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Research Note

Monetizing the Impact of Food Safety Recalls on the Low-Moisture Food Industry

CARLY B. GOMEZ AND BRADLEY P. MARKS*

Department of Biosystems and Agricultural Engineering, Michigan State University, 524 South Shaw Lane, East Lansing, Michigan 48824, USA (ORCID: https://orcid.org/0000-0002-5553-5841 [B.P.M.])

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ABSTRACT

New Food Safety and Modernization Act rules require that food producers implement and validate processes that sufficiently reduce the risk of known hazards, such as those posed by microbial pathogens. Investments in food safety technology choices are ultimately business decisions, and current decision-making methods make it difficult to quantify financial value associated with food safety risk reduction. Predicted financial loss is a tangible way to quantify how a recall might affect the manufacturer. The hypothesis of this study was that class I recalls of low-moisture foods due to the presence of microbial pathogens have a significant negative economic impact on the affected manufacturers, which can be quantified in terms of loss in market capitalization. Financial impacts of the recalls were analyzed over a 10-year period by computing the cumulative abnormal return (CAR) in stock values over a recall event period for 22 low-moisture foods made by publicly held companies. Abnormal returns were aggregated over an event window (0 to 20 days) to compute the CAR, which was multiplied by prerecall market capitalization to compute monetary losses due to the recall event. The CARs for a 20-day postrecall period were –26.5 to 8.4%, with a mean of –5.1%. These CARs translated to a median loss in corporate value due to a recall of $243 million for the recall events analyzed in this study. If implementation of a food safety technology could reduce risk of a recall by fivefold, the mean annual economic benefit would be >$2 million in reduced risk for companies such as those included in the study. Such analyses can positively impact business decisions to invest in food safety technologies.

HIGHLIGHTS

- Class I recalls of low-moisture foods are economically important events.
- Mean corporate value declined significantly over the 20 days postrecall.
- Reductions in recall risk could be monetized as benefits of food safety investments.

Key words: Economics; Food safety; Low-moisture foods; Outbreaks; Pathogens; Recalls

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To reduce transmission of foodborne illnesses, the U.S. Food Safety Modernization Act preventive controls rules require that food processing companies implement pathogen control processes where a pathogen is reasonably likely to occur *(58)*. If a system failure occurs and a food is determined to potentially contain harmful pathogens, a class I recall is issued. Costs to a company resulting from a recall include decreased corporate value, legal fees and fines or settlements, and the value of the recalled product *(32)*. Limited information is available on the relative magnitude of these cost components or the overall economic impact of such recalls on the affected companies, but one summary reported costs of $70 to $350 million *(19)*. An accurate estimate of costs associated with a recall issued by a producer of a low-moisture food is important; recent studies in the restaurant and produce industries have revealed that recall costs substantially exceed the costs of implementing preventive controls *(3, 27)*.

Most studies in which the financial effects of class I recalls have been quantified have focused on societal costs because these measures are useful for policy development. Societal costs may include those associated with medical care, lost productivity, and public health interventions such as outbreak investigations, surveillance, and research *(8)*; these factors historically were the primary means of quantifying the costs of foodborne disease and recalls *(1, 28, 33)*. Scharff *(30, 31)* found that cost-of-illness studies are valuable for policy makers needing cost-benefit analyses of food safety solutions. Some studies have incorporated quality-adjusted life year costs in their estimation of the cost of illness *(4, 23)*. Belaya et al. *(6)* reported that two-thirds of the studies on the cost of foodborne disease used cost of illness to quantify the cost of an outbreak, likely because data from the public health sector of most developed countries are readily available. Although this method is advantageous for representing costs to society and inform-

* Author for correspondence. Tel: 517-432-7703; E-mail: marksbp@msu.edu.

ing public policy decisions, these societal costs are different from those faced by industry, such as loss of business *(8)*. Many food recalls occur without an associated outbreak of foodborne illness, in which case business cost, rather than cost of illness, is the important metric. However, Belaya et al. *(6)* also reported that only approximately one-fifth of the prior studies on the cost of foodborne illnesses included an examination of the costs to industry, given that data from the private sector are much more difficult to access. These findings reveal a clear research gap in the financial impacts of a recall on the food industry.

Although the societal costs of foodborne disease are paramount, decisions regarding investment in improved food safety technologies are ultimately business decisions made by individual companies. However, traditional direct measures of economic benefits associated with capital investments (e.g., increased productivity or reduced energy costs) generally do not apply to food safety investments. Therefore, monetizing the benefits of risk reduction associated with food safety investments could have a significant positive impact on the associated business decisions and broader food safety outcomes.

