Exploring Meat and Poultry Recall Data for Policy Lessons

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Abstract:

Four measures are introduced to evaluate the likelihood of meat and poultry recalls and how firms and FSIS manage such events. These measures include the proportion of product retrieved (recovery rate), time to complete a case, the ratio of recovery rate and completion, and the hazard rate. This research aims to advance our knowledge and understanding of food safety programs by presenting statistical indicators which benchmark the food system. The results from OLS, Negative Binomial, and Cox regression models suggest that limited conclusions can be reached in terms of overall performance and factors that explain the timeliness of recalls. Evidence suggests that smaller plants perform as well as large plants in their recall actions. Also, when the firm discovers the problem recalls are more timely and therefore more effective.

Keywords: Food safety, meat and poultry recalls, PR/HACCP, count data models, recovery rate, hazard rate, survival analysis

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Introduction

Meat and poultry recalls have been subjected to increasing scrutiny over recent years with concern being voiced about the appropriateness of a predominately voluntary process. This has led to various bills being presented to Congress, particularly following recalls of nearly 19 million pounds of ground beef over concerns of contamination with *E. coli* 0157:H7 and 27.4 million pounds of chicken and turkey products that might be contaminated with *Listeria monocytogenes*[4]. The Food Safety and Inspection Service (FSIS) of USDA is the main regulatory agency responsible for the safety of meat and poultry products. In 1998, FSIS set up a working group to evaluate its recall policy and provide recommendations. The groups' findings emphasized how to reduce communication problems between the agency, firms and related parties and how to maximize product recovery (Axtell et al., 1998). Nevertheless, a subsequent report by the U.S. General Accounting Office (GAO) suggested that further action was necessary (GAO, 2000).

This paper uses the online database of meat and poultry recalls maintained by FSIS covering 1998-2002. In part, the methodology employed allows for an evaluation of the overall food safety management system in place, with particular reference to the FSIS recall process. Only with an effective recall process can the public health impact of food safety problems encountered by firms be minimized. The early discovery of contamination in the food supply is an urgent problem. Appropriate indicators that highlight the time-sensitivity of the recall process are therefore critical. Several studies have used related FSIS meat and poultry recall data. Salin and Hooker (2001), Wang et al. (2002), and Thompson and McKenzie (2001) examined the effect of meat and poultry recalls on firm's stock price, market returns, and societal reactions. Shiptsova, Thomsen, and Goodwin (2002) examined the effect of recall costs on profitability and competitiveness of the beef, pork, and poultry industries using data from 1995 to 1999. Result from an equilibrium-displacement model suggested that higher recall costs may increase producer surplus to the broiler industry and that losses resulting from recalls are accruing to the beef and pork industries. Other studies provide descriptive statistics and summaries of FDA

[4] A current example of legislation that would provide USDA and FDA with mandatory recall authority is the *Safe and Fair Enforcement and Recall for Meat, Poultry, and Food Act* (S.2803; H.R. 5230).

recall data due to microbial contamination and undeclared allergens, see Wong et al. (2000) and Vierk et al. (2002) respectively. However, no study has yet been conducted which analyzes the relationship between recall effectiveness and possible explanatory factors such as information about recalled products and firms involved.

This study has two main objectives. First, the likelihood of a recall event after firms are required to implement PR/HACCP is considered using the survival rate, which represents time prior to the recall. The survival rates draw on statistical methods used in engineering and biostatistics to describe the time until failure or, in its broadest sense, the time before occurrence of an event (the recall). Second, exploratory statistical research on effectiveness measures is conducted using the most recently available information and experience of meat and poultry product recalls. Several characteristics, which may influence recall effectiveness, are included in this study in an attempt to reveal useful information for firms and FSIS to help assess whether recall strategies need to be adjusted for different cases. Three measures of the effectiveness of meat and poultry recalls are proposed, including the proportion of recalled product retrieved (recovery rate), the case duration, and the ratio of these variables. The recovery rate-completion time ratio is included as there may be incidents where the recall case remains open for a longer period to gain a higher rate of product recovery. Even though the priority placed by FSIS is unclear, a faster recovery rate per day while cases remain open should be preferred. These four measures are unique to the literature on the economics of food safety and are an important contribution of this exploratory research.

Background on Meat and Poultry Recalls

FSIS performs inspection activities and enforces regulations to ensure that meat, poultry, and egg products are wholesome and accurately labeled and encourages the improvement of the safety of these products through various programs. In 1996, FSIS started to implement a new food safety program, the Pathogen Reduction / Hazard Analysis Critical Control Point (PR/HACCP) system, which emphasizes hazard identification and risk prevention throughout a plant's process, as a move away from the detection of potential problems at the end of the production line (FSIS, 1996). This program is designed to identify potential hazards and develop a comprehensive plan to prevent or control them. PR/HACCP can also be regarded as a risk management program. Subsequent research has focused on the overall effectiveness of this program, which is now required in all meat and poultry slaughter and processing plants. It has been suggested that PR/HACCP has led to a significant reduction in the numbers of foodborne illnesses from *Salmonella* (FSIS, 2002a).

To ensure the safety of the food supply beyond slaughter and processing plants, FSIS conducts microbial testing and investigates potential problems associated with products after they enter the supply chain, including those in warehouses and retail outlets. FSIS uses recalls as a risk management tool (of final recourse) to protect consumers from foods that may cause negative health consequences. The strategy suggests how widespread the recall should be, including affected businesses (wholesale or retail) and consumers (region of country), describes any public warning to be issued, and explains how effectiveness checks will be implemented and verified. The agency also communicates information about the recall to consumers and contacts all parties involved through press releases to ensure that these affected products are retrieved from the market.

Even though the process is voluntary and there is no statutory authority for FSIS to order recalls, producers and/or distributors generally promptly comply with recall requests (FSIS, 2000a; GAO, 2000). Failure to remove contaminated or violative products from commerce may result in negative publicity, consumer complaints, liability lawsuits, and damage to company reputation. FSIS therefore works closely with the industry at every step of the recall process to guarantee that products are removed from the food supply. The recalling firm is expected to perform effectiveness checks during the recall and inform FSIS of the result. The main purpose of these effectiveness checks is to verify that the recalling firm has provided adequate notice and that all consignees have located products and followed the recalling firm's instructions[5] (FSIS, 2000b). As part of its' risk management strategy, FSIS verifies whether the recall action is conducted in an effective manner, based in part on these effectiveness reports, that firms have made all reasonable efforts to retrieve and appropriately rework or dispose of the recalled products. The recall case is terminated, meaning that no further action is required, when FSIS and the recalling firm are in agreement that the product subject to recall has been removed and

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[5] The effectiveness check should contain the following information: the number of consignees notified of, and responding to, the recall communication, the quantity of product each consignee had on hand, the quantity of product returned to each consignee, and an estimated time for completion the recall. (FSIS, 2000c)

proper disposition or correction has been made. Only then, the Emergency Response Division (ERD), Office of Public Health and Science, issues the final document stating that the recall is terminated (FSIS, 2000b).

