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How Do *E. coli*. Recalls Impact Cattle and Beef Prices?

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We conducted an event study to examine the effect of *E. coli* recalls on prices in the vertically connected U.S. beef industry. Our findings show that the resulting price changes of beef products vary across stages in the U.S. beef industry and that the prices of disaggregated beef products are more vulnerable to *E. coli* recalls than the prices of aggregated products. This suggests that downstream agents transacting specific ground beef products may be more adversely affected by *E. coli* recalls than upstream agents trading live animals.

Key words: abnormal returns, beef industry, beef price response, cattle price response, event study, food recalls, food safety

Introduction

Foodborne illness creates individual and societal costs—including medical care, hospitalizations, and deaths. Because of these costs, food safety issues have received notable attention from researchers and policy makers. Hoffmann, Batz, and Morris (2012) estimated the total annual cost of illness caused by 14 major foodborne pathogenic diseases in the United States to be in the range of $4.4 billion to $33.0 billion and reported an annual loss of 61,000 quality-adjusted life years.[1,2] Hoffmann, Macullough, and Batz (2015) reported that about 48 million people suffer from foodborne illnesses annually at an estimated annual cost of $4.8 billion to $36.6 billion. Minor et al. (2015) estimated the annual social welfare costs of foodborne illness at $14.74 billion to $72.60 billion and the average cost burden per illness of $3,630. Scharff (2015) reported the national cost of foodborne illness at $33.87 billion to $83.25 billion annually. Given these findings, food safety is a major food policy issue in the United States.

A food safety recall, among the best-known and well-researched food safety policies, is an action taken by manufacturers or distributors to protect people from food products that have the potential to cause health problems or death. The main objective of a food safety recall is to remove potentially adulterated or misbranded products from the market. Information on food safety recalls is currently provided by the U.S. Food and Drug Administration (FDA) and the U.S. Department of

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[1] Hoffmann, Batz, and Morris (2012) covered *Campylobacter* spp., *Clostridium perfringens*, *Cryptosporidium parvum*, *Cyclospora cayetanensis*, *Escherichia coli* O157:H7 (*E. coli* O157), Shiga toxin–producing *E. coli* non-O157 (STEC non-O157), *Listeria monocytogenes* (listeria), norovirus, nontyphoidal *Salmonella enterica* (salmonella), *Shigella* spp., *Toxoplasma gondi*, *Vibrio vulnificus*, *Vibrio parahaemolyticus* and other noncholera *Vibrio* spp., and *Yersinia enterocolitica*.

[2] The quality-adjusted life year (QALY) is a measure of health outcomes in units of a year in some state of health, which is one of the most commonly used indicators of health-related quality of life (Minor et al., 2015). The QALY has a value of 1.0 for perfect health and 0.0 for death (Spicer et al., 2011).

Agriculture (USDA) and is delivered through their websites and many media outlets to help prevent the distribution and consumption of potential contaminants. Food recalls are classified as class I, II, and III according to the inherent risks of foodborne contaminants. Class I recalls are recognized as health hazard situations in which there is a reasonable probability that consuming the food products will cause illnesses or death. Class II indicates that there is a remote probability of adverse health consequences, and class III suggests a situation in which consuming the food will not cause adverse health problems (U.S. Department of Agriculture, 2013). One of the most frequently occurring class I recalls is for *E. coli* contamination, which often involves meat products.

A rational hypothesis is that when meat products are recalled, demand for meat or related products will decrease, which could lead to a decline in the price of meat products. Further, the effects of recalls on meat prices may be different within the supply chain. Different effects may be expected as the proportion of price tied to ground products differs. For instance, ground product markets are likely to react more strongly than primal, whole carcass, or live animal markets to a ground beef recall, where ground items comprise only a portion of the final products from these intermediate markets. Under this hypothesis, we investigated cattle and beef price responses to USDA Food Safety and Inspection Service (FSIS) *E. coli* recalls at different levels in the vertically connected U.S. beef industry. We conducted an event study using a constant-mean return model with 66 *E. coli*–driven recalls over 14 years. The findings provide evidence that *E. coli*–driven recalls affect cumulative abnormal returns and that the average impact lasts 4 days after the official recall releases. Importantly, our results suggest that price changes of beef products to *E. coli* recalls vary across the stages of the U.S. beef industry.

The main contribution of this study is to provide an updated and expanded assessment of price reactions throughout the beef-cattle industry to official beef safety recall information. Using data that have not been used in previous studies, this study demonstrates that food safety recalls can lead to short-term price declines in related products, which may directly affect agents' returns within the industry. This provides additional evidence that food safety recalls negatively affect live cattle futures prices (McKenzie and Thomsen, 2001; Lusk and Schroeder, 2002; Moghadam, Schmidt, and Grier, 2013) and beef prices (McKenzie and Thomsen, 2001). Further, we show that *E. coli* recall information causes a drop in boxed cutout beef prices, which expands upon McKenzie and Thomsen (2001), and that downstream local agents in the U.S. beef industry are likely to be more negatively affected by *E. coli* recalls than the upstream agents such as cattle owners.

Background Literature

Several studies have examined meat and poultry product recalls due to foodborne contaminants, such as *E. coli*, bovine spongiform encephalopathy (BSE), and other foodborne pathogens. Some articles examined the impact of meat safety information on beef and cattle prices (McKenzie and Thomsen, 2001; Lusk and Schroeder, 2002; Jin, Power, and Elbakidze, 2008; Moghadam, Schmidt, and Grier, 2013), while other studies focused on meat demand (Piggott and Marsh, 2004; Marsh, Schroeder, and Mintert, 2004; Mutondo and Henneberry, 2007; Shang and Tonsor, 2017) and investigated stock price reactions (Salin and Hooker, 2001; Thomsen and McKenzie, 2001; Seo et al., 2013; Pozo and Schroeder, 2016).

