jm})$$

where $recall\_info_{jm}$ is a vector of information available on recalls for a meat product j in state s and time t, which includes 1) the latest recall information including the number of recalls and the volume of food recalled; 2) the historical recall information including the total number of recalls in the last six months and the total pounds of meat being recalled in the last six months; and 3) the other recall information including recall classifications, recall causes, discovery channels, and health consequences.

p_{jm} is the sales-weighted average price of project j in market m.[10] X_j is the observed product characteristics, which include calorie, fat, and protein content. The nutritional facts vary across meat products since there is little variation in nutrition facts across brands. Some other nutrition facts, such as sodium, iron, total carbohydrates, potassium, and cholesterol, are dropped out due to the collinearity or the lack of data variation. ξ_{jm} is the unobserved characteristics of the product j in market m. We can model $\xi_{jm} = \xi_j + \xi_m + \Delta\xi_{jm}$, where ξ_j and ξ_m are meat products fixed effect and market fixed effect respectively. The former includes both meat category dummy variables and brand dummy

[5] Some FSIS recall data only mentioned that there is a recall of Company A's chicken products without enough details. But Company A has many brands, and each brand has different chicken products (such as legs, wings, breasts, etc.). It is nearly impossible to perfectly match this FSIS information with our detailed retail data, which is at the product level. This may cause a measurement error with substitution between meat brands. A household could respond to a meat recall by buying another species or they could respond by buying a different brand of the same species. Therefore, the result in this paper is a lower bound for the effect of recalls on the meat demand.

[6] The recalls in this paper occurred: a) in only one state, b) in multiple states, c) nationwide. For the recalls that affect multiple states, we assign the recalls to all the states that were involved; for the nationwide recalls, we assign the recalls to all the 48 states included in this paper (Alaska and Hawaii are not included) and District of Columbia. For example, if a beef recall with x pounds happened in three states in a month, then the number of recalls for these three states in the month all increased by one since the recall did happen in these states; and the total volume being recalled for each state increased by x pounds to indicate the scale of the recall.

[7] Alaska and Hawaii are not included, and the District of Columbia is noted as a state in the rest of this paper for ease of writing.

[8] Data from 2012 to 2016 are implemented in the paper, with 12 months for each year. We use one month lag for the number of recalls and the volume of food recalled for estimation, so January 2012 is dropped due to the missing value.

[9] The number of products vary across markets and the data is an unbalanced panel.

[10] We assume that local retailers in the same market charge the same prices determined by the firms. Individual retailer pricing is not the focus of this paper. However, we can assume a positive relationship of prices between the firm pricing and retail store's actual price.

variables, and the latter includes time fixed effect and state fixed effect.

$$\xi_{jm} = Dummy_{category} + Dummy_{brand} + Dummy_t + Dummy_s + \Delta\xi_{jm} \tag{3}$$

$\Delta\xi_{jm}$ is the product-market-specific components and are left as the error term, for example, the product promotion in a state in a month. We assume that both meat producers and consumers can observe all the meat characteristics when making purchase decisions. ε_{ijm} is a mean-zero stochastic term and follows identical independent Type I Extreme Value distribution.

To incorporate consumers' heterogeneity when making the purchase decision, we model the consumer-specific taste parameters as a multivariate normal distribution. Then the taste parameters can be expressed as:

$$\begin{pmatrix} \alpha_i \\ \beta_{1i} \\ \beta_{2i} \end{pmatrix} = \begin{pmatrix} \alpha \\ \beta_1 \\ \beta_2 \end{pmatrix} + \Pi D_i + \Sigma\nu_i, \nu_i\ N(0, \mathrm{I}_{K+1}) \tag{4}$$

where K is the dimension of the observed characteristics vector. D_i is a matrix of observable demographic variables.[11] ν_i is the unobservable characteristics. Π and Σ are scaling matrices. Let $\theta_1 = (\alpha\ \beta_1\beta_2)$, including the linear parameters; and $\theta_2 = (\mathrm{vec}(\Pi)\ \mathrm{vec}(\Sigma))$, containing the nonlinear parameters. $\theta = (\theta_1, \theta_2)$. Then the indirect utility function can be decomposed into three parts written as:

$$U_{ijm} = \delta_{jm}\left(p_{jm}, H_{jm}, X_j, \xi_{jm}; \theta_1\right) + \mu_{ijm}\left(p_{jm}, H_{jm}, X_j, D_i, \nu_i; \theta_2\right) + \varepsilon_{ijm} \tag{5}$$

$$\delta_{jm} = \alpha p_{jm} + \beta_1 H_{jm} + \beta_2 X_j + \xi_{jm} \tag{6}$$

$$\mu_{ijm} = \left(p_{jm}, H_{jm}, X_j\right)' * (\Pi D_i + \Sigma\nu_i) \tag{7}$$

$$U_{i0m} = \xi_0 + \pi_0 D_i + \sigma_0\nu_{i0} + \varepsilon_{i0m} \tag{8}$$

where δ_{jm} is the mean utility term and is the same for all consumers for product j in market m. μ_{ijm} is product-specific and consumer-specific deviation from the mean utility. U_{i0m} is the indirect utility of choosing outside options.