In terms of specific business costs, legal fees are difficult to quantify because many product liability cases are not publicly documented, and a considerable portion of these cases are settled out of court. Examinations of the available foodborne illness jury trials revealed that food manufacturers rarely pay extensive compensation to plaintiffs *(7)*. Plaintiffs won trials in 31.4% of cases, and the median amount awarded was only $25,560 (in 1998 dollars). Even for a premature death, the expected award was only $133,280. Therefore, legal liability alone may not be a strong motivation for companies to invest in improved food safety technology.

When the amount of product recalled is available, it is possible to estimate the direct value of the lost product; it is more difficult to monetize losses due to tarnished public reputation and lost future sales. The efficient market hypothesis has been used to quantify loss in market value after a recall in the meat and poultry industry *(26)*. This hypothesis assumes that information received by the public is promptly reflected in the company's stock value *(13, 14, 26)*. Therefore, changes in stock value reflect changes in perception of the company's value, presuming the negative impacts noted above. By measuring these changes, it is possible to monetize loss in a publicly held company's value due to a recall event as a quantitative measure of the economic impact of that recall.

Pozo and Schroeder *(26)* and Kong et al. *(20)* quantified changes in stock value based on cumulative abnormal returns (CAR), which represented the overall effect of the recall event on the company's stock value. Application of this method for the U.S. meat and poultry industry *(26)* and Chinese food industry *(20)* revealed that company shares decreased in value by 1.15% 5 days postrecall and by 3.9% 1 day postrecall, respectively. For the U.S. meat and poultry industry, this translated into an average loss in value of $109 million for a single recall event, which is a measure of the overall negative economic impact of a recall on an average company in that sector *(26)*.

Based on these previous analyses, our hypothesis was that the CAR approach can be used to quantify the negative economic impact of recent recall events specifically in the low-moisture food industry. An associated objective was to illustrate how that measure could be used to monetize the benefit of investments that improve food safety and thereby reduce the risk of recall events.

MATERIALS AND METHODS

Information on class I recalls of low-moisture foods due to foodborne pathogens was obtained from the U.S. Food and Drug Administration (FDA) *(57)* Recall Archives, which includes recall events from 2007 to the present. Criteria for inclusion in this study were (i) the recalled product was a low-moisture food, (ii) the recall was due to possible or confirmed presence of *Salmonella, Escherichia coli, or Listeria monocytogenes,* and (iii) the company implicated was publicly held, with shares traded on the open market. Low-moisture foods were defined as food products known to have a low water activity (e.g., most snacks, nuts and nut products, grains, and spices). Companies were confirmed to be publicly held when they were traded in a U.S. market, such as the New York Stock Exchange or National Association of Securities Dealers Automated Quotations.

Historical stock closing prices for each company and the overall market, represented by the Standard and Poor's index (S&P 500), were obtained from the historical prices database of the *Wall Street Journal (59)*. Companies could not be included in the study when they were bought out, merged with another company, or went bankrupt following a recall because historical stock closing prices for the original company were not available in these cases. Companies involved in a major market event, such as a merger or acquisition, within 3 months of the recall also were excluded to reduce the influence of unrelated market events. When illnesses were linked to a recall, the date of that announcement was used as day 0 of the event window. For all other expanded recalls, the first recall announcement date was used as day 0 of the event window. Market capitalization values for each company one business day before the recall announcement were retrieved from an online database *(22)*. The first step of data analysis was to develop a model for predicted returns. Expected returns were based on data collected from an estimation window of 3 years before the recall event to one business day before the recall event, which was equivalent to 1 day before the start of the event window. This large estimation window was necessary because some of the recalls studied occurred shortly after the 2008 U.S. recession, so use of a shorter estimation window would have led to predicted returns that were overly influenced by major market changes in 2008 and therefore not representative of typical market conditions.

Expected returns during the estimation window were calculated using an ordinary least squares (OLS) model as in previous studies *(11, 16, 20, 21, 26, 32, 62)*. The model was developed using Gnu Regression, Econometrics, and Time-series Library (GRETL) software *(2)*. Two sets of data were imported: the returns of the particular company during the estimation window and the returns of the broader market (S&P 500) during the estimation window. An OLS regression was computed, with the returns of the company stock as the dependent variable and the overall market returns as the independent variable *(11, 16, 20, 21, 26, 32, 62)*:

$$R_{it} = b_0 + b_1 R_{mt} + AR_{it}$$

where R_{it} is the return of company i stock on day t, R_{mt} is the return of the market on day *t*, AR_{it} is the abnormal return on day *t*, and b_0 and b_1 are regression coefficients. Returns R_{it} and R_{mt} (%) were also calculated *(25)*:

$$\text{Return} = 100 \cdot \ln \frac{\text{close}_t}{\text{close}_{t-1}}$$

where close_t is the closing value of a stock on a particular day and close_{t-1} is the closing value of the same stock on the previous day. This method, called simple return or logarithmic return, is commonly used in finance *(25)* and assumes a large number of very small return intervals (continuously compounded return). As the number of return intervals approaches infinity, the limit of the expression for return results in an exponential function. Solving this gives the natural logarithm equation above, applicable for returns during one time period. In this case, the time period for each return is 1 day.