Lusk and Schroeder (2002); Jin, Power, and Elbakidze (2008); and Moghadam, Schmidt, and Grier (2013) investigated the impact of food safety event information, concentrating on price responses to food safety events in livestock future commodity markets. McKenzie and Thomsen (2001) studied live cattle prices and wholesale beef prices. McKenzie and Thomsen; Lusk and Schroeder; and Jin, Power, and Elbakidze reported marginal or not significant effects of food safety event announcements on live cattle or live hog futures commodity prices, but Moghadam, Schmidt, and Grier found that nearby cattle future prices adversely reacted to *E. coli* recalls, which contradicts McKenzie and Thomsen's and Lusk and Schroeder's results. McKenzie and Thomsen showed that boneless beef prices react negatively and significantly to recalls, although there is no considerable

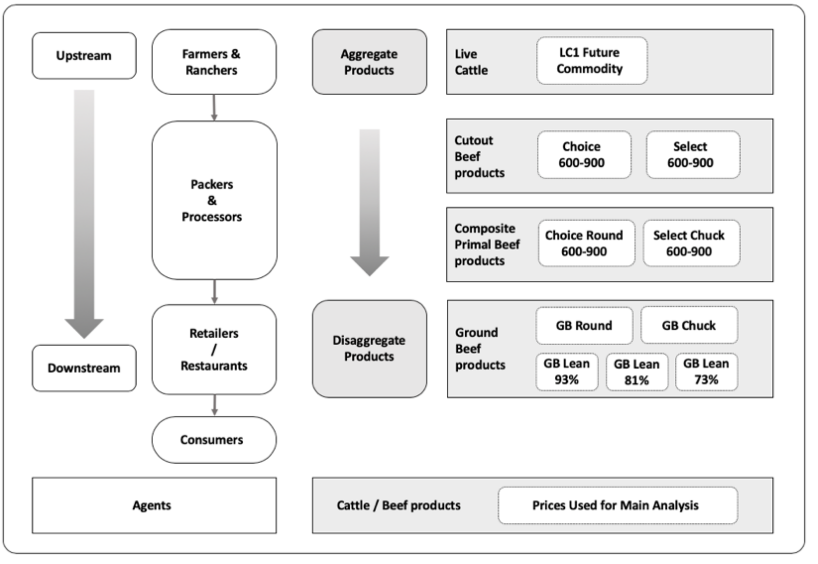

Figure 1. The Structure and Products of the Cattle and Beef Industry

reaction in live cattle prices or in boxed beef prices. Lusk and Schroeder indicated that medium-sized beef recalls about serious health concerns have a marginally negative short-term impact on live cattle futures prices. However, their results are not robust across recall size and severity. Jin, Power, and Elbakidze demonstrated that most North American BSE events appear not to have had a significant effect on live cattle futures prices and volatility, excluding the 2003 Canadian and U.S. BSE cases. The effect of the first U.S. BSE case on live cattle futures was generally stronger and more persistent for nearby maturities than it was for more distant futures contracts. Their study indicated that both the 2003 BSE cases in Canada and the United States increased the volatility of futures prices, and the increase in volatility was stronger for nearby maturity contracts than for more distant ones. Moghadam, Schmidt, and Grier found that *E. coli* O157:H7 recalls had negative impacts on the nearby cattle futures price, but the impacts were short-lived, which indicates that the release of an official recall is not considered as new information in the cattle futures market, because prices are completely adjusted before the release of information to the public.

Among studies that meat recalls adversely affect meat demand, Piggott and Marsh (2004) found that consumers have precommitted levels of meat demand, which is not sensitive to price and income, and that the average demand response to food safety events is economically small. On the other hand, other studies contradict Piggott and Marsh, suggesting a more considerable effect of meat recalls on meat demand (Marsh, Schroeder, and Mintert, 2004; Mutondo and Henneberry, 2007; Shang and Tonsor, 2017). Studies concentrating on financial markets have provided evidence that food safety recalls adversely affect stock returns (Salin and Hooker, 2001; Thomsen and McKenzie, 2001; Seo et al., 2013; Pozo and Schroeder, 2016). Some other studies have expanded the assessment of food safety impacts to a method of mitigating the probability of foodborne illness (Tonsor and Schroeder, 2015) and to consumer responses and perceptions (Taylor, Klaiber, and Kuchler, 2016; Tonsor, Schroeder, and Pennings, 2009).

In this context, we investigated price responses to a USDA FSIS food safety recall announcements at different stages within the U.S. beef industry. Figure 1 illustrates the beef-cattle industry structure and products and describes the price series of cattle and beef products for analysis. The main objective of this study is to provide a more current, less aggregated assessment by expanding the price series and analyzing different prices in the beef industry that are potentially impacted by class I foodborne pathogen recalls. This study is additional evidence that food safety recalls negatively affect live cattle futures prices (McKenzie and Thomsen, 2001;

Lusk and Schroeder, 2002; Moghadam, Schmidt, and Grier, 2013) and beef prices (McKenzie and Thomsen, 2001). This extended assessment of price impacts at various industry levels helps us better understand the economic impacts of food safety recalls in the U.S. beef industry.

Event Study

Event study methods generally measure the impact of a specific event on the value of a firm, and many empirical applications have examined the price effects of a common stock split (MacKinlay, 1997). In event study, it is assumed that market values reflect all publicly available information and only an unexpected event would change prices (MacKinlay, 1997; Moghadam, Schmidt, and Grier, 2013). In the area of agricultural and food economics, event studies have been conducted to assess agricultural and food price reactions to a certain circumstance and to quantify the impact of a specific issue on related stock returns. In our study, we use this method to compare mean returns over the estimation window—the period before a recall event—with returns over the event window—the period after the recall event (Moghadam, Schmidt, and Grier, 2013). The estimation windows are the intervals in event time $[T_1, T_2]$: $[-22, -8]$ and $[-17, -8]$, where T_1 and T_2 are the first and the last days of the estimation window. The event windows corresponding to each the estimation window include market reaction days $T_2 + 1$ to $T_2 + 12$ (i.e., -7 to +5, McKenzie and Thomsen, 2001).

Our study employed the constant-mean return model for event study to assess the impact of beef product recalls due to *E. coli* on cattle and beef prices. The constant-mean return model assumes that the mean return of a given commodity is invariant over time (MacKinlay, 1997). Thus, the constant-mean return model can be expressed as

(1) $$R_{it} = \mu_i + \xi_{it},$$

where i and t indicate event and time, respectively; R_{it} is the period-t daily return at time t; μ_i is the period-t mean return; and ξ_{it} is the period-t disturbance term (MacKinlay, 1997). In this model, we assume that $E(\xi_{it}) = 0$ and $\text{var}(\xi_{it}) = \sigma^2_{\xi}$.

We use simple daily returns (McKenzie and Thomsen, 2001; Moghadam, Schmidt, and Grier, 2013) for observed live cattle and beef product prices, which are measured as

(2) $$R_{it} = \ln\left(\frac{P_{it}}{P_{it-1}}\right) 100,$$

where P_{it} denote the observed daily prices at time t.