Consumers are assumed to buy only one product that leads to the highest utility. The probability that consumer i choose product j in market m is

$$S_{ijm} = \frac{\exp(\delta_{jm} + \mu_{ijm})}{1 + \sum_{r=1}^{J}\exp(\delta_{rm} + \mu_{irm})} \tag{9}$$

Then aggregate over consumers to get the market share of product j in market m as:

$$s_{jm} = \int \mathrm{I}\{(D_i, \nu_i, \varepsilon_i): U_{ijm} > U_{irm},\ \forall\, r = 0,1,\ldots,J\} P_D^*(D)\, dP_\nu^*(\nu)\, dP_\varepsilon^*(\varepsilon) \tag{10}$$

where P_D^*, P_ν^* and P_ε^* are the distributions of D, ν, and ε. ν is drawn from an independent normal distribution and ε follows Type I Extreme Value distribution. D is drawn from the Nielsen Consumer Panel Data from 2012 to 2016 and we draw 50 consumers with variable income and number of children in a state in a month.

Following the BLP model, we match the predicted market share with observable market shares, then solve the model using the generalized method of moments. The estimated coefficients can reveal consumers' preferences for prices and meat characteristics, as well as the effect of meat recalls on demand. With the specification, α_i is consumer-specific taste parameters for price and β_{2i} are taste parameters for nutrition contents; β_{1i} are consumer-specific preference parameters for recall information, such as the number of recalls, the volume of food recalled, and other characteristics of recalls, which are parameters of our main interests.

Table 2
Summary statistics on the number of recalls and volume recalled by different types of recall information.

Other Recall Information	Number of Recalls		Volume Recalled (Pounds)	
	Mean	Std. Dev.	Mean	Std. Dev.
Recall Classifications				
Class I	0.0259	0.1601	19,966	367,876
Class II	0.0045	0.0672	2,376	53,981
Class III	0.0027	0.0523	946	21,490
Recall Causes				
Germ contamination	0.0140	0.1174	3,915	78,108
Extraneous materials contamination	0.0053	0.0729	215	5,664
Unreported Allergen or misbranding	0.0102	0.1013	3,441	58,221
Produced without benefit of inspection or import violation	0.0036	0.0597	15,717	359,562
Discovery Channels				
Company	0.0102	0.1007	3,433	58,291
Consumer complaint	0.0139	0.1183	16,213	359,685
Illness report	0.0046	0.0680	182	3,205
Government agencies	0.0044	0.0663	3,461	77,748
Health Consequences				
Number of Patients	0.0189	0.3684		

Note: 1) For recall classifications, recall causes and recall channels, the mean is the average of the number of recalls and the volume of food recalled for each characteristic in each month at each state. For health consequences, the mean is the average number of patients reported to have adverse health reactions. 2) The number of observations is 81,545.

3.2. Instruments

$\Delta\xi_{jm}$, described in the previous section as product-market-specific components, are left in the error term. These unobserved product characteristics might be correlated with the product prices and cause biased and inconsistent estimation. We use regional average prices (excluding the state being instrumented) as instruments of the prices as in Nevo (2001). Following Hausman (1996) by controlling for brand and category fixed effect and demographics, the state-specific valuations of the product, $\Delta\xi_{jm}$, are independent across states but are allowed to be correlated within a state over time. Given the assumption, the prices of the product in other states are valid instruments for the price in a state. Prices of product j in two states will be correlated due to the common marginal costs, but they will not be correlated with the market-specific price variations of the product because of the independence assumption. The regional average prices, as instruments of the prices, are calculated as

$$Aveprice_{jmt} = \frac{\sum_{-m} p_{jmt}}{N_{jt} - 1} \tag{11}$$

where $-m$ indicates all states excluding state m. N_{jt} is the number of states that product j sold at time t. The numerator is the sum of prices j in

[11] The demographic information is collected from Nielsen Consumer Panel Data from 2012 to 2016. For the demographic information in full model regression, in each state each month, we randomly draw 50 households in the estimation. We also conducted robustness checks by sampling 100 individuals and 20 individuals. The results are very robust and available upon request.