The abnormal return term in the OLS regression was set as zero during the estimation window before the recall event. Coefficients b_0 and b_1 were estimated using the OLS modeling tool in GRETL.

Abnormal returns following a recall event were calculated by solving for the AR_{it} term of the OLS regression with the b_0 and b_1 coefficients determined during the estimation window and company and market returns from the event window. The event window was defined as the period beginning with the public announcement of the recall and lasting the subsequent 20 days. In past studies, event windows only included up to 20 days postevent because changes in stock value after 20 days are less likely to be affected dominantly by the recall event *(26)*.

Abnormal returns were aggregated during the event window; at 20 days postrecall, the sum of abnormal returns was recorded as the CAR. The CAR of each company was multiplied by the company's prerecall market capitalization to represent the monetary change in company value due to the recall event.

RESULTS AND DISCUSSION

Of the 785 recalls of low-moisture products identified from the FDA archive, 22 recalls from 15 different companies met the study criteria and were included for analysis. This data set is smaller than those used in related studies in the meat and poultry industry because recall of low-moisture foods is an emerging issue, whereas meat and poultry recalls have been acknowledged for decades. Thomsen and McKenzie *(32)* analyzed data from 252 class I meat and poultry recalls between 1982 and 1998, and Pozo and Schroeder *(26)* analyzed data from 163 class I to III meat and poultry recalls between 1994 and 2013 but modeled each class of recalls separately. In 2001, Salin and Hooker *(29)* presented a partial event analysis of three meat recalls and one apple juice recall.

Recalls included in the present study differed widely in implicated pathogen, estimated loss, associated illnesses, and company size represented by prerecall market capitalization (Table 1). Affected food products were recalled due to suspected contamination with one of three pathogens: *Salmonella, E. coli,* or *L. monocytogenes*. Estimated direct product loss was calculated by multiplying the amount of recalled product by the retail value of the product. These data were available for only 8 of the 22 recalls, and losses ranged from $22,000 to $625.9 million. Prerecall market capitalization of the affected companies ranged from $0.12 billion to $184.59 billion.

CARs were calculated for the 22 recall events at 1 to 20 days postrecall (Fig. 1). The individual CARs at 20 days postrecall were –26.5 to 8.4%, with a mean of –5.1%, which is similar to findings in previous studies for other sectors. For example, when day 0 of each event window was defined as the day the recall was announced, the 20-day average CARs reported by Thomsen and McKenzie *(32),* Pozo and Schroeder *(26),* and Salin and Hooker *(29)* were –2.7, –1.6, and –11.3%, respectively, for meat and poultry recalls. In studies of Chinese companies, Kong et al. *(20)* reported a 3-day CAR of –3.8% and Zhao et al. *(62)* reported a 1-day CAR of –2.21%.

In the present study, the average 20-day CAR was negative, but 4 (18%) of the 22 companies had positive 20-day CARs. These positive values may reflect measures taken within the company to mitigate the recall effect and other unrelated factors affecting shareholders and market value. Despite the small percentage of positive 20-day CARs, the 95% confidence interval for 20-day CARs included only negative values, from –1.43 to –8.85%. Thomsen and McKenzie *(32)* and Pozo and Schroeder *(26)* reported only the aggregated average CAR, not CARs for individual companies, so comparison of the distribution of individual CARs in those studies to those in the present study was not possible.

In 2002, Wang et al. *(60)* concluded, based on a study of five recall events from two meat producers, that the use of a more complex model that considers generalized autoregressive conditional heteroscedasticity (GARCH) effects is warranted to account for variability in the returns. However, in 2016, Murg et al. *(24)* compared abnormal returns determined by both approaches for 26 Austrian firms and concluded that the GARCH approach does not add extra value compared with the simpler regression; minimal differences were obtained between the average abnormal returns calculated with both models. In several other studies, a CAR approach has been used successfully for analyzing the economic impact of recalls in the Chinese food industry *(20),* the Chinese auto, pharmaceutical, food, and electronics industries *(62),* the U.S. auto industry *(15–17),* the U.S. toy industry *(12),* and the U.S. meat and poultry industries *(26, 32)*. Therefore, the simple OLS model and CAR approach was deemed sufficient to conduct the analyses in the present study.

The regression equations for predicted returns yielded P values of <0.001 for all 22 cases. The R^2 values for the regression models were low, from 0.032 to 0.532, with an average of 0.290, which was consistent with other stock return event studies. Thomsen and McKenzie *(32)* and Pozo and Schroeder *(26)* reported R^2 values of 0.185 and 0.148, respectively. R^2 values reported by Salin and Hooker *(29)* and Kong et al. *(20)* were <0.38 and 0.12, respectively. R^2 values were expected to be low because changes in the market do not always account for changes in the stock returns of individual companies; however, all the regression models were significant ($P < 0.001$).