Abnormal returns are defined as the deviation from normal returns and are calculated from the difference between actual returns and normal returns over the event window (McKenzie and Thomsen, 2001; Kothari and Warner, 2007):

(3) $$AR_{it} = R_{it} - \bar{R}_i,$$

where AR_{it} is the abnormal returns for recall event i at time t and $\bar{R}_i$ is the normal returns under the constant return model, calculated as $\widehat{\mu}_i = \bar{R}_i = \frac{1}{\mathrm{T}} \sum_{\mathrm{t}=1}^{\mathrm{T}} \mathrm{R}_{\mathrm{it}}$.

Abnormal returns are averaged across the recall events to find the mean abnormal return for each day of the event window (McKenzie and Thomsen, 2001; Thomsen and McKenzie, 2001; Moghadam, Schmidt, and Grier, 2013):

(4) $$AR_t = \frac{1}{N}\sum_{i=1}^{N} AR_{it}$$

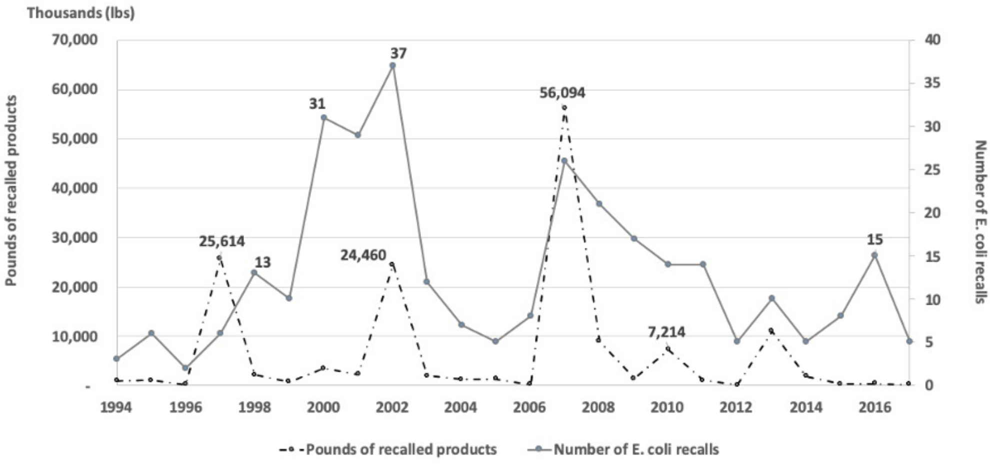

Figure 2. Recalls and Pounds of Recalled Products for *E. coli* by Year (*N* = 309)

Then, we can quantify the total impact of an event over interval of $[\tau_1, \tau_2]$ by using the cumulative abnormal returns (CAR), obtained by adding up the abnormal returns for each *E. coli* recall event:

(5) $$CAR_i(\tau_1, \tau_2) = \sum_{t=\tau_1}^{\tau_2} AR_{it},$$

where $T_2 + 1 \leq \tau_1 \leq \tau_2 \leq 5$.

In addition, the cumulative average abnormal returns (CAAR) are obtained by taking the mean of the cumulative abnormal returns over the recall events to assess the average proportional impact of the event (Thomsen and McKenzie, 2001):

(6) $$CAAR(\tau_1, \tau_2) = \frac{1}{N}\sum_{i=1}^{N} CAR_i.$$

This study considers that CAAR will be nonnegative under the null hypothesis and negative under the alternative hypothesis:

(7) $$H_0:\ CAAR(\tau_1, \tau_2) \geq 0 \text{ vs. } H_1:\ CAAR(\tau_1, \tau_2) < 0.$$

The parametric test statistic, Z_p, is used for the hypothesis test according to Moghadam, Schmidt, and Grier (2013). It is also employed for the abnormal returns since $CAAR(\tau_1, \tau_2) = AR_t$ when $\tau_1 = \tau_2 = \text{t}$:

(8) $$Z_p = \frac{CAAR(\tau_1, \tau_2)}{\text{Var}(CAAR(\tau_1, \tau_2))^{1/2}} \sim N(0,1).$$

Data

E. coli Recalls

Data for beef products recalled because of *E. coli* were obtained from the USDA FSIS website, which provides information about current recalls and on recall case archives since 1994. This includes recalled products, their producers, recall initiation dates, press releases for the recalled products, the distributed regions, and the quantities reported recovered by establishments. For this study, we collected 309 food safety official recall announcements for *E. coli* from January 1994 to

Table 1. Summary Statistics of *E. coli* Recalls per Year

	All *E. coli* Recalls				*E. coli* Recalls Used for the Analysis			
		Recalled Products (lb)				Recalled Products (lb)		
Year	*N*	Total	Average	Std. Dev.	*N*	Total	Average	Std. Dev.
2004	7	1,198,600	199,767	198,158	6	792,600	158,520	190,588
2005	5	1,248,450	249,690	369,174	4	1,242,250	310,563	396,253
2006	8	181,900	22,738	54,109	3	161,776	53,925	88,637
2007	26	56,094,333	2,157,474	5,887,042	7	231,581	33,083	42,083
2008	21	8,862,075	492,338	1,268,710	4	102,750	25,688	29,839
2009	17	1,368,100	80,476	159,327	4	9,172	2,293	2,155
2010	14	7,213,699	515,264	1,303,160	5	1,300,373	260,075	415,829
2011	14	1,003,331	71,667	108,973	6	327,372	54,562	87,042
2012	5	63,467	12,693	15,510	3	44,357	14,786	20,303
2013	10	10,967,761	1,218,640	3,481,360	5	76,059	19,015	23,005
2014	5	1,840,533	368,107	800,511	5	1,840,533	368,107	800,512
2015	8	215,593	30,799	61,081	5	197,071	39,414	72,450
2016	15	292,640	19,509	55,601	6	11,569	1,928	1,941
2017	5	148,593	37,148	31,632	3	63,512	31,756	12,620
Total	113	90,699,075	592,804	2,698,588	66	6,400,975	101,603	280,764

Notes: Average excludes three missing values for pounds of recalled products.

May 2017, including *E. coli* O26, *E. coli* O45, *E. coli* O102, *E. coli* O103, *E. coli* (STEC), and *E. coli* O157:H7. All recall events induced by *E. coli* were class I recalls, which may lead to a health hazard situation in which there is a reasonable probability that consuming the food will cause health risks or death.