Table 3
Demand estimation results: impact of the latest recall information on consumer demand.

	Mean	Standard Deviations	Interactions with Demographic Variables	
Variables	β	σ	log (income)	Child under 18
Constant	−0.6969***	0.3064*	0.0005	0.0302
	(0.1128)	(0.1729)	(0.0259)	(1.2068)
Price	−0.4048***	0.2113***	0.0143**	0.0053
	(0.0056)	(0.0098)	(0.0062)	(0.2882)
Number of recalls	−2.1921***	0.0073	−0.0045	−1.4556
	(0.7792)	(95.7678)	(0.8314)	(70.3985)
Volume recalled	−1.887***	0.0003	−0.0033	−1.2642
	(0.4564)	(42.2517)	(0.3244)	(61.8800)
Calorie	0.0725***	0.0228***		
	(0.0113)	(0.0008)		
Fat	−0.1578*	0.0587		
	(0.0941)	(0.0399)		
Protein	−1.1219***	0.0228***		
	(0.0530)	(0.0357)		
Number of Observations	81,545			
GMM objective	3.94E-15			

Note: 1) *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 2) Standard errors are in parentheses. 3) All regressions include time fixed effect, category fixed effect, brand fixed effect, and state fixed effect.

all other states except state m in each month.

3.3. Validation

Food recall may influence both supply and demand for products once it occurs. It may negatively affect the products' supply because recalled products are removed away from the market. It can also have negative effects (through safety concerns etc.) or positive effects (through trust because of voluntary recalling etc.) on the demand. To separate the effects of food recalls on consumer demand, we use one month lag of recall information as a proxy for the latest recall information. With a month lag, it is more likely that the supply of the recalled products has recovered, and the consumers can observe the recalls and respond when making the purchase decisions Besides, during our sample period, the percentage of volume recalled over the total volume sales is relatively small, with an average of 1.77 %. Specifically, 6.37 %, 0.34 %, 0.00 %, 0.26 %, 0.00 % for beef, chicken, lamb, pork and turkey respectively. We thus assume that the supply of the product category being recalled is not significantly affected.

4. Results

4.1. The latest recall information

Table 3 present the results of the demand estimation. The means of the distribution of marginal utilities, θ_1, are presented in the first column. Column (2) presents the standard deviations of the means, where estimates of the heterogeneity around the means are reported. Columns (3) and (4) show the heterogeneity across different demographics measured by the log of income and if there is at least one child under 18 in the household.[12]

Among all food recall information, the latest recall information, including the number of recalls ($Num_{js,t-1}$) and the volume of food recalled ($Vol_{js,t-1}$), are our focuses, which are used as a proxy of the health risk perception in our main model:

$$H_{jst} = \eta_1 Num_{js,t-1} + \eta_2 Vol_{js,t-1} + \mu_{jst} \tag{12}$$

While the volume of food recalled is expected to have a negative impact on food demand, the relationship between the number of recalls and food demand can be either positive or negative. On one hand, a large number of latest food recalls implies that the food safety system or the food quality control system might not work efficiently. Consumers are more likely to avoid recalled products with higher health risks. On the other hand, some scholars and policymakers claimed that.

a growing number of recalls could suggest that companies are actively and voluntarily recalling their products once potential health threats surface (Ducharme, 2019). Therefore, it is also possible that these precautionary actions help gain the trust of consumers, thus increasing the demand. The estimated coefficient of the number of recalls is negative and significant, suggesting that the net effect of the number of recalls on meat demand is negative. In other words, the negative impact of recalls due to health concerns dominates the potential positive impact because of the overall trust with precautionary and voluntary recalling. Specifically, the coefficient indicates that one additional recall could lead to a 0.18 % decrease in the market share of fresh meat products. The volume of food recalled shows a negative and significant impact on meat demand. This result is in line with our expectations. With more food products and consumers involved, a large-scale recall can pose a higher risk to public health. These results are consistent with previous literature showing that sales of the recalled products declined after a food safety recall occurred (Schlenker & Villas-Boas, 2009; Bakhtavoryan et al., 2012; Toledo & Villas-Boas, 2019).

Moreover, the interaction terms of recall characteristics and demographics are estimated to be negative and statistically insignificant, which suggests that the heterogeneity in the coefficients may not be able to be explained by the included demographics. In addition, consumers prefer fresh meat products with lower prices, higher calories, and less protein. The standard deviations of price, calories, and protein are all significant, suggesting that there is significant heterogeneity of consumer preference in these characteristics. Besides, the interaction term of price and log of income is positive, suggesting that consumers with higher income are less price sensitive.