Conceptual Framework

The U.S. food control system functions through the voluntary cooperation of the industry within the bounds of regulatory supervision and threats of legal action. There are competing forces and incentives involved in achieving the balance between quality and costs that characterizes the system. To encompass the varying forces that shape the system, we draw upon the disciplines of business management and policy analysis to develop hypotheses that can be tested with the available data.

Business management models of information, learning, and signaling provide a perspective of PR/HACCP as process control. An effective process will be able to quickly identify faults and respond, because it exists in a world in which the "costs of poor quality exceed the cost of developing processes which produce high quality products" (Mazzocco, 1996). Even the best process control systems will fail from time to time, but the rare failures should not follow a discernable pattern. The time path of food recalls that one would expect from an effective process control would be a low and constant hazard rate of recalls, which is associated with an exponential distribution of times before failure. This leads to our first testable hypothesis:

Hypothesis 1: After PR/HACCP implementation, food recalls are rare random events having a constant hazard rate.

PR/HACCP embodies a blend of regulatory objectives with deliberate allowance for discretion on the part of business managers. While conforming to a design standard is a sunk cost, which disadvantages smaller firms, according to Antle (1996), flexibility in implementation means that both large and smaller firms would be able to design systems that are equally effective in preventing food contamination, given their constraints with respect to scale, manpower and managerial talent, organization, and technology. Even a small firm can hire expertise for the one-time design of a system that accommodates its circumstances. Therefore, effectiveness in terms of outcomes for quality would not be expected to differ across firm sizes.

Hypothesis 2: Recall hazards (the probability of an event) are not related to plant size in the post- PR/HACCP food system.

Scale factors obviously do impact certain features of management, particularly the expertise and record keeping that are key success factors in a crisis management situation such as a recall. A smaller plant, in which management cover many duties, is unlikely to devote as much effort to closing a recall case, both in terms of data and the communication with customers and regulators. Another scale factor is with respect to the recall case itself, rather than the size of the enterprise involved. Firms involve in large recalls are likely to take a longer period to complete the case. Meanwhile, a moral hazard issue should be considered among firms recalling product. The problem of moral hazard occurs when firms have an incentive to complete the case as early as possible after announcing the event without putting efforts to remove all affected products from the market.

Hypothesis 3: Recall cases at small plants exhibit longer duration and have lower recovery rates than recalls from large plants.

Hypothesis 4: Recall cases for larger amounts of product have longer duration.

Hypothesis 5: A moral hazard is likely to occur when a firm exhibits a low recovery rate and short completion time even if the ratio of recovery rate-case duration remains unchanged.

The concept of signaling is the foundation of the next hypothesis. A firm launches a brand and invests in its development to send a signal of its quality, a vital function in a world of imperfect information. Without a brand to differentiate, there is no way for a firm to earn returns on its investments in value added and quality. Once developed, the brand is an important intangible asset and it will provide an incentive for a better food control system. This is the basis for:

Hypothesis 6: Processed products have lower recall hazards, and the cases have shorter duration, because the firm is protecting its reputation. We use processed foods as a proxy for branded products.

Supply chain linkages and boundaries of the firm frame the context for a series of testable questions. Plants that are the point of origin for a diffuse supply chain, covering many states or even national distribution, would be marked by complex trace-back systems. Simply because of the scope of distribution, one would expect recalls from plants with numerous distribution linkages, such as multiple states or nationwide, to have lower recovery rates and longer case durations. The notification level can imply how far affected products have been distributed in the supply chain. Even though a plant distributes to customers nationwide, it may sell to only a few supply chain partners downstream, as would be the case for a slaughter plant that sells to a major processor in an exclusive supply chain relationship. In that case, a single phone call may be all that is needed to execute the recall, leading to shorter duration of cases. Further, it should be easier to recover products that are distributed to restaurants than to consumers. Thus, it is further hypothesized that firms distributing only to the next level buyer have a tight supply chain relationship and will have higher recovery rates. The two supply chain-related hypotheses are:

Hypothesis 7: Plants with spatially dispersed buyers, determined by the distribution level, have longer recall case duration and lower recovery rates.

Hypothesis 8: Plants involved in short supply chains, determined by the notification level, have shorter duration of recalls and higher recovery rates.

Regulatory models of feedback drawn from the policy analysis literature (e.g., Olson, 1997) are based on the premise that regulators respond to signals from external stakeholders. FSIS has at least two sets of key stakeholders: meat and poultry firms and the general consuming public. These stakeholder groups may offer conflicting feedback to an action by the regulator, in which case their relative influence may simply cancel out. One clear proposition would be that both camps of external stakeholders would approve of prioritizing the responses to the most severe food safety problems. Our notion of prioritizing is not simply to close the case quickly. Severe cases should remain open longer in order to assure safety. Businesses would respond favorably to effective handling of cases that might invoke legal liability and support their ethical business practices. The time until a problem is found is also important because early discovery is likely to result in a higher recovery rate and shorter completion time. These notions of regulatory response to feedback lead to the following hypotheses on timing:

Hypothesis 9: The most serious food recall cases have longer duration and high average recovery rates. The proxies for severity are Class I recalls and biological hazards.

Hypothesis 10: The sooner the problem is discovered, the shorter recall duration and the higher the average recovery rate.

Data

Defining a Measure of Likelihood of Recall Event after PR/HACCP

The duration of **time before recall** is the survival time or spell of time without a recall, following PR/HACCP implementation by the plant. The survival statistics and related functions are the basis for hazard rates, the probability that a recall occurs, conditional on survival to a particular time. The beginning of the post-PR/HACCP period is defined variously chronologically as the regulation was phased in more slowly for smaller plants. Large meat and poultry slaughter and processing plants (those with more than 500 employees) were required to have PR/HACCP systems in place by January 26, 1998. The regulation for small plants (having between 10 and 500 employees) became effective January 25, 1999, and finally for very small plants (fewer than 10 employees or less than $2.5 million in annual sales) on January 25, 2000 (Teratanavat and Hooker, 2001). The variable used for post-PR/HACCP time before recall was created by counting days elapsed between the final PR/HACCP deadline for the plant of that size and the initiation of the recall.