A secondary regression between days postrecall (0 to 20) and CARs for each company had a significant ($P = 2.6$

TABLE 1. *Summary of recalls included in this study*

Year	Reference	Company	Food product(s)	Pathogen	Estimated retail value ($) of recalled product (ref.)	No. of associated illnesses (ref.)	Precall company market capitalization (billion $)	20-Day CAR
2007	*10*	A	Peanut butter	*Salmonella*	625,900,000 *(61)*	>700 *(34)*	7.18	−4.96
2009	*38*	B	Cookies and sandwich crackers	*Salmonella*	49,000,000 *(24)*	>700 *(9)*	12.59	−4.32
2009	*37*	C	Pistachios	*Salmonella*		0	0.12	−1.65
2009	*36*	D	Snack bars	*Salmonella*	229,500 *(36)*	0	9.94	−6.48
2009	*39*	E	Nut topping	*Salmonella*		0	15.73	−7.25
2009	*35*	F	Pistachios	*Salmonella*		0	80.53	−8.60
2010	*41*	G	Potato crisps	*Salmonella*		0	184.59	−3.86
2010	*40*	H	Dip and bread mixes	*Salmonella*		0	4.27	−2.30
2011	*42*	I	Peanut butter	*Salmonella*	67,000 *(61)*	0	7.24	5.98
2012	*43*	D	Granola bars	*Salmonella*	863,000 *(18)*	0	21.94	0.647
2014	*44*	C	Walnuts and cookie pieces	*Salmonella*		0	0.44	−26.49
2014	*46*	H	Ground oregano	*Salmonella*	22,000 *(46)*	0	8.27	−1.58
2014	*45*	J	Carob powder	*Salmonella*		0	0.53	−24.21
2015	*47*	E	Seasonings	*Salmonella*		0	36.94	−8.02
2016	*49*	D	Flour and baking mixes	*Escherichia coli*	23,310,000 *(5)*	63 *(49)*	35.53	−0.09
2016	*54*	K	Sunflower seeds and granola bars	*Listeria monocytogenes*		0	4.09	4.77
2016	*56*	L	Bread mix	*Salmonella*		0	4.64	−11.99
2016	*50*	B	Waffles	*L. monocytogenes*	2,500,000 *(50)*	0	26.17	−3.91
2016	*51*	M	Cereal	*L. monocytogenes*		0	5.27	8.39
2016	*53*	N	Sunflower kernels	*L. monocytogenes*		0	0.45	−14.54
2016	*48*	O	Tea	*Salmonella*		0	103.09	−2.44
2016	*52*	F	Snack bars	*L. monocytogenes*		0	150.33	−2.06

$\times 10^{-6}$) negative slope (–0.268), indicating a negative relationship between time after a recall announcement and CAR. With the 95% confidence interval for the 20-day CAR, these results provide strong evidence that CAR is negatively affected by a class I recall.

Separate regressions indicated no significant relationship ($P = 0.59$, 0.50, and 0.90) between CAR and market capitalization (a representation of company size), CAR and total value of recalled product (for recalls which the information was available), and CAR and number of product-associated illnesses, respectively. Thus, none of these factors were considered to be confounding variables for this study. These results differ from those of Pozo and Schroeder *(26)*, who found that company size and size of

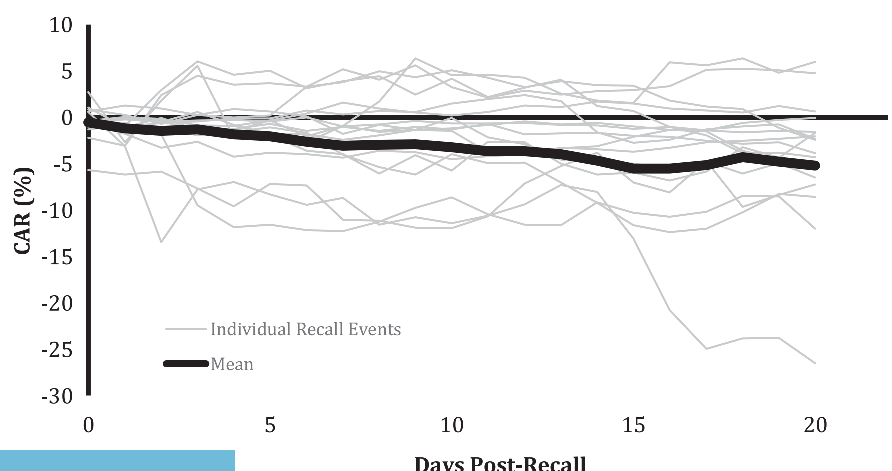

FIGURE 1. *Cumulative abnormal returns (CAR) after 22 recalls by publicly held companies in the low-moisture food industry (thin lines), and the corresponding cumulative average abnormal return (thick line). Day 0 is the day of the company's recall announcement.*

recall had significant positive and negative relationships, respectively, with abnormal returns. This difference is likely due to the much larger size of their study and use of a more advanced regression model, which could be of value for analyzing the low-moisture food industry if a larger data set were available.