To check the assumption that the price coefficients follow a normal distribution, we plot a figure showing the distribution of individual price sensitivities, referring to Nevo (2001). It seems to be normal, which is consistent with our assumption of the price taste distribution. It is true that the right tail of the distribution can be positive, meaning that consumers prefer higher prices. However, for the given specification, the percent of positive price coefficients is only 2.77 %. There are as much as 11.72 % of the price coefficients are positive after considering the heterogeneity across demographics. We also did a robustness check by assuming a log-normal distribution of price estimates and the estimation results are very stable and similar to the current results in Table 3.[13]

4.2. The historical recall information

Besides the latest recall information, the historical recall information in the past can also change consumers' perceptions of health risks and then affect consumers' shopping decisions. It can either amplify or mitigate the negative impact of the latest recalls. On one hand, a history of frequent recalls in certain products implies higher health risks, which may lose consumers' trust in food safety and thus reduce the demand

[12] We include demographics that are more likely to affect consumers' preferences for prices or food recall. For example, higher-income households might be less sensitive to prices. Households with children might be more sensitive to food recall because children have a high risk of foodborne illness and related health problems. According to FDA, children's immune systems are still developing, and they cannot fight off infections as well as adults.

[13] Distribution plots of individual price sensitivities, and results of robustness check for the lognormal distribution of prices are available upon request.

Table 4
Demand estimation results: impact of historical recall information on consumer demand.

Variables	Mean β	Standard Deviations σ	Interactions with Demographic Variables log (income)	Child under 18
Constant	−1.3503***	−0.3083*	0.0005	0.0002
	(0.1170)	(0.1771)	(0.0245)	(1.1559)
Price	−0.3538***	0.2024***	0.0142**	0.0003
	(0.0059)	(0.0103)	(0.0059)	(0.2774)
Number of recalls	−5.3826***	−0.0073	0.0002	−1.496
	(1.5403)	(67.2431)	(1.6031)	(101.9251)
Volume recalled	−4.6156***	0.0003	0.0005	−0.0034
	(1.3411)	(118.0713)	(2.2685)	(133.4875)
Num6*Number of recalls	4.9568***	0.0231		
	(1.5543)	(133.7187)		
Vol6* Volume recalled	1.1265**	0.0591		
	(0.5443)	(43.7755)		
Calorie	0.0700***	0.0229***		
	(0.0117)	(0.0006)		
Fat	−0.0833	0.0023		
	(0.0973)	(0.0536)		
Protein	−1.1407***	0.0003		
	(0.0548)	(0.0379)		
Number of Observations	71,238			
GMM objective	7.35E-15			

Note: 1) *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 2) Standard errors are in parentheses. 3) All regressions include time fixed effect, category fixed effect, brand fixed effect, and state fixed effect. 4) "Num6" and "Vol6" represent the total number of recalls and the volume of food recalled in the last six months respectively.

even more. Taylor et al. (2016) found robust evidence that the 2003 Bovine Spongiform Encephalopathy (BSE) recall changed the way people view and respond to ground beef recalls. Their research showed that before the event, ground beef recalls had no impact on household purchases, while in the post-BSE period, consumers reduced the retail purchases of ground beef by 0.26 lb per person. On the other hand, government agencies, food companies, and consumers may have learned from historical recalls. The food safety system may have more experience and work more efficiently in identifying the recalls and notifying the public, and consumers may grow accustomed to frequent recalls and avoid overreaction once a recall happens again. Therefore, we further include the interaction terms of the total recall information in the last six months and the latest recall information in the main model to estimate their cross effects.[14] $Num_{js,6}$ is the total number of recalls in the last six months, and $Vol_{js,6}$ is the total pounds of meat being recalled in the last six months. The results are presented in Table 4.

$$H_{jst} = \eta_1 Num_{js,t-1} + \eta_2 Vol_{js,t-1} + \eta_3 Num_{js,t-1} {}^* Num_{js,6} + \eta_4 Vol_{js,t-1} {}^* Vol_{js,6} + \mu_{jst} \quad (13)$$

The positive signs of the interaction term suggest that the negative impact of health concerns is outweighed by the potential positive impact of the experiences from past recalls. The results imply that the negative impact of the latest food recalls will be mitigated if there is already a recall of the same product in the past six months. We further calculated the net marginal effect of the number of recalls on market share for markets with at least one recall and no recall in the past six months and found that an additional recall reduced market share by 0.08 % and 1.58 % respectively. This result is different from Taylor et al. (2016) that the consumers respond more negatively to ground beef recalls after the 2003 BSE event and Li et al. (2017) that there were no significant differences in consumer preferences before and after the 2010 egg recall. One possible explanation is that there was no widespread recall that caused severe damage during our sample period, which is from 2012 to 2016. The largest nationwide recall in our sample is approximately 8,742,700 lb of beef products in February 2014 with no adverse health reports. Moreover, the largest number of people reported having adverse health consequences is 17, which happened in July 2016 and lasted a month, regarding a beef recall. However, the total amount of the products being recalled is 8,800 lb, of which 2,640 lb were recovered. Under these circumstances, the possibility of the recall to make a change to consumers' health perception of the affected products is limited. But the experiences from the past recalls are important to mitigate the negative impact of the latest recalls on the market once it happens again.