Figure 2 shows *E. coli* recall releases over time in terms of the number of recalls and pounds of recalled products. The number of recalls increased from 1994 to 2002, ending with 37 recalls as a result of *E. coli* in 2002. In 2003, the annual incidence of recall events decreased substantially, and the frequency remained below 10 recalls until 2006. The annual frequency of *E. coli* recalls has declined since 2007, when *E. coli* recalls surged. The volume of recalled items was large when expansions occurred several days after the original recalls, particularly in 2002 (three recall expansions, totaling 21.5 million pounds) and in 2007 (four expansions, totaling over 49.5 million pounds).

We used 66 of 113 recall events between 2004 and 2017 to examine price responses in the U.S. beef industry (Table 1). To maintain consistency with the period of the price data, the collected recall data were sorted, leaving 66 appropriate recall events. First, we excluded non-U.S. and non-beef recall events, including recalls of lamb, poultry, bologna, pizza, and salami products as well as the recalls of products imported from Canada, leaving 294 U.S. beef recall events. Second, we ruled out 17 events that were expansions of recalls that added products processed from and/or commingled with the source material implicated in the original recall, leaving 277 recall events. These events were removed because these recall expansions were not only extensions of the original recalls but also overlapped with them.

Third, we restricted the price series from after February 2, 2004, to compare the effect of *E. coli* recalls on multiple prices within the U.S. beef industry. This is because data on the market values of boxed cutout and composite primal products were available after February 2, 2004. Fourth, there is a data issue related to clustered recall events. McKenzie and Thomsen (2001) highlighted that the impact of a single event on price could not be isolated from the impact of successive recalls. To address this problem, McKenzie and Thomsen excluded recall events occurring within 18 days of one another, while Moghadam, Schmidt, and Grier (2013) used 21 days as their threshold. Following Moghadam, Schidt, and Grier, we applied accounted for only one recall event every 21 days, to

Table 2. Summary Statistics of Cattle and Beef Prices Employed for Event Study

Variable	Description		*N*	Mean	Std. Dev.	Min.	Max.
Live cattle	LC1 ($/100 lb)		1,276	109.1	23.721	73.6	171.0
Boxed cutout	Choice 600–900 ($/100 lb)		1,267	179.2	38.179	123.9	263.8
	Select 600–900 ($/100 lb)		1,267	170.2	37.374	117.2	260.8
Composite primal	Chuck	Choice 600–900 Chuck ($/100 lb)	1,267	142.5	38.594	86.6	243.5
		Select 600–900 Chuck ($/100 lb)	1,267	141.1	37.666	86.0	243.8
	Round	Choice 600–900 Round ($/100 lb)	1,267	154.6	36.603	104.9	263.6
		Select 600–900 Round ($/100 lb)	1,267	153.4	37.151	102.6	265.5
Ground beef	Ground beef chuck ($/100 lb)		1,267	173.9	48.814	105.2	337.2
	Ground beef round ($/100 lb)		1,213	200.7	64.840	116.9	373.3
	Ground beef lean 93% ($/100 lb)		1,200	223.3	68.071	117.0	388.8
	Ground beef lean 81% ($/100 lb)		1,269	165.8	45.498	97.4	320.0
	Ground beef lean 73% ($/100 lb)		1,268	144.5	43.323	76.2	294.4

rule out the effect of clustered events, which may have happened in 113 recall release events since February 2004.[3] The final dataset for our study includes 66 recalls.

Cattle and Beef Prices

To compare the impact of *E. coli* recalls on various prices, we first employed the Chicago Mercantile Exchange's Daily Live Cattle settlement prices of Live Cattle Commodity 1 (LC1) from the Bloomberg Terminal for cattle futures prices.[4] Live cattle settlement prices for LC1, which are based on nearby contracts, were collected between January 3, 1994, and June 30, 2017. We also used National Daily Boxed beef cutout (LM_XB403) from the USDA Agricultural Marketing Service's Data Mart for beef prices. Observed beef prices since January 5, 2004, were obtained from the USDA Agricultural Marketing Service. We used the boxed cutout, composite primal, and ground beef values to assess the effect on the prices of beef products. The boxed cutout and composite primal beef products prices are for both Choice 600–900 and Select 600–900 and cover the period from January 5, 2004, through June 30, 2017. Ground beef products prices in the National Daily Boxed beef cutout (LM_XB403) consist of prices of ground beef sirloin, round, and chuck products as well as prices of 93%, 90%, 85%, 81%, 75%, and 73% ground beef products.[5] The price series of ground beef products cover the period from April 3, 2001, to June 30, 2017. The number of observed prices of the ground beef products varies among products. Thus, we used the price data for the ground beef round and chuck products and the ground beef products of lean 93%, 81%, and 73% products, respectively, to analyze the impact on the prices of ground beef products. For consistency, we compared ground beef round and chuck products with the composite primal round and chuck products, respectively. We used 93%, 81%, and 73% lean ground beef products to examine whether the impacts of *E. coli* vary across ground beef products in terms of the lean-to-fat ratio.

As previously mentioned, to make appropriate comparisons we must balance the periods among different price series, corresponding with the *E. coli* dataset. Thus, we used cattle and beef prices and *E. coli* events between February 2, 2004, and June 9, 2017, to accomplish our main objective.

[3] The number of recall events that are applied in analysis varies across the prices and estimation windows in practice. To examine the impact of *E. coli* recalls on respective beef products' price series, we used recalls corresponding to the price series collected.

[4] Bloomberg Terminal is a computer software system that provides financial market data, market news, analytic tools, and an electronic trading platform.

[5] The percentage indicates the lean content of ground beef products. For instance, 93% indicates that the ground beef product contains 93% lean beef and 7% fat.

Table 2 describes the price data used for our analysis. Each product has a slightly different number of observations, but all are around 1,267 (except 1,200 for the 93% lean ground beef product). This difference in the number of observations among different price series resulted from some missing values. The price of LC1 is $109.1 per 100 pounds, on average. Average values of cutout Choice 600–900 and Select 600–900 are $179.2 and $170.2, respectively, indicating that Choice cutout value is about $9 higher than Select cutout value. In the case of composite primal values, round and chuck have a little spread between Choice 600–900 and Select 600–900. The 93% ground beef item has the highest average value, $223.3, and 73% ground beef has the lowest average value ($144.5) among ground beef products. The average prices of ground beef round and chuck products are between 93% and 81% ground beef (Table 2). This more complete spectrum of cattle, aggregated beef, and disaggregated beef product price series enables a more complete assessment of recall impacts described in the next section.

