Economics of traceability for mitigation of food recall costs

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Abstract

Traceability of food products and particularly meats is increasingly advocated as a means to provide consumer confidence in credence attributes (e.g., range fed, organic, country of origin) as well as for improved quality control. In the case of food safety, where there are failures in testing and there is not likely to be zero failure rates, traceability may also improve the overall process efficiency and cost effectiveness of recalls. This study relies on case observations to develop a general conceptual model of traceability for food product recall. This conceptual model incorporates quality control in a vertical food supply chain and identifies key factors (e.g. the nature of contamination event and shelf-life of the product) that affect the cost-benefit of traceability in a risk context. Our conceptual model is adapted and parameterized for the context of a simulated recall due to E. coli in ground beef. The results of our simulations indicate that traceability might be valuable in terms of its return in saved recall costs. In addition, the effect of improved quality control measures on the traceability value is simulated and discussed. The simulated results indicate that improved quality controls and traceability seem to be substitutes. Despite this, we argue that traceability might improve information as to the source of quality control failure and therefore might play a complimentary role in achieving quality control improvements.

Keywords: Food safety, quality control, recall, risk assessment, risk modeling, traceability.

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Introduction

Food safety issues in meat and livestock have come to the forefront in recent years. High profile incidences of contamination by *E. coli*, BSE, dioxin, hormones and antibiotics have contributed to a desire to find ways to improve quality control systems in the meat supply chain. The meat industry has also implemented extensive branding of non-observable product attributes (credence attributes) including, hormone free (e.g., Coleman Beef) organic, free range and antibiotic free among others in an attempt to differentiate products to consumers.

One response to these demands has been to improve quality control systems. Ollinger, Moore and Chandran reported that from 1996 through 2000, U.S. meat and poultry processors had spent about $380 million annually and $570 million in long term investments to comply with USDA's 1996 Pathogen Reduction/Hazard Analysis and Critical Control Point (PR/HACCP) regulation. Further, they spent an additional $360 million in long term food safety investments not included in PR/HACCP regulations.

Still, as reported by Teratanavat and Hooker, in 2002 nearly 19 million pounds of ground beef possibly contaminated with *E. coli O157:H7* were recalled having moved beyond the processors' quality control system. Thomsen and McKenzie report that a Class I recall defined as a reasonable probability that eating the contaminated food will cause health problems or death reduces shareholder wealth in the offending food company by 1.5-3 percent. Considering that Tyson Foods 2003 Annual Report shows shareholder equity to be nearly $4 billion, this translates to a potential shareholder risk of $60-120 million per Class I recall event. Salin and Hooker conducted a similar analysis using event studies methodology and found there were negative impacts to share prices due to recalls, but that they were not significant. Shiptsova,

Thomsen and Goodwin estimate that the annual loss from recall in beef ranged from a minimum of $1.43 million in 1996 to a maximum of $344.34 million in 1998.

Others have considered the issue of food safety and quality control from the perspective of the firm and risk assessment. For example Malcolm et al. consider the 'cost-effectiveness' of pathogen reduction technologies in cattle by examining the cost of implementing technologies such as dehiding, steam pasteurization and irradiation relative to their effectiveness in reducing pathogen levels which is the primary objective. Jensen, Unnevehr and Gómez provide estimates of fixed and variable costs of implementation of several intervention technologies, and also estimated levels of pathogen reduction. Of interest as a concept for this article, they also described the effects of employing combinations of technologies, recognizing that they were not necessarily additive in their effects. However, none of the studies explicitly consider the dynamics of a product recall and how improved ability to make recalls utilizing information technology related to traceability might affect the costs of recall.

A few recent economic studies have broadly addressed the traceability issue. Golan et al., provide an overview of the state of traceability in the U.S. food supply. They note that traceability systems can help track product distribution and target recalls, and that the advent of grocery store or club cards may enable tracing to the final consumer. In addition to case studies of firms' in produce, meat and grains, they provide insights into the qualitative costs and benefits of traceability as well as broader conceptual economic issues related to traceability. A recent study by Dickinson and Bailey shows that consumers in the U.S. may be willing to pay for traceability and transparency in meat products. Hooker, Nayga and Siebert examine the food safety activities in the beef industry and primarily focus on the results of surveys regarding the ability to implement food safety practices, including traceable supply chains. Most processors in

the U.S. and Australia viewed it as technically feasible, but the particulars of how it might be implemented or the economic costs of implementation are not directly addressed. Hobbs develops an economic engineering approach to examine implementation of traceability in beef processing. Buhr provides case study illustrations based on existing European meat and poultry firms to examine the firm organization implications of traceability. Buhr recognizes the organizational implications of traceability and its role in improving both general quality control through improved information capture and learning and by its direct ability to limit the depth and scope of recalls should testing procedures or technical intervention strategies fail.