We then calculate the combined effects using the mean value of the number and volume being recalled in the last six months and find that the effects of the latest number of recalls and the volume of food recalled are still negative. It is consistent with the results in the main model in Table 3, implying that the manufacturers may still want to avoid food recalls and associated reduced demand. The results of other variables are stable as the main model.

4.3. The other recall information

The other characteristics of recalls include recall classifications, recall causes, discovery channels, and health consequences. According to the FSIS, recall classification directly indicates the severity of health hazards to consumers. The recall causes provide the reasons why the products are determined to be recalled, such as a) germ contamination, b) extraneous materials contamination, c) unreported allergens or misbranding, and d) produced without benefit of inspection or import violation. Discovery channels indicate how the recall is discovered, such as a) by government agencies such as the FSIS, b) by companies' self-checking, c) identified after receiving consumer complaints or d) after receiving illness reports. Consumers' health consequences inform the public if there exist confirmed reports of adverse reactions, such as illness, hospitalization, or death, and how many cases are reported.

Similarly, we assume that the perceived health risk can be written as a linear function of these characteristics. The results are presented in Tables 5 and 6. The number of recalls and the volume of food recalled are divided into three recall classifications and are estimated in two separate models due to the existence of multicollinearity.[15] As shown in Part A of Table 5, the number of Class I recalls presents a significant negative effect on fresh meat demand, and the volumes being.

recalled for Class I and Class II recalls are also negatively correlated with the demand. For the recall causes, the number of recalls due to being produced without the benefit of inspection or import violation, germ contamination, and extraneous material contamination negatively and significantly affected the fresh meat demand. The impacts of the volume of food recalled of other material contamination and germ contamination on demand are greater than other causes. Specifically, the coefficients for material contamination and germ contamination are 49 and 14 times higher than that for being produced without the benefit of inspection or import violation respectively. For the discovery channels, recalls discovered by consumers and government agencies have larger negative effects on the demand for fresh meat. Finally, we

[14] We also did robustness check using varying time frames of 3 months and 12 months for the historical recalls. The results are very robust and available upon request.

[15] The main reason of using these specifications is because the regressors are highly correlated when dividing the recalls into different classifications. The fresh meat recalls issued by the FSIS are mostly Class I recall, and the number of Class II and Class III recall for each meat type in each month in each state is either zero or one. As a result, the number of recalls and the volume of food recalled for recall classifications are highly correlated. This multicollinearity problem comes with several symptoms claimed by Greene (2018).

Table 5
Demand estimation results: the impact of the other recall information on consumer demand: recall classifications, recall causes, and discovery channels.

Other Recall Information	The Number of Recalls		The Volume Recalled	
	β	σ	β	σ
A. Recall Classifications				
Class I	−4.4750***	0.0230	−2.4126***	0.0231
	(1.0722)	(5.9731)	(0.4368)	(1.6320)
Class II	−1.7530	0.1581	−3.3188**	0.0528
	(1.7803)	(23.6266)	(1.6796)	(210.6809)
Class III	−4.1749	0.0028	−8.3211	0.0128
	(2.8647)	(27.0342)	(5.7196)	(53.1929)
B. Recall Causes				
Germ	−5.9266***	0.0028	−33.3683*	0.003
	(2.0733)	(48.4628)	(19.4976)	(98.9163)
Material	−5.5226***	0.0513	−115.5079***	0.0227
	(1.6904)	(26.8786)	(37.8136)	(150.8174)
Allergy	−0.5343	0.0223	−3.0293*	0.0007
	(1.2873)	(17.1960)	(1.6760)	(14.3768)
Inspect	−20.5543***	0.0594	−2.3635***	0.0221
	(3.7341)	(72.4524)	(0.4357)	(10.9321)
C. Discovery Channels				
Company	−2.0974*	0.0028	−3.1862*	0.0028
	(1.1992)	(5.6786)	(1.6795)	(81.0055)
Government	−22.0397***	0.0502	−2.375***	0.0229
	(3.4929)	(126.7863)	(0.4365)	(6.7619)
Complaint	−3.425*	0.0219	−47.8213	0.0007
	(1.9821)	(16.0748)	(41.9889)	(112.5822)
Illness	−4.0816**	0.0593	−30.7649	0.0227
	(2.0617)	(25.5796)	(19.5993)	(248.0834)