Defining Measures of Recall Effectiveness

The discussion and debate about the voluntary recall process has centered on the question of timeliness of recalls (GAO, 2000). We concur with GAO's perspective about the urgency of response when contamination in the food supply is discovered, and therefore developed measures of effectiveness that highlight the time-sensitivity of the recall process: the recovery rate, the speed or duration of the recall case, and the ratio of recovery rate-completion time. The overall goal of FSIS is to protect consumers by ensuring that meat, poultry, and egg products are safe, wholesome, and accurately labeled (FSIS, 2001). Once these products are considered to be adulterated or misbranded, it is necessary to locate and remove them from commerce (FSIS, 2002b). It can be assumed that the recall process is effective if a large proportion of these recalled products are recovered or returned back to producers in a prompt manner. One key limitation of these indicators is that they do not fully take severity of the recall case into account, although the regressions do imperfectly control for severity with certain explanatory variables. As shown in table 1, the effectiveness measures are defined as:

1. The **recovery rate** is the proportion of volume recovered to the total volume recalled.
2. The **case duration** measures speed of the recall action, in the number of days to complete the case. This indicator is the most direct measure of timeliness the focus of GAO's evaluation.
3. The **recovery rate-duration ratio** is calculated as the recovery rate divided by the days to complete the case. This measure was selected in recognition of the moral hazard problem that could arise if performance is measured exclusively by case duration, as managers may be tempted to close a case early and recover only a small amount of product.

Explanatory Factors for Survival Analysis of Recall Events

The key covariates analyzed with the Cox method are business and industry factors (size of the plant, products recalled, extent of distribution), and management signals (firm finding the contamination, and whether it was found within a relatively short period of time) (table 2). The binary variable for large recalls in pounds used to analyze proportional hazards can be contrasted with the procedure of Lusk and Schroeder (2002), who created size categories of equal frequency in 5 increments, which differed for the type of product recalled. For example, the largest size category for pork products in Lusk and Schroeder was recalls above 45,512 pounds and the largest size category for beef products was recalls above 175,288 pounds.

Explanatory Factors for Recall Effectiveness Measures

Four main categories of explanatory variables are available in the FSIS database, including product specific, firm specific, timing, and other factors. The **product** specific category includes factors describing the item being recalled, such as recall size (weight in pounds), product shelf life (raw or processed food), recall class[6], hazard type[7], and whether the product is imported. Since recall size is used to derive the recovery rate and the recovery rate-completion time ratio, it is included only in the models where the efficiency measure is completion time. In general, the larger the recall size, the longer time it takes to remove affected products from the market. Products with a relatively short shelf life such as ground beef may have lower recovery rate and take less time to complete the case, as these products are less likely to be left in the retail store when problems are discovered. If the recall process is effective, higher recovery rates and shorter completion times are desirable outcomes for cases involving more serious issues such as class I and biological hazards.

The **firm** or plant specific factors capture the effect of PR/HACCP, plant size, and location where the recall case originated[8]. The implementation of PR/HACCP can imply an improvement in hazard control and inspection during the production process. Such improvement may indirectly facilitate the recall process, which is likely to result in a higher recovery rate and shorter completion time. Larger plants are expected to be better able to deal with product recalls because they tend to have enhanced food safety technologies and more staff to handle problems. Location of the firm is also included in the model to examine if the recall effectiveness and efficiency varies across regions.

The **timing** category includes the period between production date and problem discovery date, a time indicator over the study period, and the season in which the firm announced the recall. The sooner the problem is discovered, the more affected product can be removed in a shorter period because items may not yet be distributed to different levels of the supply chain. It is easier to recall products that are still in manufacturers' warehouses than to remove products

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[6] According to FDA and USDA, recalls can be classified into 3 classes, I, II, and III, depending on the potential negative health consequences.

[7] Foodborne biological hazards include bacterial, viral and parasitic organisms. Cross contamination and improper food processing and handling are the main reasons that these pathogens are found in food products. Chemical hazards involve naturally occurring or artificial contaminants arising in the production or processing of foods. Physical hazards include cases when hard foreign objects are found in food products.

[8] The American Meat Institutes (AMI) classification of states into six regions is used; Pacific, Mountain, North Central, South Central, North Atlantic, and South Atlantic.

that are on supermarket shelves or in consumers' homes. Any improvement in recall effectiveness over time can be captured by the time trend variable included in the model. If FSIS has been successful in improving its recall program, an increase in the recovery rate and a decrease in the number of days to complete recall cases over time are expected. Seasonal factors are included in the model to examine if recall effectiveness varies throughout the year.

Other characteristics are also available in the dataset. The distribution level is represented by the number of states in which affected products were shipped. The depth of the recall, as defined by FSIS, includes consumer, user (restaurants), retail, and wholesale levels. Problems can be discovered through FSIS microbial sampling, by firms, consumer complaints, foodborne illness incidents, and other epidemiological data by local and state public health department. Whether the firm provided a press release to the public is also included.

Data Collection

FSIS recall summaries (available at http://www.fsis.usda.gov/OA/recalls/rec_intr.htm) contain information about recall dates, identifying codes, company names, location of incidents, recalled products, reason and description, and size of recall and recovery in pounds. The recall data is updated regularly and is currently available on the FSIS website from 1994. In most cases, press releases are also available. Since 1998, FSIS has provided recall information in a single format called a Recall Notification Report (RNR). The RNR contains the same information provided in the report summary with the addition of production date, how problems were discovered, distribution level, and depth of recall. Although certain variables are available for the entire 1994-2002 period, various information has been collected more recently or is not yet complete. Recalls in 2001 and 2002 are not included in the models involving recovery rates and case duration because recovery data and closure dates are not available. Teratanavat, Hooker, and Salin (2002) analyzed the data from 1994 to 2000 and found that the subset of data from 1998 to 2002 provided consistent results for the three effectiveness measures reported here. Thus, this study uses data from 1998-2002 for the survival analysis of recall events where information regarding recovery rate and case duration is not required and data 1998-2000 for the analysis of recall effectiveness measures.

Descriptive Statistics

Even though there are two separate sets of variables for the survival analysis of recall events and the measures of recall effectiveness, the first set of variables (table 2) includes only selected variables whereas the second set of variables (table 3) includes a broader range of explanatory factors. Thus, the descriptive statistics will focus on the explanatory variables used in the effectiveness measures. During 1998 to 2000, the average amount of recalled product recovered was 49.9 percent while it took an average of 174 days to complete a recall case (tables 1 and 3). The average ratio of the recovery rate and the time for case completion implies that 0.42 percent of product is recovered each day a case remains open. Approximately 7 percent of the observations report zero percent recovery. It is also possible that the actual amount of product recovered exceeds the amount the firm initially announced because firms or FSIS may discover later that the case was more serious than originally thought to be. In these cases, the amount of product to be removed from the market may be extended, as can be seen when the recovery rate goes beyond 100 percent[9].

Considering first the variables in the product specific category, the average size of recalls varied considerably over the period, peaking to over 1 million pounds per recall in 1998 (Teratanavat and Hooker, 2001)[10]. These figures are strongly influenced by a few very large, outlier recall cases including 35 million pounds by Bil Mar Foods (1998), 35 million pounds by Thorn Apple Valley (1999), and 17 million pounds by Cargill Turkey Products (2000). There are a number of smaller recalls in the data sets, with 24% of total cases comprising less than 1,000 pounds, 54% between 1,000 and 100,000 pounds, and only 4% larger than one million pounds (Teratanavat and Hooker, 2001). While these outlier observations affect the average in the raw data, they do not have a significant effect on any of the measures of recall effectiveness discussed in this paper. The regression models without outlier observations (available upon request) are not significantly different from the models with these observations included.