To date, the studies of the economic value of traceability have been mostly descriptive or qualitative conceptual observations. This is probably due to the fact that traceability and the process which underpins it is poorly defined. While traceability has been described for credence attribute verification, process quality control, and recalls, attempting to address all three involves far too complex of an array of logistics problems and conceptual definitions. This article considers only the economic modeling of traceability as a tool to improve recall processes from food borne pathogens and specifically E. coli in ground beef. To refine the potential economic worth of implementing traceability, a model for traceability is developed which incorporates, risk and uncertainty related to testing and quality assurance effectiveness, a model of product flows which allows one to simulate recalls which would occur if a contaminated product breaks through the quality assurance, and a simple cost model of this recall. This framework follows the broad conceptual framework described by Fox and Hennessy. One of the difficulties with traceability is that it is a highly diffuse technology. Therefore, our approach utilizes a process risk simulation approach wherein the recall problem is modeled as a simulation model and this allows one to evaluate which factors contribute the greatest value to traceability. To further

illustrate the trade-offs we develop a numerical simulation based on prior study estimates of key technical coefficients and parameters. An inductive approach is taken, so that simulating the marginal difference between a more precise recall allowed by traceability provides estimates of how much could be invested in a traceability system to improve precision of recall.

Conceptual Model of Traceability for Recall

Case Observations

To define the recall process, two firms were interviewed regarding their recall processes. One was a meat processing company and the other a dry grain products manufacturing company. Both requested anonymity regarding their recall processes, however, to describe the recall process reliance is also placed on previous case studies of European meat processors (Buhr 2003). The USDA Food Safety Inspection Service also has research guidelines which must be followed which can also be reviewed to better understand the recall process.

In the case of the meat processor, the recall process described was from the final product at the plant to the distribution/retail sector. This processor conducted mock recalls approximately quarterly. The goal with the mock recall is to recover all potential product contaminated within a specified time period (usually 48 hours depending on the specifications of the mock recall). This particular plant had never had a true recall, so their recall objectives are based on the scenarios they have constructed previously. The typical recall scenario includes plant managers, quality control specialists, shipping/distribution and information technology sections. They viewed recall as primarily a quality control problem and not an information systems problem. Currently they used date/time product code with plant identification to define batch sizes of products. For purposes of their recall standards, they viewed this as completely sufficient for narrowing the recall window to the point where they could minimize total product loss exposure. The main

role of information was for verification and cross-referencing. Their primary identification trail relies on shipping records and invoices of transactions, and provides the main recall link back to the plant. Unfortunately, the firm does not track or know the costs of recalls, they did however, view the primary costs as being the loss of product sales. Next, was the cost of labor for managing the recall, however, they viewed this as a cost of their overall quality control system since the same people who manage day to day quality control, invoicing, shipping and IT were the same people who managed the recall if it should occur. The firm did make the point that they viewed electronic systems as improving the efficiency of the recall process itself - improving the cross-referencing of shipping records to plant and product type and the ability to match ship totals to production totals and product re-work totals. However, as indicated earlier, they viewed this as not additionally affecting their quantity of product recalled since this was dictated by the date/time product code. One of the key quality control issues was to limit the amount of product rework because this is where cross-contamination occurs and with co-mingling products, batch integrity is also lost. Again, the focus on reducing product rework was implemented as quality control.