Note: 1) *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 2) Standard errors are in parentheses; 3) All regressions include time fixed effect, category fixed effect, brand fixed effect, and state fixed effect. 4) "Germ", "Material", "Allergy", and "Inspect" represent recall causes of germ contamination, extraneous material contamination, unreported allergens or misbranding, and being produced without the benefit of inspection or import violation respectively. 5) "Company", "Government", "Complaint", and "Illness" respectively mean that the recalls were discovered through companies' self-testing or the food establishments' identification, by government agencies through routine verification activities or other inspection processes, through consumers' complaints, and when there was at least one person injured or ill due to the recall. 6) The number of observations is 81,545 for all these estimations.

Table 6
Demand estimation results: the impact of the number of patients on consumer demand.

	Mean	Standard Deviations	Interactions with Demographic Variables	
Variables	β	σ	log (income)	Child under 18
Constant	−0.7474***	0.3128*	0.0005	0.0312
	(0.1126)	(0.1828)	(0.0265)	(1.2309)
Price	−0.3840***	0.1988***	0.0140**	0.0053
	(0.0056)	(0.0102)	(0.0063)	(0.2924)
Number of recalls	−1.9227**	0.0073	−0.0044	−1.4651
	(0.7849)	(81.9764)	(2.3720)	(127.2431)
Volume recalled	−1.9202***	0.0023	−0.0033	−1.2352
	(0.4556)	(56.2157)	(0.4403)	(59.4810)
Number of patients	−0.0310*	0.0011		
	(0.0179)	(1.0336)		
Calorie	0.0752***	0.0233***		
	(0.0113)	(0.0009)		
Fat	−0.1802*	0.0593		
	(0.0941)	(0.0514)		
Protein	−1.1357***	0.0232		
	(0.0529)	(0.0345)		
Number of Observations	81,545			
GMM objective	7.67E-14			
R-squared	0.4667			

Note: 1) *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 2) Standard errors are in parentheses. 3) All regressions include time fixed effect, category fixed effect, brand fixed effect, and state fixed effect.

Table 7
Counterfactual 1: simulated impact of the latest recall information on meat sales by category.

A. **Simulation Design**	**S1**	**S2**	**S3**
Sample group	Beef	Beef	Beef
Increase in the number of recalls	1	2	1
Increase in recall pounds	50,100	50,100	100,200
B. **Simulation Results**	**Average Market Share Change (%)**		
Beef	−0.242	−0.446	−0.251
Chicken	0.120	0.221	0.125
Lamb	0.277	0.492	0.287
Pork	0.137	0.253	0.142
Turkey	0.134	0.243	0.139

evaluate the effect of the health consequences caused by the recalls by adding the number of patients associated with the recalls into the main model. As can be seen in Table 6, recalls with more reports of adverse health consequences have a larger negative effect on demand.

5. Counterfactual analysis

Using the estimated structural parameters from the previous model, we evaluate and compare the effects of alternative levels of the number and volume of food recalled on meat product demand by simulating the market outcomes over the sample periods under different scenarios.

5.1. Counterfactual 1: Impact of the latest recall information

In this analysis, we use the beef market as a case study and simulate three different scenarios to quantify the effect of the latest recall

Table 8
Counterfactual 2: simulated impact of the historical recall information on meat sales.

	Average Market Share Change (%)	
	S4 No recall in the last six months	**S5** At least one recall in the last six month
Beef	−0.295	−0.157
Chicken	0.133	0.111
Lamb	0.276	0.046
Pork	0.140	0.108
Turkey	0.135	0.117

information with different recall numbers and volumes.[16] In this set of simulations, we choose 50,100 lb as the volume of food recalled which is the median volume of a beef recall in our sample. Simulations S1 and S2 will allow us to quantify the net impact of one additional food recall with fixed volume, while a comparison between S1 and S3 will allow us to quantify the net impact of recall volume, holding the number of recalls fixed.

S1: One new beef recall with 50,100 lb.
S2: Two new beef recalls with 50,100 lb in total.
S3: One new beef recall with 100,200 lb.