Results

We evaluated the average daily abnormal returns (AR) and the cumulative average abnormal returns (CAAR) for a live cattle future commodity (LC1) price, two boxed cutout beef prices, two composite primal beef prices, and five ground beef product prices. First, we explain the results of the average daily AR estimations and then continue with more detailed discussions focusing on the CAAR assessments.

We estimated the average daily AR for the LC1 price and various beef product prices and then calculated the CAAR based on the estimated the average daily AR. We also conducted multiple sensitivity analyses to examine how average daily AR and CAAR respond to a change in estimation and event windows. Table 3, which reports the average daily AR for prices of LC1 and different beef products, is a collection of some representative results of sensitivity analyses.[6]

Table 3 reports some negative AR pre-event price reactions, especially on market reaction days −5 and −4, although the event price responses vary across the products examined. The average daily AR of the boxed cutout and composite primal beef products in columns 3–6 have negative values and are statistically significant on market reaction days −5 and −4. There are some differences between the impacts on Choice and Select beef grades. In particular, the average daily AR of the Choice cutout in column 3 and the Choice composite primal beef round products in column 5 are negative, which are statistically significant between market reaction days −7 and −4, whereas the average daily AR of the Select-graded beef products in columns 4 and 6 are statistically significant negative values between market reaction days −6 and −3 (−5 and −3 for the Select chuck product). Ground chuck and the 93% and 81% ground beef products have significant negative AR at market reaction day −4.

These findings are consistent with McKenzie and Thomsen (2001) and Moghadam, Schmidt, and Grier (2013), who also find *ex ante* price reactions before food safety events. These price movements may be caused by the leakage of *E. coli* recall information prior to the official recall, but the reason is not apparent in this analysis. Further, compared to AR for composite beef products, the degree of the *ex ante* price declines of the less aggregated beef products are larger than that of aggregated products. This indicates that the *E. coli* impact on less aggregate beef products is larger than for more aggregate products.

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6 In Tables 3 and 4, we used the estimation windows of [−17, −8] and [−22, −8] periods, which are statistically significant on the many market reaction dates and easy to compare in parallel. The estimation windows are used to find normal returns (i.e., when the effects of a recall event do not occur). The [−17, −8] estimation window indicates the period of 17 to 8 days before a recall occurs, and the [−22, −8] estimation window is 8 to 22 days before a recall event. Normal returns may vary with the estimation window. This means that the average daily abnormal returns and cumulative average abnormal returns also depend on how set the period of the estimation window is set. We carried out sensitivity analyses of average daily abnormal returns and cumulative average abnormal returns according to changes in the estimation window; Tables 3 and 4 present some of the results.

Table 3. Average Daily Abnormal Returns (AR) for Cattle and Beef Products Prices

	Live Cattle	Boxed Cutout		Composite Primal		Ground Beef				
Market Reaction Day	LC1 [−17, −8]	Choice 600–900 [−17, −8]	Select 600–900 [−22, −8]	Choice Round [−17, −8]	Select Chuck [−22, −8]	Round [−22, −8]	Chuck [−22, −8]	Lean 93% [−17, −8]	Lean 81% [−17, −8]	Lean 73% [−17, −8]
−7	0.062	−0.135*	−0.035	−0.206*	0.080	−0.349	−0.206	0.380	−0.275	−0.589
	(0.457)	(−1.443)	(−0.412)	(−1.618)	(0.632)	(−0.998)	(−0.349)	(0.931)	(−0.550)	(−1.164)
−6	0.024	−0.181**	−0.143**	−0.459***	−0.051	−1.029***	−0.149	0.206	0.057	−0.047
	(0.163)	(−1.818)	(−1.581)	(−4.107)	(−0.319)	(−2.929)	(−0.272)	(0.477)	(0.139)	(−0.080)
−5	−0.185	−0.214***	−0.277***	−0.450***	−0.395***	−0.539	−0.111	−0.081	−0.815*	−0.104
	(−0.954)	(−2.758)	(−3.575)	(−4.164)	(−3.226)	(−1.011)	(−0.212)	(−0.168)	(−1.552)	(−0.208)
−4	−0.057	−0.266**	−0.331***	−0.488***	−0.540**	−0.258	−1.780**	−2.434***	−1.493***	−1.009
	(−0.271)	(−1.979)	(−3.270)	(−3.035)	(−2.332)	(−0.640)	(−2.294)	(−4.023)	(−2.759)	(−1.171)
−3	−0.270**	−0.056	−0.174**	−0.079	−0.402**	−0.495	0.426	0.313	0.032	−0.624
	(−2.165)	(−0.443)	(−1.798)	(−0.521)	(−2.217)	(−0.974)	(0.645)	(0.427)	(0.060)	(−1.104)
−2	−0.224	0.003	−0.039	−0.306*	−0.078	−0.302	−0.227	−0.185	0.618	−0.695
	(−0.662)	(0.021)	(−0.251)	(−1.466)	(−0.358)	(−0.679)	(−0.432)	(−0.234)	(0.959)	(−1.053)
−1	−0.182	−0.095	−0.169*	−0.169*	−0.122	0.300	0.690	0.686	−0.602	−0.137
	(−1.174)	(−0.789)	(−1.347)	(−1.311)	(−0.629)	(0.565)	(1.545)	(1.309)	(−1.022)	(−0.230)
0	−0.461***	−0.049	−0.072	−0.015	−0.087	−0.044	−0.494	0.037	0.418	0.217
	(−3.388)	(−0.508)	(−0.927)	(−0.142)	(−0.679)	(−0.116)	(−1.030)	(0.072)	(0.861)	(0.536)
1	0.274	−0.252***	−0.204***	−0.492***	−0.312**	−0.762**	0.471	0.135	−0.647*	−0.274
	(1.024)	(−2.645)	(−2.582)	(−3.662)	(−2.276)	(−1.774)	(0.996)	(0.287)	(−1.349)	(−0.573)
2	0.025	−0.339***	−0.279***	−0.457***	−0.433***	−0.427	−0.798*	−0.385	−0.704**	−1.427***
	(0.228)	(−3.091)	(−2.818)	(−3.558)	(−2.655)	(−1.161)	(−1.561)	(−0.707)	(−1.770)	(−3.644)
3	0.102	−0.198**	−0.234**	−0.156	−0.303*	−0.392	−0.497	0.164	−0.656*	−0.154
	(0.420)	(−1.607)	(−1.842)	(−1.217)	(−1.496)	(−0.802)	(−0.862)	(0.259)	(−1.417)	(−0.280)
4	−0.134	−0.052	−0.158	−0.173	−0.061	−0.174	−1.229**	−0.824*	−0.051	−0.611
	(−0.753)	(−0.417)	(−1.221)	(−1.225)	(−0.317)	(−0.286)	(−1.896)	(−1.400)	(−0.085)	(−0.841)
5	−0.669***	0.106	−0.119	0.026	−0.010	0.283	0.136	0.816	0.120	−0.389
	(−3.775)	(0.661)	(−0.834)	(0.164)	(−0.043)	(0.422)	(0.260)	(1.383)	(0.332)	(−0.812)
Min. avg. daily AR	−0.669	−0.339	−0.331	−0.492	−0.540	−1.029	−1.780	−2.434	−1.493	−1.427
Max. avg. daily AR	0.274	0.106	−0.035	0.026	0.080	0.300	0.691	0.816	0.618	0.217
Difference	0.942	0.445	0.296	0.518	0.620	1.329	2.470	3.250	2.111	1.644