The present study did not include an examination of the effects of other peripheral variables, such as media coverage and experience administering a recall. However, these factors affect the economic impact of recalls on companies *(26, 29)*. Inclusion of such variables in a more advanced model could account for some of the variability in CAR seen in the existing data.

The mean loss in the market capitalization of the affected companies, corresponding to the average 20-day CAR, was $1.22 billion. This loss was heavily influenced by a few recalls by companies with very high market capitalizations, and therefore the median loss of $243 million is a more relevant statistic for representing potential loss in market capitalization.

To illustrate the potential positive economic benefit of implementing food safety technologies that might reduce recall risk, an example annual loss due to risk of recall was approximated based on an estimated probability of recall due to foodborne pathogens for companies producing low-moisture foods. First, the number of publicly held companies that produce or utilize low-moisture foods in the United States was roughly estimated as 200. The annual number of pathogen-linked recall events for these companies was roughly estimated as 2.2, based on observed occurrences of recalls for publicly held companies in the FDA recall archives (i.e., 22 recalls over a 10-year period). Given these two rough estimates, the annual probability of a recall event for a given company was then estimated as 0.011, and this value was multiplied by the median company loss in value to yield a median impact of ~$2,673,000, which represents an example annual cost of risk due to potential class I recalls within this population of companies.

In the same illustration, if we assume that the installation of an improved pathogen control system or other food safety intervention will reduce the risk of pathogen survival by 1 log CFU and therefore reduce the annual risk of a recall by some lower factor such as a conservatively estimated fivefold (to 0.0022), then the annual cost of recall risk would be reduced to about $534,600. Therefore, in this scenario, investing in food safety technology could result in an estimated savings of about $2.1384 million in annual risk reduction. Therefore, an example $1 million investment in an improved pathogen control technology or other risk reduction system would have a payback period of approximately 6 months. The assumptions for risk of recall and risk reduction from implementation of food safety technologies used in this example were very rough but presumably conservative estimates and ultimately should be modeled with more detailed probability distributions to more accurately describe a range of risk. However, this analysis is presented here as an illustration of how monetizing the costs of recall events could be used to inform business decisions for investments in food safety interventions.

Numerous recall events could not be included in this study because the individual affected company merged with another company, was bought out, or went bankrupt, and stock value data were not available for these cases. However, because those excluded events actually resulted in more catastrophic business outcomes for the affected companies, the results in the present study actually might underrepresent the magnitude of the negative economic impact of recalls of low-moisture foods across the entire industry. The economic impact of recalls also will be increasingly more important as the use of whole genome sequencing *(55)* is expected to increase the number of detected outbreaks and therefore increase the number of recalls.

The methods described in this study make it possible to quantify recall-associated losses in value of publicly traded food companies in the low-moisture food industry. This quantification could provide incentive and financial justification for food producers to invest in food safety technologies. Further studies are needed to incorporate this approach into risk-based analyses linking improved pathogen control systems to recall risk and the associated economic impacts.

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REFERENCES

1. Abe, K., S. Yamamoto, and K. Shinagawa. 2002. Economic impact of an *Escherichia coli* O157:H7 outbreak in Japan. *J. Food Prot*. 65:66–72.
2. Baiocchi, G., and W. Distaso. 2003. GRETL: econometric software for the GNU generation. *J. Appl. Econ*. 18:105–110.
3. Bartsch, S. M., L. Asti, S. Nyathi, M. L. Spiker, and B. Y. Lee. 2018. Estimated cost to a restaurant of a foodborne illness outbreak. *Public Health Rep*. 133:274–286.
4. Batz, M., S. Hoffmann, and J. G. Morris. 2014. Disease-outcome trees, EQ-5D scores, and estimated annual losses of quality-adjusted life years (QALYs) for 14 foodborne pathogens in the United States. *Foodborne Pathog. Dis*. 11:395–402.
5. Beach, C. 2016. More sick; General Mills recalls 15 million more pounds of flour. Available at: https://www.foodsafetynews.com/2016/07/more-sick-general-mills-recalls-more-flour-traced-to-outbreak/. Accessed 24 October 2019.
6. Belaya, V., H. Hansen, and B. Pinior. 2012. Measuring the costs of foodborne diseases: a review and classification of the literature. Presented at the German Association of Agricultural Economists (GEWISOLA) 52nd Annual Conference, Stuttgart, Germany, 26 to 28 September 2012.
7. Buzby, J. C., P. D. Frenzen, and B. Rasco. 2001. Product liability and microbial foodborne illness. Agricultural economic report AER-799. U.S. Department of Agriculture, Economic Research Service, Washington, DC.
8. Buzby, J. C., and T. Roberts. 2009. The economics of enteric infections: human foodborne disease costs. *Gastroenterology* 136:1851–1862.
9. Centers for Disease Control and Prevention. 2009. Multistate outbreak of *Salmonella* Typhimurium infections linked to peanut butter, 2008–2009 (final update). Available at: https://www.cdc.gov/salmonella/2009/peanut-butter-2008-2009.html. Accessed 11 September 2019.