As shown in part B of Table 7, in all three scenarios, the sales of beef decline due to increases in food recall, while demand for other meat categories all increases. The increase in the percentage changes of market shares from the largest to the smallest is lamb, pork, turkey, and chicken. These results indicate that consumers are more likely to purchase similar products as a substitute when there is a food recall in one meat category. In this case, beef, lamb, and pork are red meat, while chicken and turkey are white meat.[17] If there is one additional 50,100-pound recall in the beef category (S1), the sales of beef would decline by 0.242 % on average. As a result, it would lead to an average increase in demand for chicken, lamb, pork, and turkey by 0.120 %, 0.277 %, 0.137 %, and 0.134 %, respectively.

Further, by comparing S1 with S3, we find that the higher the recalled volume, the larger the loss in sales. However, although the volume of food recalled is doubled in S3, the decrease in sales in the beef category is only slightly larger, from a 0.242 % drop to a 0.251 % drop. The spillover effects for the non-recalled products were found different across brands and food types (Bakhtavoryan et al., 2012; Marsh et al., 2004; Toledo & Villas-Boas, 2019) and the results from this paper provide evidence for the positive spillover. Comparison between S1 and S2 suggests that, while holding the volume of the recall constant and increasing the number of recalls from one to two, the market sales experience a considerable decrease, from −0.242 % to −0.466 %. The comparison between the three simulation results implies that the number of recalls plays a much larger role in meat demand.[18] For a meat product, frequent recalls of a smaller scale would probably cause larger losses than one recall with a higher volume.

5.2. Counterfactual 2: Impact of the historical recall information

In this section, we focus on the impact of historical recall information. More specifically, we are interested in quantifying the heterogeneous impact of a new food recall on products with different recall histories. Still using the beef category as a case study, we first classify our markets into two groups, depending on whether there is a food recall happened in the past six months. Then in each group, we simulate two scenarios similar to the previous section.

S4: No recall in the last six months: one new beef recall with 50,100 lb.
S5: At least one recall in the last six months: one new beef recall with 50,100 lb.

The simulation results are presented in Table 8. Comparing S4 with S5, the market share changes for beef in S4 are larger than that in S5. Results suggest that, given the same food recall event, the marginal shock to the demand is larger in markets with no recalls in the last six months than that with at least one recall. For example, when there is a beef recall of 50,100 lb in markets with no recalls in the last six months (S4), the average market share of beef declines by 0.295 %. However, in S5 where the same recall happens in markets with at least one recall in the last six months, this average market share declines by only 0.157 %. In addition, the market shares increase for other product categories in the first group is also larger in the second group. It is worth mentioning that these results do not imply that more recalls in the past are better than no recall for the manufacturers. Suppose there are two markets that both have a recent recall. Market A already has a recall in the past six months, but Market B does not. Our results suggest that when there is a recall that happened in the last six months, the marginal effect of a recent recall on meat sales in that period in Market A is smaller than in Market B. However, because there are more recalls in Market A in total (2 recalls) compared to Market B (1 recall), the overall impact is much worse in Market A. Therefore, a manufacturer would still want to avoid a food recall.

Table 9
Counterfactual 3: impact of simulated other recall information on beef sales.

Simulation Design	Average Market Share Change (%)		
	All Markets	No recall in the last six months	At least one recall in the last six month
A. One additional recall with different recall causes			
S6 Germ	−1.381	−1.464	−1.154
S7 Material	−1.351	−1.429	−1.133
S8 Allergen	−0.946	−0.940	−0.863
S9 Inspect	−2.326	−2.585	−1.841
B. One additional recall from different discovery channels			
S10 Company	−0.192	−0.233	−0.124
S11 Government	−1.544	−1.841	−1.093
S12 Complaint	−0.302	−0.366	−0.197
S13 Illness	−0.355	−0.429	−0.232

5.3. Counterfactual 3: Impact of the other recall information

In this section, we focus on the impact of other recall information. More specifically, we are interested in quantifying the heterogeneous impact of one new food recall on products with different characteristics of recall information. Using the parameters from estimations of other characteristics of recalls, including recall causes and discovery channels, we evaluate and compare the effects of one additional number of recalls for each characteristic of recall information on meat product demand by simulating the market outcomes over the sample periods under different scenarios.[19] In this set of simulations, we still use the beef category as a case study and simulate one additional beef recall with different causes and discovery channels in each of the following scenarios.

[16] We did a similar analysis assuming the simulated recall happened in other categories such as chicken, lamb, pork, or turkey in the revised version. The results are very similar and are available upon request.

[17] See https://ask.usda.gov/s/article/Is-pork-white-meat.

[18] We tested the statistically significance of the difference in market share changes among the simulation scenarios. The results from the *t*-test between groups show that the differences are all statistically significant at 1% confidential level.

[19] We do not conduct a similar set of simulations broken down by recall classification because the estimation coefficients of Class II recall and Class III recall are not significant in Table 5.