Notes: Single, double, and triple asterisks (*, **, ***) denote significance at the 10%, 5%, and 1% level, respectively. Test statistics are presented in parentheses.

Table 4. Cumulative Average Abnormal Returns (CAAR) for Cattle and Beef Products Prices

	Live Cattle	Boxed Cutout		Composite Primal		Ground Beef				
Event Window	**LC1** [−17, −8]	**Choice 600–900** [−17, −8]	**Select 600–900** [−22, −8]	**Choice Round** [−17, −8]	**Select Chuck** [−22, −8]	**Round** [−22, −8]	**Chuck** [−22, −8]	**Lean 93%** [−17, −8]	**Lean 81%** [−17, −8]	**Lean 73%** [−17, −8]
[−7, −7]	0.062	−0.135*	−0.035	−0.206*	0.080	−0.349	−0.207	0.380	−0.275	−0.589
	(0.457)	(−1.443)	(−0.412)	(−1.618)	(0.632)	(−0.998)	(−0.349)	(0.931)	(−0.550)	(−1.164)
[−7, −6]	0.050	−0.221	−0.119	−0.599***	0.054	−0.931**	−0.433	0.679	−0.156	−0.533
	(0.239)	(−1.246)	(−0.724)	(−2.839)	(0.204)	(−2.368)	(−0.827)	(1.806)	(−0.222)	(−0.964)
[−7, −5]	−0.116	−0.335*	−0.319*	−0.962***	−0.227	−1.109**	0.104	0.882	−0.315	−0.664
	(−0.394)	(−1.473)	(−1.471)	(−3.544)	(−0.666)	(−2.250)	(0.166)	(1.657)	(−0.500)	(−0.819)
[−7, −4]	−0.221	−0.460**	−0.546**	−1.313***	−0.594*	−1.666***	−1.382*	−1.814**	−1.928**	−1.926*
	(−0.708)	(−1.727)	(−2.236)	(−3.505)	(−1.321)	(−3.179)	(−1.347)	(−2.283)	(−2.126)	(−1.478)
[−7, −3]	−0.366	−0.349	−0.601**	−0.825**	−0.662	−1.821***	−0.323	−0.487	−1.465*	−1.207
	(−1.010)	(−1.222)	(−2.158)	(−1.807)	(−1.267)	(−3.362)	(−0.309)	(−0.662)	(−1.609)	(−1.157)
[−7, −2]	−0.003	−0.549*	−0.571*	−1.013**	−0.640	−1.894***	−1.241	−0.372	−0.683	−0.902
	(−0.007)	(−1.457)	(−1.487)	(−1.929)	(−1.098)	(−3.389)	(−1.065)	(−0.560)	(−0.631)	(−0.751)
[−7, −1]	−0.369	−0.663**	−0.719**	−1.504***	−0.936*	−1.748***	−0.999	−0.936	−1.884*	−2.109*
	(−0.871)	(−1.683)	(−1.846)	(−2.935)	(−1.573)	(−2.971)	(−0.931)	(−1.269)	(−1.648)	(−1.468)
[−7, 0]	−0.927***	−0.746**	−0.869***	−1.522***	−1.036**	−1.739***	−1.451*	−0.617	−1.464*	−1.928*
	(−2.562)	(−2.135)	(−2.575)	(−3.338)	(−1.924)	(−3.157)	(−1.491)	(−1.048)	(−1.619)	(−1.515)
[−7, +1]	−0.659*	−0.969**	−1.057***	−2.241***	−1.437**	−2.396***	−1.448*	−0.268	−2.052**	−2.697**
	(−1.515)	(−2.147)	(−2.504)	(−4.116)	(−2.255)	(−3.548)	(−1.365)	(−0.444)	(−1.779)	(−2.102)
[−7, +2]	−0.790*	−1.297**	−1.263**	−2.689***	−1.802**	−2.580***	−1.493	−0.149	−1.869*	−3.381**
	(−1.679)	(−2.336)	(−2.411)	(−3.845)	(−2.116)	(−3.752)	(−1.104)	(−0.187)	(−1.383)	(−2.281)
[−7, +3]	−0.974**	−1.437**	−1.561***	−2.742***	−2.104**	−2.865***	−1.529	−0.640	−2.778**	−3.074**
	(−2.182)	(−2.367)	(−2.742)	(−3.577)	(−2.239)	(−3.621)	(−1.109)	(−0.886)	(−2.055)	(−1.813)
[−7, +4]	−0.522	−1.328**	−1.633***	−2.214***	−1.803**	−2.899***	−2.990**	−1.474*	−3.024**	−3.945**
	(−1.135)	(−2.261)	(−2.829)	(−2.711)	(−2.089)	(−2.904)	(−2.036)	(−1.664)	(−1.975)	(−1.996)
[−7, +5]	−1.186**	−0.750	−1.301**	−1.515*	−1.267	−2.062**	−1.483	−0.143	−1.233	−2.218
	(−1.966)	(−1.035)	(−1.803)	(−1.615)	(−1.283)	(−2.119)	(−0.881)	(−0.161)	(−0.835)	(−1.102)
Min. CAAR	−1.186	−1.437	−1.633	−2.742	−2.104	−2.899	−2.990	−1.814	−3.024	−3.945
Max. CAAR	0.062	−0.135	−0.035	−0.206	0.080	−0.349	0.104	0.882	−0.156	−0.533
Difference	1.248	1.302	1.598	2.536	2.185	2.550	3.094	2.696	2.869	3.412

Notes: Single, double, and triple asterisks (*, **, ***) denote significance at the 10%, 5%, and 1% level, respectively. Test statistics are presented in parentheses.