Of these recalls, some 75 percent involved processed foods, which have longer shelf lives than raw or fresh products[11]. Class I and II recalls account for 83 and 13 percent respectively

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[9] The actual recovery rate, even beyond 100 percent, is included in the regression models.
[10] The log transformation of the volume of product recalled (LNPOUND) is used to avoid scale effects.
[11] The authors are aware that different raw or processed foods have a range of shelf lives. One processed food may last 3 months, whereas another may last a few years. To capture this effect, product shelf life

with two-thirds of the cases related to biological hazards. More than 90 percent were domestic cases, which mean products were manufactured and marketed in the U.S. In the firm specific category, the average of 78 percent implementation of PR/HACCP for the 1998-2000 period indicates the rapid adoption of the program and reflects the legal requirement that nearly all firms were required to have adopted the program by 2000. Almost half of the recall cases were from small plants and about one third of all cases originated in the north central area. Recall cases were distributed equally across the four seasons, suggesting little timing effects throughout the year. The lag between the production date and the discovery of the problem indicate that, on average, it took 43 days to announce a recall. Almost half of the recall cases were distributed as far as the consumer level and problems were mostly determined by FSIS through regular sampling. A press release was made available in 73 percent of all recall cases.

Methodology

The effectiveness measures examined in this study are a mix of performance indicators in percentages and performance indicators in duration, or count data. All of the indicators are censored at zero, which requires appropriate econometric testing and procedures described below.

Model Selection for Analysis of Time before Recall

Nonparametric methods are recommended for the initial step in analyzing survival functions and the related hazard functions (Lee, 1992). The survivorship function (also called survival function or cumulative survival rate) depicts the probability that a recall has not occurred at time t, and is defined as:

$$\begin{aligned} S(t) &= \Pr(\text{time before failure is at least } t) \qquad (1) \\ &= \Pr(T > t)\,. \end{aligned}$$

By definition, the survival function is closely related to the cumulative distribution function (CDF) of times before recall:

$$S(t) = 1 - \Pr(T < t) \qquad (2)$$

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should be treated as a continuous variable. However, FSIS recall data does not provide such information;

$$= 1 - F(t), \text{ where } F(t) \text{ denotes the CDF.}$$

Hazard functions describe the conditional failure rate, or the probability of failure during a very small interval, given survival up to the beginning of the interval. In this context, the hazard rate refers to the conditional probability that the firm will involve in recall in this period, given that no recall has been occurred in the past. The hazard function is defined as:

$$h(t) = \lim_{\Delta t \to 0} \frac{P\{\text{subject with survival to age t fails in the time interval } (t, t + \Delta t)\}}{\Delta t} \quad (3)$$

Cox's proportional hazards model, a multiple regression technique that requires no assumptions on the mathematical form of the underlying probability distribution (Cox, 1972), is used to assess the relationship of key factors to the hazard of a recall. The model embodies the assumption that different plants have hazard functions that are proportional to one another, yielding a ratio of hazard functions for those two plants that does not vary with time. The specification of the hazard function is:

$$h_f(t) = h(t; x_f) = h_0(t) \exp(x'_f \beta) \quad (4)$$

where $h_0(t)$ is a baseline hazard function, x_f is a vector of explanatory variables for plant *f,* and β is a vector of regression parameters to be estimated. If each firm has the same baseline hazard function, the Cox regression method will be valid.

The Cox regressions identify factors that relate significantly to the hazard of the plant. The explanatory variables are all in the form of (0 or 1) indicator variables (table 9). The hazard function of the sample that does not have the characteristic (x = 0) represents the baseline hazard rate, and the sample that has the characteristic (x = 1) has a hazard rate of the baseline multiplied by exp(β). This specification does not allow for the covariates to be time-dependent.
The model was estimated with maximum likelihood techniques using SAS 8.0.[12]

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an indicator variable, 0 for raw food and 1 for processed food, is assigned instead.
[12] Options selected were: Full model, Discrete logistic method.

Model Selection for Recovery Rate Analysis

The recovery rate and the recovery-duration ratio are percentages potentially censored at zero, but relatively few zeros occur in the series (some 7% of all observations). An OLS model is used to examine the linear relationship between the recovery rate, the recovery rate-time ratio, and factors that may influence recall effectiveness. Greene (2000) suggests that when the dataset is significantly truncated or censored, OLS estimates are inconsistent, but our results did not exhibit this problem. Tobit estimates are available upon request; however these findings are consistent with the OLS model, which is reported here for ease of interpretation.

Model Selection for Duration Data

Variables that report a frequency, for example, the number of days to complete a recall case, are often investigated using count data models (Long, 1997). Count data models have been applied in various research disciplines such as agricultural economics, economics, political science, and/or medical sciences. Examples include the number of times that shoppers decide to purchase irradiated meat products (Rimal, Fletcher, and McWatter, 1999), the duration of unemployment, the number of doctor visits (Cameron and Trivedi, 1986), the number of trips to recreation sites (Haab and McConnell, 2002), and so forth.

In this study, both censored and count data modeling techniques are applied when the duration of the recall case is the dependent variable, because the time is censored at zero. The count data regression models such as Poisson or Negative Binomial are more appropriate than Tobit or Truncated models since the number of days taken to complete the case are nonnegative integers (Haab and McConnell, 2002).

In the model explaining the duration of recall cases, Y_i is the number of days to complete the recall. This variable is assumed to be drawn from a Poisson distribution with parameter λ_i. The probability that the number of days equals any particular value can be written as (Cameron and Trivedi, 1998):

$$\Pr(Y_i = y) \quad = \quad \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!} \qquad y = 1,2,....... \tag{5}$$

The parameter λ_i, representing the conditional probability of the dependent variable, is an exponential function of a constant and exogenous variables to ensure the non-negativity of Y_i. The mean parameter, also called the exponential mean, and the likelihood function are shown below. The coefficients (β) can be estimated using the maximum likelihood method.

$$E[y_i|x_i] = \lambda_i = \exp(x_i\,\beta) \qquad (6)$$

$$L(\beta|x,y) = \prod_{i=1}^{n} \frac{\exp(-e^{x_i\beta})\,e^{(x_i\beta)\,y_i}}{y_i!} \qquad (7)$$

The main property of the Poisson distribution is that the conditional mean $(E[y_i|x_i\beta])$ is equal to its conditional variance $(Var[y_i|x_i\beta])$. As seen from table 1, the conditional variance of the dependent variable (total days) is far greater than the conditional mean, implying over-dispersion of the data. This over dispersion yields consistent coefficient estimates, but standard errors are biased downward (Gourieroux, Monfort, and Trognon, 1984).