10. ConAgra Brands. 2015. ConAgra Foods announces resolution related to 2007 voluntary peanut butter recall. Available at: https://www.conagrabrands.com/news-room/news-conagra-foods-announces-resolution-related-to-2007-voluntary-peanut-butter-recall-2051831. Accessed 25 October 2019.
11. Dranove, D., and C. Olsen. 1994. The economic side-effects of dangerous drug announcements. *J. Law Econ*. 37:323–348.
12. Ekanayake, E., and S. Sengupta. 2012. The impact of toys recall announcements on market returns. *J. Int. Bus. Stud*. 1:72–85.
13. Fama, E. F. 1970. Efficient capital markets: a review of theory and empirical work. *J. Finance* 25:383–417.
14. Fama, E. F. 1991. Efficient capital markets. II. *J. Finance* 46:1575–1617.
15. Gokhale, J., R. M. Brooks, and V. J. Tremblay. 2014. The effect on stockholder wealth of product recalls and government action: the case of Toyota's accelerator pedal recall. *Q. Rev. Econ. Finance* 54:521–528.
16. Govindaraj, S., B. Jaggi, and B. Lin. 2004. Market overreaction to product recall revisited—the case of Firestone tires and the Ford Explorer. *Rev. Quant. Finance Acc*. 23:31–54.
17. Hoffer, G. E., S. W. Pruitt, and R. J. Reilly. 1987. Automotive recalls and informational efficiency. *Financial Rev*. 22:433–442.
18. Hughlett, M. 2013. General Mills recalls some granola bars. Available at: http://www.startribune.com/general-mills-recalls-some-granola-bars/173406691/. Accessed 11 November 2019.
19. Hussain, M. A., and C. O. Dawson. 2013. Economic impact of food safety outbreaks on food businesses. *Foods* 2:585–589.
20. Kong, D. M., L. Shi, and Z. Q. Yang. 2019. Product recalls, corporate social responsibility, and firm value: evidence from the Chinese food industry. *Food Policy* 83:60–69.
21. MacKinlay, A. C. 1997. Event studies in economics and finance. *J. Econ. Lit*. 35:13–39.
22. Macrotrends. 2019. Stock research and analysis. Available at: https://www.wsj.com/news/markets/stocks. Accessed 10 November 2019.
23. Minor, T., A. Lasher, K. Klontz, B. Brown, C. Nardinelli, and D. Zorn. 2015. The per case and total annual costs of foodborne illness in the United States. *Risk Anal*. 35:1125–1139.
24. Murg, M., M. Pachler, and A. C. M. Zeitlberger. 2016. The impact of analyst recommendations on stock prices in Austria (2000–2014): evidence from a small and thinly traded market. *Cent. Eur. J. Oper. Res*. 24:595–616.
25. Panna, M. 2017. Note on simple and logarithmic return. *APSTRACT* 11:127–136.
26. Pozo, V. F., and T. C. Schroeder. 2016. Evaluating the costs of meat and poultry recalls to food firms using stock returns. *Food Policy* 59:66–77.
27. Ribera, L. A., M. A. Palma, M. Paggi, R. Knutson, J. G. Masabni, and J. Anciso. 2012. Economic analysis of food safety compliance costs and foodborne illness outbreaks in the United States. *HortTechnology* 22:150–156.
28. Roberts, T. 1988. Salmonellosis control—estimated economic costs. *Poult. Sci*. 67:936–943.
29. Salin, V., and N. H. Hooker. 2001. Stock market reaction to food recalls. *Rev. Agric. Econ*. 23:33–46.
30. Scharff, R. L. 2015. State estimates for the annual cost of foodborne illness. *J. Food Prot*. 78:1064–1071.
31. Scharff, R. L. 2018. The economic burden of foodborne illness in the United States, p. 123–142. *In* T. Roberts (ed.), Food safety economics. Springer, New York.
32. Thomsen, M. R., and A. M. McKenzie. 2001. Market incentives for safe foods: an examination of shareholder losses from meat and poultry recalls. *Am. J. Agric. Econ*. 83:526–538.
33. Todd, E. C. D. 1985. Economic loss from foodborne disease and non–illness related recalls because of mishandling by food processors. *J. Food Prot*. 48:621–633.
34. U.S. Department of Justice. 2016. December 13, 2016: ConAgra subsidiary sentenced in connection with outbreak of S*almonella* poisoning related to peanut butter. Available at: https://www.fda.gov/inspections-compliance-enforcement-and-criminal-investigations/press-releases/december-13-2016-conagra-subsidiary-sentenced-connection-outbreak-salmonella-poisoning-related. Accessed 25 October 2019.