A second case is that of a dry mix manufacturer plant which accounts for more than 300 dry products SKU's and 35 million packages per year shipped. This firm also conducts about four mock recalls per year, which they also track by lot number, product code and date/time of manufacture. Like the meat processor they maintained a 24 hour window for mock recalls. In their case, however, they rarely had a Class I recall, but rather recalls for mis-labeling of product or foreign materials such as metal were typical, if infrequent. As with meat processing the products identified are recalled primarily using shipping and invoicing records of products in the system. One of their emerging issues was the potential for recalls based on genetically modified

organisms (similar to the Starlink case in corn). In this regard, they were in the process of developing an electronic system to correlate certificate of analyses of ingredients with their final products. The certificate of analysis is a report provided by the supplier which identifies the ingredients and chemical composition of a food ingredient for human consumption. The problem was that while quality control tested for restricted substances and quality, it was typically not possible to identify the supplier of the ingredient as there was no correlation between the certificate of analysis and the ingredient once it entered the supply chain. Hence, if a product was found with a restricted substance or foreign material, all products manufactured during the period would need to be discarded. Typically, they asserted that their quality control identified nearly all the products so that improvements would not necessarily affect recalls from consumer to processor. The primary incentive was to reduce the loss of product at the plant and also be able to identify quality suppliers. Again, as they were currently only considering implementing the information system, cost information was not available on the application of the electronic information system to the process. However, in conversation with their IT development contractor the major costs were startup creation of electronic forms and routing routines. It was not clear what the savings from reduced discarded product might be as there were no estimates on frequencies or quantities lost that were reliable.

A third example of an actual recall situation came from previous site visits to European firms (Buhr). This case is a feed supplier for a veal production group which uses electronic ration balancing for their milk replacer mixing. As a result they are able to uniquely identify all sources and quantities of ingredients in each batch of milk replacer. A subset of this information (ingredient list (not quantities), batch identification number, and microbiological assays) is uploaded to their web server that can be accessed via a password. Subsequent stages in the chain

(veal farmers and packers) can examine this information, but cannot access other information which may be proprietary such as the proportion of ingredients used in the formulation, or price of ingredients. Related to recall issues, their veterinary services identified a salmonella problem in routine on-farm testing. They immediately sampled feed batches at the farm. Through traceability databases they were then able to identify all other farms using feed from the same batches and which ingredients and their sources had gone into the suspected feed batches. Therefore, they were also immediately able to go back to plant records to crosscheck feed testing which had occurred prior to its sale. They found that no feed was contaminated and that the salmonella had been introduced by other means on the farm. Without traceability they would have recalled all suspected feed immediately to reduce the risk of cross contamination to other farms, and likely would not have been able to identify as quickly that the contamination had occurred on the farm versus at the manufacturing plant. Had it occurred at the manufacturing plant, they also would have been able to trace the product forward and been able to target farmers that received the feed rather than issue a broader recall. The feed company conducted an ex post assessment of the cost savings from traceability in this circumstance, and estimated in this single instance it saved them over $100,000 in recalls and recovery costs.

Although these case studies are limited in their ability to produce parameters useful to develop models, they clearly suggest that the key to recall will depend on the effectiveness of the quality control systems in place, and that traceability or information systems are used mostly as a tool to improve the efficiency of the recall process through records management and verification. However, as part of quality control systems all firms also recognized the need to manage batch sizes and to maintain batch integrity whenever possible; reducing the risk of cross-contamination and unknown source effects. Based on these observations, we have developed the following

conceptual and numerical simulations of recall utilizing quality control systems and information to increase the precision of recall.

Defining the Conceptual Model of Recall: Quality Control Subsystem

As a conceptual simplification, there are only two vertical links in the chain between the manufacturer or processor and the retailer and the consumer. This is consistent with "case-ready" meat products in which the final packaging may be conducted by the slaughter/processing/packing entity of the chain and where there is no additional input from the subsequent retail stages of the chain other than providing service activities such as unpacking, pricing and displaying the final product. The second feature relates to the production and quality assurance activities of each of the firms. As a baseline the firms are assumed to employ representative PR/HACCP procedures and related technologies required as described in prior studies (e.g., Ollinger et al.). Finally, the processor is assumed to face a hazard that generates the risk or probability of a product recall event. We assume that any product defect is discovered after it has left the processor's control. In our present scenario, this implies that the discovery of a recallable situation is made at the consumer/retail level. In reality, items which are mislabeled, for example, may be found at the distribution or retail stage. We further assume that at some break point in time (end of shift, end of day's operation, etc.) the plant is completely sterilized or the processing line completely discharged. This allows us to use the assumption that any given recall event is independent from other recall events. In reality, however, it is likely that poorly operated or "bad actor" plants may have multiple events which would be correlated through time and for such players, traceability may provide added incentives to become a 'good actor'. Given these assumptions, the risk or probability of a product recall event per day of production (R) may be estimated as follows:

(1) $\Pr(R)=((1-\Pi_{g|+})F_{cc}f(C_r, m)\Pr_I(C_r, \mathrm{m}))$

where, $\Pi_{g|+}$ denotes the posterior percentage of product of good quality that has passed the quality control. Therefore $(1-\Pi_{g|+})$ is the posterior percentage of product of bad quality that has passed the quality control; subscript *g* represents a truly good-quality product unit and subscript + indicates that a product unit has been found as of good quality by the quality control system; F_{cc} refers to the factor of cross-contamination; C_r is the concentration of microbial in the product at consumption given in terms of $\log_{10} CFU$ (colony-forming units); m is the mass of product ingested by the final consumer. The dose ingested by a typical final consumer is given then by $D=m*C_r$, and $f(C_r, m)$ is the probability of $D > 0$ in a meal of mass m and microbial concentration C_r (see Cassin et al. for more details). The probability of consumer exposure to the contaminated food is given by $(1-\Pi_{g|+})F_{cc}f(Cr,m)$, and $\Pr_I(C_r, \mathrm{m})$ denotes the probability of illness from dose. Hence, the probability of at least one individual getting sick by consuming a meal of mass *m* with microbial concentration C_r is also given as equation (1).

This component of the model describes the physical parameters of the model. Clearly, the probability of recall depends on the nature of the product contamination (bacterial contamination is most common, but may include foreign objects) as well as the methods to detect and control the quality of the product. These variables will be adjusted to evaluate the alternative scenarios of the value of traceability for recalls.

Defining the Conceptual Model of Recall: Defining the Recall Process

It is clear that the type of event (i.e., pathogen v. foreign matter v. mislabel) and the reliability of the quality control system ($\Pi_{g|+}$) both affect the probability of a product recall and therefore, the value of a product recall. Other very important but less obvious factors that affect the value of a

product recall are the product dispersion and the number of traceable products in the supply chain at the time of a product recall. We discuss these two factors separately as follows.

First of all, the dispersion is affected by the unit size reduction in sales units. For example, if a plant produces 500,000 lbs. of ground beef per day, and these are sold as one pound chubs, the maximum dispersion would be 500,000 consumers; assuming each buys only one pound. From this illustration, one can easily imagine the potential dispersion effect from mixing beef products in soups, other pre-prepared meals which creates dispersion by product and by store or location. In Figure 1 it is illustrated the impact of product dispersion on recall. The traceable product is dispersed first to several stores and then further dispersed to consumers at the store level. In Figure 1, 'cons. n, m' refers to an m^{th} consumer who purchases a traceable product at store or restaurant n. The potential merit of traceability in this case is that cross-referenced samples may be obtained quickly to verify if all components of the traceable product are involved and if so, that all must be recalled, if no other traceable products are involved, then the event may be caused by another factor outside the product (handler contamination, etc.). In this way, traceability allows for improved recovery by the process of elimination.