Cameron and Trivedi (1998) suggest the negative binomial model, a more generalized specification that relaxes the equality of the conditional mean and variance. The negative binomial has a gamma distributed error term (ε) in the mean:

$$\lambda_i = \exp(x_i\beta + \varepsilon) \qquad (8)$$

The density function is shown below where α is the over-dispersion parameter

$$f(y|\lambda_i,\alpha) = \frac{\Gamma\left(y_i + \frac{1}{\alpha}\right)}{\Gamma(y_i+1)\,\Gamma\left(\frac{1}{\alpha}\right)} \left(\frac{\frac{1}{\alpha}}{\frac{1}{\alpha}+\lambda_i}\right)^{\frac{1}{\alpha}} \left(\frac{\lambda_i}{\frac{1}{\alpha}+\lambda_i}\right)^{y_i} \qquad (9)$$

Both parameters, α and β, can be estimated using the maximum likelihood method. With a negative binomial distribution, the conditional mean can now differ from the conditional variance:

$$E[y_i|x_i\beta] = \lambda_i = \exp(x_i\beta + \varepsilon) \qquad (10)$$

$$Var[y_i|x_i\beta] = \lambda_i(1+\alpha\lambda_i) \qquad (11)$$

It is noted that if α = 0, the negative binomial model becomes the Poisson model; as a result, a test of α = 0 assesses both over-dispersion and the nested model (Haab and McConnell, 2002). Results of the over-dispersion test support the negative binomial specification for modeling the duration of recall cases because the hypothesis of no over-dispersion ($\alpha = 0$) is rejected at the 0.01 level (table 6 and 7).

Results

Distribution of Times before Recall

The result of the non-parametric estimation of times before recall using the Kaplan-Meier product-limit procedure[13] is shown in figure 1. Steep survival curves represent short survival times or recalls that are occurring close together in time. The survivorship function (and a 95% confidence interval around the estimate) does not show convexity, suggesting a nearly constant rate of occurrence of recalls under the PR/HACCP program. There is no remarkable agglomeration of recalls, nor are there periods that are remarkably free of recalls. The flatter portion of the function near the end of the time is an artifact of the data collection process: There were no small or very small plants that had recalls 1,400 days or more after PR/HACCP because there had not been that much time elapsed since PR/HACCP was required for those size plants.

Hazard rates per unit time are quite small (figure 2), due to the large number of days observed. While there is some visual evidence of hazard rates increasing modestly with time, overall during the period they are nearly constant. The observation of a constant hazard rate would be consistent with an exponential distribution of times before recalls, if one were using a parametric specification. These two distribution functions support *hypothesis 1*, that the dynamic character of recalls following adoption of PR/HACCP reflect sound process control.

Factors Explaining Time before a Recall

The key result from the estimation of proportional hazards is a measure of relative risk, the hazard ratio (table 5). The hazard ratio is the ratio of the risk of failure for a plant that has a particular characteristic, relative to the average plant that does not have that characteristic.

Large plants are at a significantly lower risk of recall events than small and very small plants, conditional on having not experienced a recall at time *t*. This result is consistent with the aggregate statistics showing a large number of recalls among smaller plants. These findings provide no support for *hypothesis 2,* which was based on a premise that flexible regulatory

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[13] See Salin, Hooker, and Teratanavat (2003) for an explanation of this procedure.

frameworks result in processes that are well-suited to address the circumstances of that firm, and chances of failure after implementation are scale-neutral.

Hazard rates did not differ by food product type (beef or poultry, compared with pork or other). Plants that produce processed foods had a higher estimated hazard ratio 1.4 times higher than that for fresh foods. Processed foods are predominantly sausage and wieners, with lesser incidence of ham, lunch meats, and frozen chicken products. This evidence did not support the arguments based on branding and value added underlying *hypothesis 6*.

There was a higher risk that the product had reached the consumer level of distribution, rather than being contained at the wholesale or retail levels. This result raises concerns about lack of effectiveness of the recall process, since even under PR/HACCP; there is a higher risk of contaminated products reaching consumers than being withheld earlier in distribution.

The factors under closer control (or at least influence of) the recalling authorities (size of recall in pounds and class of recall) did not significantly relate to the risk of the recall occurring. These two variables are within the discretion of FSIS, so may be relevant for analysis of effectiveness, and also can be considered indicators of severity. The lack of statistical significance suggests that conditional risks are not related to severity - that is, the risk of a “severe” recall is not different than the risk of a less severe recall. Similar logic applies to the lack of a significant impact of the binary variable for large recalls. What constitutes a “severe” recall in terms of pounds has not been established in policy or in applied analysis. While we do not claim to resolve the question of how to measure severity, either in terms of human health or potential financial consequences, the lack of evidence that these severity measures are related to the hazard rate is interesting.

Explanatory variables were included to measure managerial signals of quality in monitoring food safety: (1) whether the firm found the problem, in contrast to the discovery of the problem by FSIS or other monitoring authorities, and (2) if the problem was identified quickly after production. Binary variables were created for recalls in which the problem was found within a week and within a month of production. These managerial signals all had a significant relationship to the recall risk. The firm identifying the problem is associated with a lower hazard rate than if external sources found the contamination. The hazard ratio suggests that the plants at which management found the problem had a hazard rate of 0.556 times that of a plant that did not identify its own problem.

Factors Affecting Recall Recovery Rates

While the recovery rate models both pass the joint significance test, using the F-statistic, only a limited number of explanatory variables about the firm and timing have a significant effect on percent recovered (alone and in the ratio with case duration) (tables 6).

Larger plants have lower estimated recovery rates than smaller plants, contrary to *hypothesis 4*. The significant positive estimate for PR/HACCP suggests that the recovery rate has been increasing since firms implemented the program. Other factors in the product specific category and the management-supply chain information do not have an impact on the recovery rate, according to the regression models; thus the results do not support *hypothesis 7, 8, 9 and 10*. The only exception is how the problem was discovered. The result shows that the recovery rate is 41% higher when firms found the problem themselves (table 6), implying that the recall process is more effective when it is initiated by the firm.

Considering the ratio of recovery rate to case duration, the positive significant estimate for PR/HACCP indicates that firms recovered 0.26 percent more affected product per day, on average, after they implemented the program. As for the firm specific characteristics, large plants have lower average daily recovery rates (by 0.40 percent) than small and very small plants (again contrary to *hypothesis 3*). Other factors such as recall class, hazard type, or domestic/imported products do not have a statistically significant impact on the recovery rate-completion time ratio. The results show that recalls in the summer, spring, and fall are likely to have lower recovery rates per active day.

Factors Affecting Recall Case Duration

The regression results show that only three factors, recall size, time trend, and how problem is found, affect the completion time or case duration even though the model has joint significance according to the likelihood ratio test (table 7). Since the parameters generated by the count data models do not have a direct interpretation, the marginal effects computed from coefficient estimates evaluated at sample means of explanatory variables are also reported.