Price reactions after the official announcement of *E. coli* recalls are prominent on market reaction days +1 and +2, although they vary by product. The average daily AR of the boxed cutout values is less sensitive than that of the composite primal products. Compared to composite primal beef products, ground beef prices are more affected by *E. coli* recall events. In the case of ground beef products, products with higher lean content are relatively less sensitive to *E. coli* recalls than those with higher fat content.

For instance, the average daily AR of the Choice boxed cutout are −0.252 and −0.339 on market reaction days +1 and +2, respectively, less than those of the Choice round beef product, −0.492 and −0.475, respectively, on the same market reaction dates. In addition to the Choice grades, the average daily AR of the Select cutout are −0.204 and −0.279, respectively, less than those of the Select chuck beef product of −0.303 and −0.433 on market reaction days +1 and +2. The average daily AR of the 73% and 81% ground beef on market reaction day +2 are both statistically significant at −1.427 and −0.704, respectively. This illustrates that the price of the 73% ground beef is more likely to be sensitive to *E. coli* recall information than the 81% lean product.

Further, the average daily AR of Choice boxed cutout, Choice composite primal round, and ground beef round products on market reaction day +1 are −0.252, −0.492, and −0.762, respectively, all of which are statistically significant. Similarly, the average daily AR of the Select boxed cutout, Select composite primal chuck, and ground beef chuck on market reaction day + 2 are also statistically significant at −0.279, −0.433, and −0.798, respectively. These imply that less aggregated ground beef products are more likely to be more susceptible to *E. coli* recall information than more aggregated beef products.

Table 4, which reports the CAAR assessments for LC1 and beef products prices, is a collection of some representative significant results based on our sensitivity analysis. The significant CAAR estimates correspond to the estimation windows of [−22, −8] or [−17, −8].

The most notable result of this study is that the impact of *E. coli* on price becomes relatively smaller further upstream. In other words, the less aggregated the beef product, the bigger the absolute value of CAAR. In terms of absolute value, boxed cutout beef products have greater CAAR greater than do LC1, and the ground beef products have larger values of CAAR than the cutout beef products have. The prices of the ground beef products that are the most separated fluctuate more than those of other relatively aggregated products as a result of *E. coli*–driven beef recalls. For composite primal products, we need to consider that the average price of different composite primal beef products would be the price of the boxed cutout beef products since the boxed cutout beef is separable into several composite primal beef products to be distributed to markets. For this reason, the values of some composite primal beef products may be more or less sensitive than cutout beef prices.

In the example of the relationship between the LC1 and the boxed cutout with the event window of [−7, +1], the LC1 have CAAR of −0.659, while the Choice cutout and Select cutout products have CAAR of −0.969 and −1.057, respectively. This shows that the cutout beef products have greater CAAR than does the LC1. We can see the same phenomenon during the event windows of [−7, +2] and [−7, +3].

With the comparison between the boxed cutout and composite primal beef products, we also can see that more separated beef has larger absolute values of CAAR. In Table 4, this is shown with the evaluation of cutout in column 3 and round in column 5 for the Choice grade across all event windows and the evaluation of cutout in column 4 and chuck in column 6 for the Select grade after the [−7, −4] event window. Specifically, the Choice boxed cutout and the Choice round have CAAR of −0.460 and −1.313, respectively, over the [−7, −4] event window and −1.328 and −2.214, respectively, over the [−7, +4] event window. Thus, the Choice boxed cutout beef product—which is more aggregated—has a smaller absolute value of CAAR than does the Choice round beef. For Select-grade beef, the boxed cutout and the chuck have CAAR of −0.546 and −0.594, respectively, over the [−7, −4] event window and −1.633 and −1.803, respectively, over the [−7, +4] event window. Hence, the magnitude of negative impact of *E. coli* on the Select chuck is larger than that

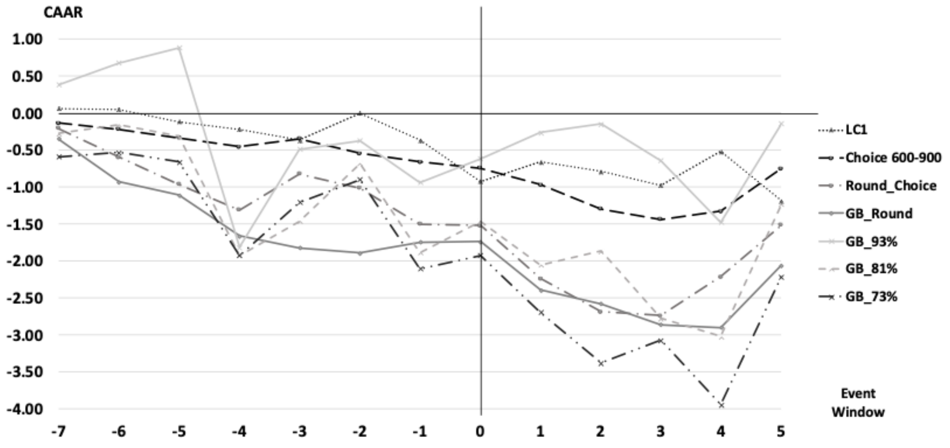

Figure 3. Cumulative Average Abnormal Returns (CAAR) Movements

on the Select boxed cutout. This case is also the same as the example of the evaluation of the Choice boxed cutout and the Choice round.

The results in Table 4 also suggests the same for the composite primal and the ground beef products. In detail, on the formal recall announcement date [−7, 0], Choice round and ground beef round products have CAAR of −1.522 and −1.739, respectively. This implies that the effect of *E. coli* recalls is more pronounced in ground beef product prices than in the Choice round price. Moreover, all of the Choice round products in column 5 have smaller absolute values of CAAR than do the ground beef round in column 7 for each event window, all of which are statistically significant and negative except for the [−7, −7] and [−7, +2] event windows. The fact that less aggregated beef products have greater absolute values of CAAR is the comparable case between Select chuck in column 6 and ground beef chuck in column 8. A similar trend exists in some cases where the Select chuck and ground beef chuck have statistically significant CAAR.