35. U.S. Food and Drug Administration. 2009. Frito-Lay issues nationwide voluntary recall of in-shell pistachio nuts due to possible health risk. Available at: http://wayback.archive-it.org/7993/20170112160659/http:/www.fda.gov/Safety/Recalls/ArchiveRecalls/2009/ucm135969.htm. Accessed 8 November 2019.
36. U.S. Food and Drug Administration. 2009. General Mills issues voluntary recall of LÄRABAR and JamFrakas peanut butter snack bars. Available at: http://wayback.archive-it.org/7993/20170112161830/http:/www.fda.gov/Safety/Recalls/ArchiveRecalls/2009/ucm128576.htm. Accessed 8 November 2019.
37. U.S. Food and Drug Administration. 2009. John B. Sanfilippo and Son, Inc. voluntarily recalls roasted salted inshell pistachios due to possible health risk. Available at: http://wayback.archive-it.org/7993/20170112160647/http://www.fda.gov/Safety/Recalls/ArchiveRecalls/2009/ucm135981.htm. Accessed 25 October 2019.
38. U.S. Food and Drug Administration. 2009. Kellogg Company announces precautionary hold on Austin and Keebler branded peanut butter sandwich crackers. Available at: http://wayback.archive-it.org/7993/20170112161904/http://www.fda.gov/Safety/Recalls/ArchiveRecalls/2009/ucm128682.htm. Accessed 26 October 2019.
39. U.S. Food and Drug Administration. 2009. Kroger recalls nut topping due to possible health risk. Available at: http://wayback.archive-it.org/7993/20170112161700/http:/www.fda.gov/Safety/Recalls/ArchiveRecalls/2009/ucm128699.htm. Accessed 26 October 2019.
40. U.S. Food and Drug Administration. 2010. McCormick & Company initiates recall due to possible health risk from HVP ingredient. Available at: http://wayback.archive-it.org/7993/20170112155452/http://www.fda.gov/Safety/Recalls/ArchiveRecalls/2010/ucm203339.htm. Accessed 25 October 2019.
41. U.S. Food and Drug Administration. 2010. P&G joins industry ingredient recall by voluntarily recalling two flavors of Pringles® in the United States in response to FDA industry guidance. Available at: http://wayback.archive-it.org/7993/20170112155439/http:/www.fda.gov/Safety/Recalls/ArchiveRecalls/2010/ucm203957.htm. Accessed 25 October 2019.
42. U.S. Food and Drug Administration. 2011. The J.M. Smucker Company announces a limited voluntary recall on two specific best-if-used-by dates of 16 oz. Smucker's® Natural Peanut Butter Chunky due to possible health risk. Available at: http://wayback.archive-it.org/7993/20170112151042/http://www.fda.gov/Safety/Recalls/ArchiveRecalls/2013/ucm280281.htm. Accessed 25 October 2019.
43. U.S. Food and Drug Administration. 2012. General Mills voluntarily recalls limited number of Cascadian Farm snack bars containing peanuts. Available at: http://wayback.archive-it.org/7993/20170111132637/http://www.fda.gov/Safety/Recalls/ArchiveRecalls/2012/ucm323308.htm. Accessed 26 October 2019.
44. U.S. Food and Drug Administration. 2014. John B. Sanfilippo & Son, Inc. voluntarily recalls Fisher Brand 8 oz. chopped walnuts and Fisher Brand 8 oz. pecan cookie pieces because of possible health risk. Available at: http://wayback.archive-it.org/7993/20170111125405/http://www.fda.gov/Safety/Recalls/ArchiveRecalls/2013/ucm428489.htm. Accessed 26 October 2019.
45. U.S. Food and Drug Administration. 2014. Natural Grocers by Vitamin Cottage issues voluntary recall for various chunks of energy products because they contain organic carob powder from Ciranda, Inc., which may be contaminated with *Salmonella*. Available at: http://wayback.archive-it.org/7993/20170112134641/http:/www.fda.gov/Safety/Recalls/ArchiveRecalls/2013/ucm407197.htm. Accessed 8 November 2019.
46. U.S. Food and Drug Administration. 2014. Voluntary recall notice of McCormick ground oregano due to possible *Salmonella* risk. Available at: http://wayback.archive-it.org/7993/20170112134538/http://www.fda.gov/Safety/Recalls/ArchiveRecalls/2013/ucm410107.htm. Accessed 25 October 2019.
47. U.S. Food and Drug Administration. 2015. Kroger recalls four seasonings due to possible health risk. Available at: http://wayback.archive-it.org/7993/20170112072609/http://www.fda.gov/Safety/