The size of the recall is positively correlated with case duration implying that larger recalls tend to take a longer time to complete the case; this result supports *hypothesis 4*. The significant negative coefficient on the time trend variable (DATE) implies that the recall process now takes less time to complete as compared to the earlier years within the sample. This result is consistent with a previous recall trend analysis (Teratanavat, Hooker, and Salin, 2002) and it represents an improvement of the recall process over time if case duration is used as an evaluation metric. It is shown that cases when the firm found the problem themselves tend to take a longer period to complete. When firms discovered that their products are not safe, they presumably want to be sure that all affected products are removed from the market even though it will take longer to complete the case, as shown by significant positive coefficient of the recovery rate and negative coefficient of the case duration. This result suggests moral hazard for firms involved in product recalls is not an issue, thus rejecting *hypothesis 5*.

Discussion and Conclusions

Four measures are presented and used to test hypotheses about food recalls. This research advances our knowledge of food safety in presenting statistical indicators that can be used to benchmark the status of the food safety control system, but only limited conclusions can be reached in terms of overall performance and factors that explain the timeliness of recalls.

It is important to understand whether a regulatory system has differential impacts on firms of different sizes. Our initial hypotheses were that the system is scale-neutral with respect to occurrence of recalls, as PR/HACCP provides flexibility for firms to design their process control plans, but that smaller firms would experience more difficulties than larger firms in executing the recall process in a timely way. Neither of these premises was supported by the evidence. There was no statistical evidence that recall cases at large plants had shorter durations than cases at small plants. The results contradict our hypothesis that management at larger plants can carry out a recall in a more timely way than at smaller plants, as both the recovery rate and the ratio of recovery rate to duration are lower for large plants than small or very small plants. While these findings suggest that difficulties remain with respect to the recall process for larger facilities, further analysis should also consider the impact of corporate management on recall effectiveness for the cases in which multiple plants are operated by a single firm.

As food companies invest in value-added or branded products, we hypothesized that their care in reducing the likelihood of recalls and in completing a recall efficiently would increase because the firm is protecting an investment in reputation. Using the limited information on the types of products involved in the recall that is available at this time, we found that processed meat and poultry products had significantly higher hazards of recall than fresh foods. There was no evidence that the cases involving processed foods were closed more quickly, although there was a weak indication of higher rates of recovery, on average, per day the case was open, for processed foods compared to fresh. The interpretation of this evidence for processed items is further hampered by the weakness of the proxy we use: clearly not all processed products are branded, nor high-value-added. Nevertheless, these results may be an indication that processing techniques and product positioning in the meat and poultry sector are not consistent with the theory of reputation-building.

While there are opportunities for supply chain management plans to improve managerial responses to a food control failure, a widely dispersed chain of distribution would logically expect more difficulty in recalling products. In addition, if a recall notification was only to the next level of distribution, one would expect the process to be more effective. No statistical support was found for these hypotheses. Another key finding here is that firms demonstrate their efforts in recovering unsafe products from the food supply chain. The result suggests that recalls are completed in a more timely way when the firm has processes in place that allow it to discover the problem on its own. Also, it is unlikely that the moral hazard exists when firms try to close the case without putting effort into recovering product.

Finally, we began with the premise that severe cases, those with Class I designation and involving biological hazards, would take more time and attention in the recall process, justifiably so. There was no support for this idea from the research. Also puzzling is the lack of statistical significance of the conditional risk that a recall occurs. We found that the risk of a "severe" recall is not different than the risk of a less severe recall. Acknowledging the difficulty of defining severity, the results raise the possibility that the system is not targeting its resources appropriately to address the greatest risks to human health.

The major challenge facing those interested in statistical work on food recalls is that the data collection is divorced from the hypotheses of interest to business managers and regulatory authorities. Information on recalls is collected at the plant, when the unit of analysis for an understanding of business incentives should include the firm. Corporate ownership and business linkages may have changed during the period examined, which means that it will take further work to develop the most appropriate tests of our managerial hypotheses.

Implementation of PR/HACCP is an ongoing process, and not all of the dynamics are captured with the timing variables that we have collected. For example, the official notices of the final regulatory changes to come under the PR/HACCP program were published beginning in 1996, and it is possible that some plants adopted PR/HACCP or other quality control systems prior to the final implementation date. Nevertheless, we simplify through a post-PR/HACCP period starting with the required date of implementation. New microbiological testing technologies may have allowed more precise detection, and "zero tolerance" directives by FSIS may have influenced the prevalence of recalls, other factors that are not measured well in the data we use.

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Table 1: Descriptive Statistics of Dependent Variables

Dependent Variables	Definition	Mean	Std. Dev.	Min.	Max.
RECOVERY	Recovery rate (%) = Amount recovered / amount recalled *100	49.90%	-0.6	0.00%	650.90%
TOTAL DAYS	Number of days to complete case	174.3	-104.6	35	616
RATIO	Recovery rate (%) / Number of days to complete case	0.40%	-0.4	0.00%	2.10%
HAZARD RATE	Probability that recall event occurs at time interval *t*	0.005	0.0103	0.125	0.00016

Table 2: Explanatory Variables used in Proportional Hazard

Explanatory Variables	Definition	Mean	(Standard Deviation)
BEEF	=1 if product is beef	0.360	(0.481)
POULTRY	=1 if product is poultry	0.239	(0.427)
PROCESSED	=1 if product is processed	0.720	(0.450)
FIRM_FOUND	=1 if contamination discovered by firm (omitted categories are found by FSIS or others)	0.247	(0.432)
CONSUMER	=1 if product had reached consumer level of distribution	0.222	(0.416)
LARGE	=1 if plant size is large as defined by FSIS	0.246	(0.431)
POUNDSHI	=1 if recall involved 100,000 or more pounds of product	0.218	(0.414)
CLASS1	=1 if recall is Class 1 as defined by FSIS	0.775	(0.418)
NATIONAL	=1 if firm distributes to 50 states	0.218	(0.414)
WEEK	=1 if contamination was found within 7 days of production	0.253	(0.435)
MONTH	=1 if contamination was found within 30 days of production	0.339	(0.474)

Table 3: Description of Explanatory Variables used in Recall Effectiveness Measures