These findings can be continuously applied in the example of the ground beef products in which the response to the *E. coli* recalls varies with the lean-to-fat ratio. The last three columns of Table 4 indicate that the prices of ground beef products with lower lean contents are more sensitive to *E. coli* recalls. For instance, on the first 4 days after the official recall notice, the 93%, 81%, and 73% ground beef products have CAAR of −1.474, −3.024, and −3.945, respectively, all of which are statistically significant and negative. The tendency among ground beef products is shown after the [−7, −2] event window (2 days before the formal recall date), although not all CAAR are statistically significant. It makes sense that most beef *E. coli* events involve ground beef products: The fact that the price of low-lean ground beef products are more sensitive than high-lean ground beef is also likely to be affected by the expenditure elasticity, in that 70%–77% lean ground beef products have a greater expenditure elasticity than 90%–95% lean products (Schulz, Schroeder, and Xia, 2012).

Figure 3 illustrates the CAAR movements around the recall announcement date, reporting that LC1 experiences the smallest fluctuation in CAAR (between −1.186 and 0.062) and 73% ground beef products experience the largest fluctuation (between −3.945 and −0.533). This gives us an insight that the effect of *E. coli* recalls is bigger in the downstream of the beef industry than upstream. Compared with the CAAR of different prices in parallel, the CAAR of the beef prices are negative, with the lowest values in the [−7, +3] or [−7, +4] event window (with the exception of 93% ground beef). All products' CAAR generally recover after the event [−7, +4] window, with the exception of that of the LC1, as shown in Figure 3. Thus, the effect of *E. coli* recalls on beef prices continues for approximately 4 days after official *E. coli* warnings.

The main result of this study is that *E. coli* recalls have different magnitudes of impact within the U.S. beef industry; local downstream firms, such as supermarkets and grocery stores, are likely to be more financially affected by *E. coli* recalls than the upstream agents, such as cattle ranches. Since local downstream agents are more likely to be impacted financially, they may consider expanded incentives for upstream agents to implement additional risk-mitigating effort beyond what is currently optimal for them in current markets.

This study suggests that *E. coli* recall information is likely to have a negative impact on the beef industry in the form of cumulative abnormal returns. This result may motivate agents in the U.S. beef industry to establish and manage a food safety control mechanism on the whole beef value chain, including slaughtering, transportation, storage, packaging, and retailing. The beef industry could manage feedlots with a regimented disease prevention and control adoption of *E. coli* vaccination (Tonsor and Schroeder, 2015). Additionally, they could secure and run a food safety management system throughout the entire production process (Shang and Tonsor, 2017).

Conclusions and Discussions

This study examined the impact of *E. coli* recall information on cattle and beef prices using an event study method. Our findings provide evidence that *E. coli* recalls can negatively affect cumulative abnormal returns in the U.S. beef industry. The impact of *E. coli* recalls on beef prices is generally limited to the short term. The impact lasts for 4 days after the official announcement, after which actual returns tend to recover. Moreover, we describe how *E. coli* recalls affect the U.S. beef industry by analyzing the abnormal returns and the cumulative abnormal returns in the representative steps in the vertically connected beef industry. Our results reveal that price changes of beef products due to *E. coli* recalls vary across stages in the U.S. beef industry; downstream agents are likely to be more affected by *E. coli* recalls than upstream agents in terms of financial returns. This may be because *E. coli* bacterial contamination is a greater risk factor in ground beef products, which have a large surface area than other beef items. This gives additional evidence that food safety recalls can harm live cattle futures prices (McKenzie and Thomsen, 2001; Lusk and Schroeder, 2002; Moghadam, Schmidt, and Grier, 2013) and beef prices (McKenzie and Thomsen, 2001). Our results also reveal that *E. coli* recalls can cause a drop in the price of the boxed cutout beef, extending McKenzie and Thomsen's results.

The key insight of this study is that downstream agents in the U.S. beef industry such as retailers (including supermarkets and grocery stores) are likely to see abnormal returns as a result of *E. coli* recalls than upstream agribusiness agents such as cattle ranches and feedlots. Since local downstream agents are more likely to be impacted financially, they may consider expanded incentives for upstream agents to implement additional risk abatement efforts beyond what is currently optimal for them in current markets. This also could be applied to comparisons among downstream agents in that the degree of the impact of recalls may depend on the products they transact. For example, entities that supply primarily ground beef products to fast-food hamburger restaurants are likely more vulnerable to *E. coli* recalls than suppliers who provide primarily muscle-cut items to dine-in restaurants, where steaks and related items are more common. These differences would correspond with justifiable differences in the level of concern about *E. coli* recall risk and hence may justify new, perhaps expanded incentives for upstream agents to further invest in risk mitigation efforts given the externality currently experienced by downstream agents.

Our study shows that food safety information about *E. coli* has a negative impact across the beef industry in terms of economic returns. The result should cause the U.S. beef industry to consider the costs and benefits of further investment in risk-abatement efforts beyond what is currently optimal for them in current markets. To be specific, to prevent the occurrence of *E. coli* in live cattle and beef products, the beef industry can manage farms and feedlots with regimented disease prevention and control such as *E. coli* vaccinations (Tonsor and Schroeder, 2015). They could also establish and operate a food safety management system throughout the entire beef production process (Shang and Tonsor, 2017). Moreover, meat processors and packers that deal with many ground beef items should continue to pay careful attention to potential sources of *E. coli* contamination.

This paper measured the effect of *E. coli* recalls on cattle and beef prices using recent price data. Although we attempted to use as many observed prices as possible from the data collected, many observed prices of some beef products were dropped to maintain duration across price series. Further study may provide stronger evidence by matching multiple long-term price series. We assessed the cumulative average abnormal returns (CAAR) based on class I recalls of beef products. Examining the effect of different classes of food safety recalls could provide insight into the impact of food safety issues on the beef industry. Additionally, event study methods have been improved methodologically recently and may be adopted for future research; the application of different analytical methodologies could be compared with the results of this study. In this study, we were only able to conjecture the causes of price responses before the official recall announcement, referring to other studies about its potential causes. It would be worth investigating what causes negative AR before the formal recall notices. The future studies we proposed are expected to complement our analysis and enhance the understanding of the impact of food safety recalls.

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