Recalls/ArchiveRecalls/2015/ucm456182.htm. Accessed 8 November 2019.
48. U.S. Food and Drug Administration. 2016. CVS Pharmacy announces voluntary recall of Gold Emblem Abound organic spiced herbal tea due to possible health risk. Available at: http://wayback.archive-it.org/7993/20170112133338/http://www.fda.gov/Safety/Recalls/ucm497299.htm. Accessed 8 November 2019.
49. U.S. Food and Drug Administration. 2016. General Mills expands retail flour recall. Available at: http://wayback.archive-it.org/7993/20170112133038/http://www.fda.gov/Safety/Recalls/ucm513288.htm. Accessed 8 November 2019.
50. U.S. Food and Drug Administration. 2016. Kellogg Company voluntarily recalls limited number of Kellogg's® Eggo® Nutri-Grain® whole wheat waffles due to potential health risk. Available at: http://wayback.archive-it.org/7993/20170112132938/http://www.fda.gov/Safety/Recalls/ucm521434.htm. Accessed 26 October 2019.
51. U.S. Food and Drug Administration. 2016. Post Consumer Brands voluntarily recalls limited quantity of Great Grains Protein Blend—Honey, Oats & Seeds Cereal due to possible *Listeria* contamination. Available at: http://wayback.archive-it.org/7993/20180126102341/https://www.fda.gov/Safety/Recalls/ucm506257.htm. Accessed 26 October 2019.
52. U.S. Food and Drug Administration. 2016. The Quaker Oats Company issues voluntary recall of Quaker quinoa granola bars due to possible health risk. Available at: http://wayback.archive-it.org/7993/20170112133243/http://www.fda.gov/Safety/Recalls/ucm501248.htm. Accessed 11 November 2019.
53. U.S. Food and Drug Administration. 2016. TreeHouse foods issues voluntary product recall due to possible health risk. Available at: http://wayback.archive-it.org/7993/20170112133322/http://www.fda.gov/Safety/Recalls/ucm499538.htm. Accessed 25 October 2019.
54. U.S. Food and Drug Administration. 2016. TreeHouse foods expands voluntary product recall due to possible health risk. Available at: http://wayback.archive-it.org/7993/20170112133238/http://www.fda.gov/Safety/Recalls/ucm502367.htm. Accessed 10 November 2019.
55. U.S. Food and Drug Administration. 2016. Whole genome sequencing: cracking the genetic code for foodborne illness. Available at: https://www.fda.gov/consumers/consumer-updates/whole-genome-sequencing-cracking-genetic-code-foodborne-illness. Accessed 25 October 2019.
56. U.S. Food and Drug Administration. 2016. Williams-Sonoma announces the voluntary recall of Meyer lemon poppy quick bread. Available at: http://wayback.archive-it.org/7993/20170110235030/http://www.fda.gov/Safety/Recalls/ucm533821.htm. Accessed 26 October 2019.
57. U.S. Food and Drug Administration. 2018. Archive for recalls, market withdrawals & safety alerts. Available at: https://www.fda.gov/safety/recalls-market-withdrawals-safety-alerts. Accessed 10 November 2019.
58. U.S. Food and Drug Administration. 2018. FSMA final rule for preventative controls for human food. Available at: https://www.fda.gov/food/food-safety-modernization-act-fsma/fsma-final-rule-preventive-controls-human-food. Accessed 10 November 2019.
59. Wall Street Journal. 2019. Stocks. Available at: https://www.wsj.com/news/markets/stocks. Accessed 8 November 2019.
60. Wang, Z. J., V. Salin, N. H. Hooker, and D. Leatham. 2002. Stock market reaction to food recalls: a GARCH application. *Appl. Econ. Lett*. 9:979–987. Accessed 3 July 2019.
61. Yada, S., and L. J. Harris. 2019. Recalls of tree nuts and peanuts in the U.S., 2001 to present (version 2). *In* U.S. recalls of nuts. Available at: https://ucfoodsafety.ucdavis.edu/sites/g/files/dgvnsk7366/files/inline-files/162415.pdf. Accessed 9 September 2019.
62. Zhao, X. D., Y. N. Li, and B. B. Flynn. 2013. The financial impact of product recall announcements in China. *Int. J. Prod. Econ*. 142:115–123.