Explanatory Variables	Definition	Mean	(Standard Deviation)
Product/ Case Characteristics			
LNPOUND	Log value of total pounds of recalled product	3.8725	(1.31)
SHELFLIFE	Short/long shelf life (1=processed food; 0=raw or fresh products)	0.75	(0.45)
CLASSI	Class I recall (1=yes;0=no)	0.8314	(0.37)
CLASSII	Class II recall (1=yes;0=no)	0.1337	(0.33)
CLASSIII	Class III recall (1=yes;0=no)	0.0349	(0.18)
BIOLOGICAL	Hazard type: Biological (1=yes;0=no)	0.7674	(0.42)
CHEMICAL	Hazard type: Chemical (1=yes;0=no)	0.1395	(0.18)
PHYSICAL	Hazard type: Physical (1=yes;0=no)	0.093	(0.25)
IMPORT	Domestic/ Imported products (0=domestic; 1=imported)	0.064	(0.24)
Firm/ Plant Characteristics			
PR/HACCP	PR/HACCP implemented at time of recall (1=yes; 0=no)	0.7849	(0.46)
LARGE	Plant size: Large (1=yes;0=no)	0.2267	(0.42)
SMALL	Plant size: Small (1=yes;0=no)	0.4651	(0.50)
VSMALL	Plant size: Very small (1=yes;0=no)	0.2093	(0.41)
MOUNTAIN	Location where recall occurs: Mountain region (1=yes;0=no)	0.0523	(0.25)
PACIFIC	Pacific region (1=yes;0=no)	0.1105	(0.31)
NATLANTIC	North Atlantic region (1=yes;0=no)	0.2093	(0.40)
SATLANTIC	South Atlantic region (1=yes;0=no)	0.1105	(0.33)
NCENTRAL	North Central region (1=yes;0=no)	0.2907	(0.45)
SCENTRAL	South Central region (1=yes;0=no)	0.157	(0.37)

Table 3: Description of Explanatory Variables used in Recall Effectiveness Measures (Continued)

Explanatory Variables	Definition	Mean	Std Dev.
Timing Factors			
DISCOVERYTIME	Time from production date until the problem is discovered	43.2797	-60.745
DATE	Range from 1 to 3 representing year 1998 to 2000	2.2143	-0.775
FALL	Season when recall occurs: Fall (Oct-Dec) (1=yes;0=no)	0.1919	-0.416
WINTER	Winter (Jan-Mar) (1=yes;0=no)	0.2326	-0.416
SPRING	Spring (Apr-Jun) (1=yes;0=no)	0.3081	-0.459
SUMMER	Summer (Jul-Sep) (1=yes;0=no)	0.2674	-0.441
Other Factors			
DISTRIBUTION_LEVEL	Number of states in which product was distributed	11.12	-17.451
CONSUMER	Depth of the recall as identified by recall committee - targeting household consumers	0.4767	-0.501
USER	Depth of the recall as identified by recall committee - targeting restaurant and other food service institutions	0.2965	-0.46
RETAIL	Depth of the recall as identified by recall committee - targeting all retail stores	0.2093	-0.411
WHOLESALE	Depth of the recall as identified by recall committee - targeting wholesale distributors	0.1221	-0.339
FSIS_FOUND	Problem was discovered through test result if sample taken by FSIS	0.6047	-0.491
FIRM_FOUND	Problem was discovered through the firm reporting the problems	0.1047	-0.314
OTHER_FOUND	Problem was discovered through consumer complaints, foodborne illness incidents, or other epidemiological data collected by state/local public health department, other than USDA	0.2907	-0.456
PRESS_RELEASE	Press Release (whether it is available) (1= yes;0=no)	0.7267	-0.415

Notes:

a) FSIS assigns recalls into Class I, II and III depending on the severity of the potential negative health consequences.

b) Large plants have more than 500 employees. Small plants have between 10 and 500 employees. Very small plants have less than 10 employees or less than $2.5 million in sales.

c) The Food Code specifies foodborne hazard types, which are biological, chemical and physical hazards (CFSAN, 1997)

Table 4: Summary of Hypothesis Testing By Different Measures

Hypotheses	Proposed Measures			
	Survival Analysis/ Hazard Rate	**Recovery Rate**	**Ratio of Recovery and Case Duration**	**Case Duration**
H1: After PR/HACCP implementation, food recalls are rare random events having a constant hazard rate.	Yes			
H2: Recall hazards (the probability of an event) are not related to plant size in the post- PR/HACCP food system.	Yes			
H3: Recall cases at **small plants** exhibit longer duration and have lower recovery rates than recalls from large plants.		Yes		Yes
H4: Recall cases for **larger amounts** of product have longer duration.				Yes
H5: The Moral Hazard is likely to occur when a firm exhibit lower recovery rate with shorter completion time while the ratio of recovery rate to case duration remain unchanged.		Yes	Yes	Yes
H6: **Processed products** have lower recall hazards, and the cases have shorter duration, because the firm is protecting its reputation. We use processed foods as a proxy for branded products.	Yes			Yes
H7: Plants with spatially dispersed buyers (**distribution level**) have longer recall case duration and lower recovery rates.		Yes		Yes
H8: Plants involved in short supply chains (**notification level**) have shorter duration of recalls and higher recovery rates.		Yes		Yes
H9. The **most serious food recall** cases have longer duration and high average recovery rates. The proxies for severity are Class I recalls and biological hazards.		Yes		Yes
H10: **The sooner the problem is discovered**, the shorter recall duration and the higher average recovery rate.		Yes		Yes

Table 5: Maximum Likelihood Estimates of Proportional Hazards, Post-PR/HACCP

Explanatory Variables	Parameter Estimate	Standard Error	Hazard Ratio	
BEEF	-0.0128	0.1620	0.987	
POULTRY	0.0143	0.1699	1.014	
PROCESSED	.03714	0.1743	1.450	**
FIRM_FOUND	-0.5833	0.1597	0.558	*
CONSUMER	.03314	0.1521	1.393	**
LARGE	-0.5984	0.1854	0.550	*
POUNDSHI	0.0880	0.1847	1.092	
CLASS1	0.0808	0.1533	1.084	
NATIONAL	-0.0589	0.1864	0.943	
WEEK	0.4234	0.1758	1.527	**
MONTH	0.3384	0.1515	1.403	**

Note

a) Total observations are 262 from 1998 to 2002. This model does not involve recovery rate and closing date, which are not available in 2001 and 2002.

b) * significant at 0.10 level. ** significant at 0.05 level.

Table 6: Maximum Likelihood Estimates of Recovery Rate and Ratio of Recovery to Case Duration