S6: One new beef recall caused by germ contamination.
S7: One new beef recall caused by extraneous material contamination.
S8: One new beef recall caused by unreported allergens or misbranding.
S9: One new beef recall caused by being produced without the benefit of inspection.
S10: One new beef recall discovered through companies' self-testing.
S11: One new beef recall discovered by government agencies.
S12: One new beef recall discovered through consumers' complaints.
S13: One new beef recall discovered when at least one person is ill due to the recall.

The simulation results are presented in Table 9. We also compare the results among three groups: all markets, markets with no recall in the last six months, and markets with at least one recall in the last six months. As can be seen in the first column, the results for different scenarios in all the markets are consistent with previous results from demand estimation on the impact of other recall information on consumer demand.

Specifically, the shock of the same recall to the demand is the largest for the recalls due to being produced without the benefit of inspection or import violation. Comparing recalls discovered by different channels, our results suggest that the negative impact on meat demand from a recall discovered by government agencies is over eight times higher than that initiated by a manufacturer itself. Similar to counterfactual analysis 2, we divide the samples into two groups depending on if there was at least one recall in the past. As can be seen in the last two columns that the demand shocks are higher in the markets with no recall in the last six months than in the markets with at least one recall in the last six months.

6. Conclusion and policy implication

6.1. Conclusion

When recalls are issued, consumers' health risk perceptions on the related products are affected by various recall information, which may further change their purchasing behaviors and food demand. Results from the random coefficient discrete model show that the latest recalls, including both the number of recalls and the volume of food recalled, have a significant negative impact on the demand for fresh meat. Historical recalls are also important to mitigate the negative impact of the latest recalls on the market. In addition, Class I recalls, large recalls caused by product contamination, recalls due to produce without benefit of inspection or import violation, and recalls discovered by government agencies are more likely to cause a larger loss in meat demand.

This analysis is not without limitations. It's important to note that the data in this study does not contain non-UPC products such as random-weight meat. This paper only covers packaged meat and focuses on fresh meat products of the five categories, and we should be cautious when generalizing the conclusion to the entire meat market. However, we think it should be reasonable to assume that consumers have similar purchase preferences when buying packaged meat and random weight meat. Therefore, our main results should not be affected significantly. In addition, due to the higher representation of beef sales in our sample, the results in the paper might overestimate the market share for beef.

6.2. Policy implication

Given that consumers heterogeneously respond to the food recall information received from various channels such as the FSIS website, results from this paper shed light on related government policies and business strategies that aim to reduce the negative impact of recalls on the fresh meat demand.

In general, reducing the number of food recalls by preventing food safety issues from occurring is the most straightforward way to avoid demand reduction. For example, government agencies and food companies could take action to prevent recalls by increasing the mandatory inspection of fresh meat products prior to food distribution, to reduce recall scales and to respond quickly by developing standard regulations, guides, and procedures for recalling, especially for frequently recalled foods.

Specifically, to minimize the negative impact of recalls, the highest priority should be given to prevent a) large-scale recalls that have a wider range and greater severity; b) Class I recalls and product contamination recalls that have higher health risks to consumers; c) recalls due to being produced without benefit of inspection or import violation. Given that larger-scale recalls are more likely to occur in larger food manufacturers and distributors, more inspections and routine inspections should be carried out for large food companies. In addition, product contamination is the most common reason for recalls, and food companies should pay attention to production hygiene during the production process and avoid large-scale product contamination. For example, increasing the frequency of testing for bacterial contamination during production and before distribution, especially for bacteria with higher health risks and higher frequency, such as *E. coli* and *Listeria*. Moreover, government agencies can require retail stores not to sell products without benefit of inspection, advocate consumers not to buy uninspected products, and encourage them to report the non-inspected manufacturers to USDA if violations are discovered. Both the estimation results and simulation results show that recalls due to being produced without benefit of inspection or import violation have the largest negative impact on consumer demand. Therefore, if retail stores check manufacturers for USDA inspections and consumers check product packaging for USDA inspection marks, uninspected products will be discovered as quickly as possible before products are distributed to more stores and purchased by more consumers.

Furthermore, food companies should invest in strengthening food safety supervision during production and proactively recall when problems arise. Our results suggest that the negative impact on meat demand from a recall discovered by government agencies is over eight times higher than that initiated by a manufacturer itself. Voluntary recalls continue to be the fastest, most effective way for a company to keep consumers safe and to minimize the loss to the manufacturers themselves. For example, food companies can introduce automatic detection and alerting system to detect contamination as soon as possible before causing health risks to consumers or being discovered by the government.

CRediT authorship contribution statement

Pei Zhou: Data curation, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Yizao Liu:** Methodology, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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