Explanatory Variables	Recovery Rate			Ratio of Recovery Rate to Case Duration		
	Parameter Estimate	Standard Error		Parameter Estimate	Standard Error	
Product/Case Specific Category						
LNPOUND						
SHELFLIFE	3.402	(11.531)		0.119	(0.076)	
CLASS I	-8.621	(44.494)		-0.196	(0.292)	
CLASS II	23.266	(42.257)		0.002	(0.277)	
BIOLOGICAL	13.066	(26.358)		0.109	(0.173)	
CHEMICAL	-18.642	(24.520)		-0.121	(0.161)	
IMPORT	25.081	(25.398)		0.221	(0.167)	
Firm/Plant Specific Category						
PR/HACCP	65.994	(19.772)	***	0.363	(0.130)	***
LARGE	-60.263	(21.550)	***	-0.351	(0.141)	**
SMALL	-42.062	(16.993)	**	-0.180	(0.111)	
MOUNTAIN	8.453	(24.268)		-0.069	(0.159)	
PACIFIC	35.450	(19.910)	*	0.147	(0.131)	
NCENTRAL	-4.309	(15.437)		-0.003	(0.101)	
NATLANTIC	-9.590	(15.940)		-0.082	(0.105)	
SATLANTIC	-3.275	(19.013)		-0.144	(0.125)	
Timing Factors						
DISCOVERYTIME	-0.108	(0.111)		-0.001	(0.001)	
DATE	-25.639	(8.843)	***	-0.033	(0.058)	
SUMMER	-17.005	(14.783)		-0.163	(0.097)	*
SPRING	-14.543	(13.994)		-0.160	(0.092)	*
FALL	-28.410	(15.765)	**	-0.173	(0.103)	*
Other Factors						
DISTRIBUTIONLEVEL	0.009	(0.416)		-0.001	(0.003)	
CONSUMER	-5.264	(19.144)		-0.050	(0.126)	
USER	-8.011	(17.545)		-0.056	(0.115)	
RETAIL	-4.508	(18.039)		-0.010	(0.118)	
FSISFOUND	15.759	(14.115)		0.061	(0.093)	
FIRMFOUND	41.219	(21.921)	*	0.121	(0.144)	
PRESSRELEASE	8.070	(16.813)		0.049	(0.110)	
F-Statistic	1.629	**		1.579	**	
R-squared	0.243			0.237		
Adjusted R-squared	0.094			0.087		
Log likelihood	-858.037			-58.77		

Note:

a) Total observations are 159 from 1998 to 2000. No information about recovery rate and closing date is available for 2001 and 2002 data

b) * significant at 0.10 level. ** significant at 0.05 level. *** significant at 0.01 level.

Table 7: Maximum Likelihood Estimates of Case Duration

Explanatory Variables	Parameter Estimate	Standard Error	Marginal Effect	
Product/ Case Specific Category				
LNPOUND	0.0677	(0.0195)	0.1062	***
SHELFLIFE	0.0851	(0.0918)	1.0889	
CLASS I	0.0113	(0.3280)	1.0114	
CLASS II	0.1425	(0.3072)	1.1531	
BIOLOGICAL	0.1637	(0.1927)	1.1778	
CHEMICAL	-0.1158	(0.1809)	0.8907	
IMPORT	-0.2052	(0.1831)	0.8145	
Firm/ Plant Specific Category				
PR/HACCP	0.0100	(0.1495)	1.0101	
LARGE	-0.1047	(0.1703)	0.9006	
SMALL	-0.1776	(0.1358)	0.8373	
MOUNTAIN	0.2666	(0.1782)	1.3055	
PACIFIC	0.0637	(0.1554)	1.0657	
NCENTRAL	-0.1193	(0.1145)	0.8875	
NATLANTIC	-0.0083	(0.1183)	0.9917	
SATLANTIC	0.2152	(0.1398)	1.2401	
Timing Factors				
DISCOVERYTIME	0.0009	(0.0008)	0.0007	
DATE	-0.1741	(0.0630)	-0.1254	***
SUMMER	0.0497	(0.1100)	1.0510	
SPRING	0.0603	(0.1049)	1.0622	
FALL	-0.0738	(0.1165)	0.9289	
Other Category				
DISTRIBUTION_LEVEL	0.0007	(0.0034)	0.0008	
CONSUMER	0.0378	(0.1394)	1.0385	
USER	0.0604	(0.1246)	1.0623	
RETAIL	0.0292	(0.1254)	1.0296	
FSIS_FOUND	0.1185	(0.1012)	1.1258	
FIRM_FOUND	0.3094	(0.1580)	1.3626	**
PRESS_RELEASE	-0.0234	(0.1238)	0.9768	
Over Dispersion Test	0.1761	0.02		***

Notes:

a) significant at 0.10 level. ** significant at 0.05 level. *** significant at 0.01 level.

b) LNPOUND, DISCOVERYTIME, DATE, and DISTRIBUTION_LEVEL are continuous variables. The marginal effect is calculated by using partial derivative of the conditional mean as follows:

$$\frac{\partial E\left[y \mid x_i \beta\right]}{\partial x_j} = \beta_j \exp\left(x_i \beta\right)$$

where all independent variables are held at their means.

c) Other explanatory variables are discrete variables. The marginal effect is calculated as the factor change in the conditional mean as follow

$$\frac{E\left[y \mid d=1, x_2\right]}{E\left[y \mid d=0, x_2\right]} = \frac{\exp(\beta_1 + x_2 \beta_2)}{\exp(x_2 \beta_2)} = \exp(\beta_1)$$

Figure 1: Survivorship Function for Time before Recall, Post-PR/HACCP Period

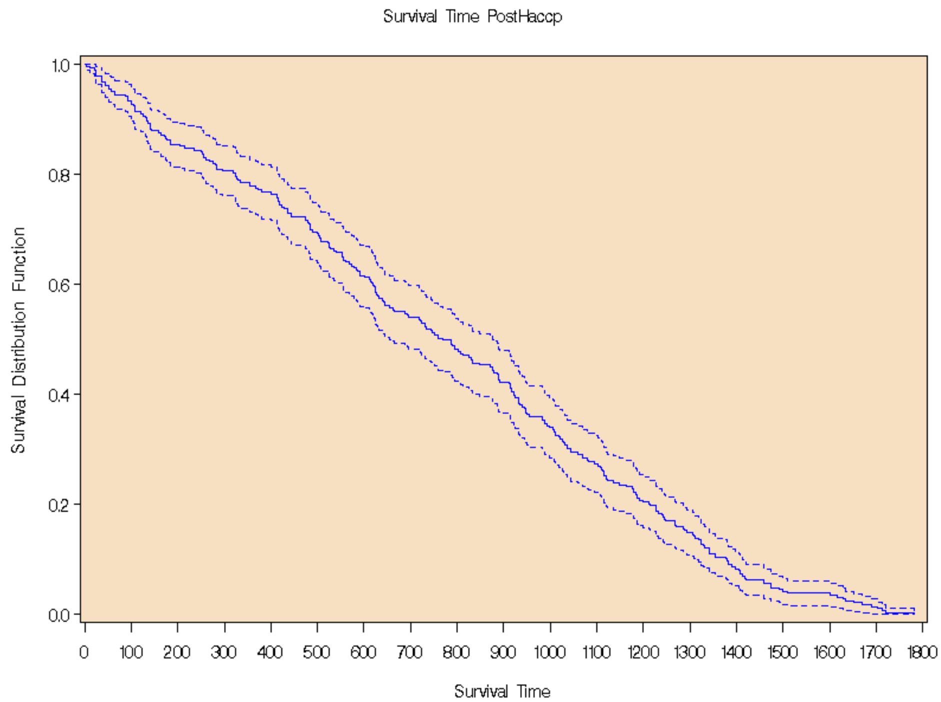

Figure 2: Hazard Rate for Post-PR/HACCP Period, All Plants