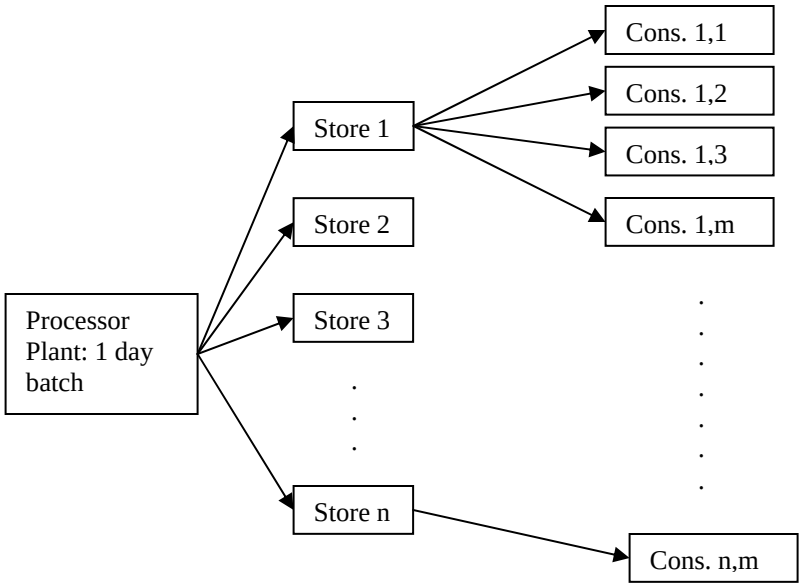

Figure 1. Product Dispersion in Supply Chain

The dispersion factor for a single traceable product may be quite large and affect the size of recall, but the recall size also depends on the number of traceable products in the supply chain at any given time. Therefore, the number of traceable products in the supply chain will depend on the shelf life of the product, its characteristics for storage, and its rate of consumption. Continuing to use our example of ground beef based on a single days' batch being one traceable product, Figure 2 illustrates the timeline which occurs and how it affects traceability. For simplicity we assume only three days' production enter the supply chain. Each day's product is identified as a traceable unit (TU).

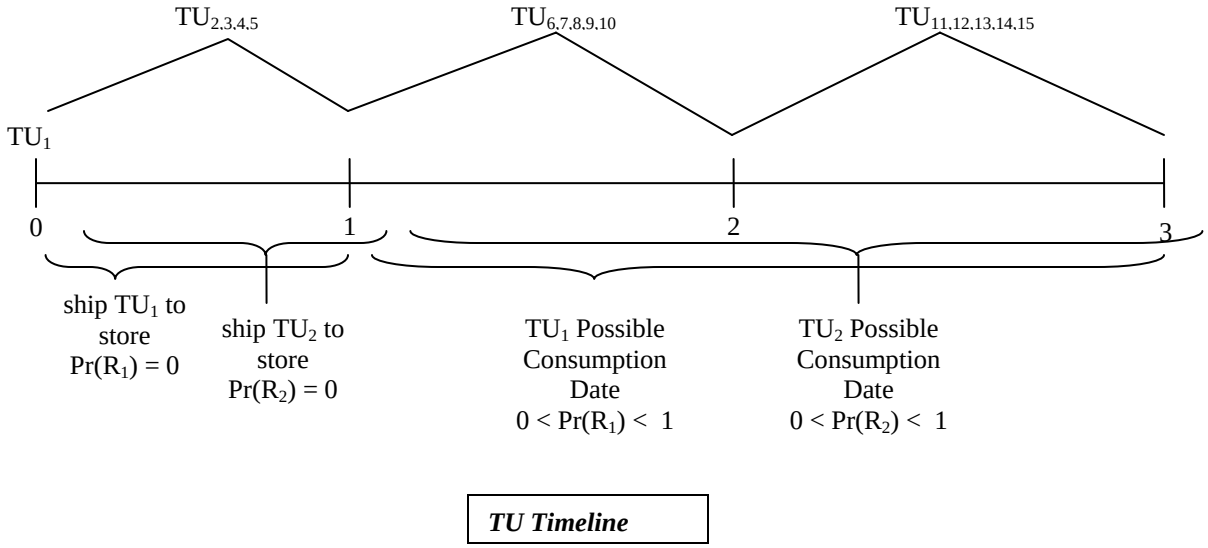

Figure 2. Product Shelf-Life Timeline

Regardless of dispersion, Figure 2 shows that time or duration of product in the supply chain (hereafter referred to as 'shelf-life') has two effects. First, there is a chance that a product recall will be necessary because of any given TU. So, for TU_1 the probability of recall is truncated by zero and, if we assume that the consumer is the detector of a defect (through illness), only becomes positive after the product has reached the store after week 1. During week 2, consumers begin to purchase TU_1 and the probability of a recall occurring then becomes positive as some consumers may purchase for near immediate (at least within day) consumption. We also assume that product is no longer saleable by the store after week 1 and that the only remaining product is already purchased by consumers (e.g., fresh ground beef has a shelf-life of 14 days). Finally, the product is assumed perishable and so all products is consumed by week three or thrown out. Obviously, this timeline varies depending on product perishability, storability and quality (freezing v. fresh), and even the final consumer's conscientiousness in destroying past due product. The issue related to recall is that during the entire product consumption cycle of

TU_1 other TU's are entering the consumption chain. With only a three week horizon at least nine other TU's enter the chain (the last five do not enter until after week three when they begin to arrive at the store). In essence this creates an envelope of probabilities of recalling product when there is an illness as shown in Figure 3. Assuming independence of events, the probabilities are additive.

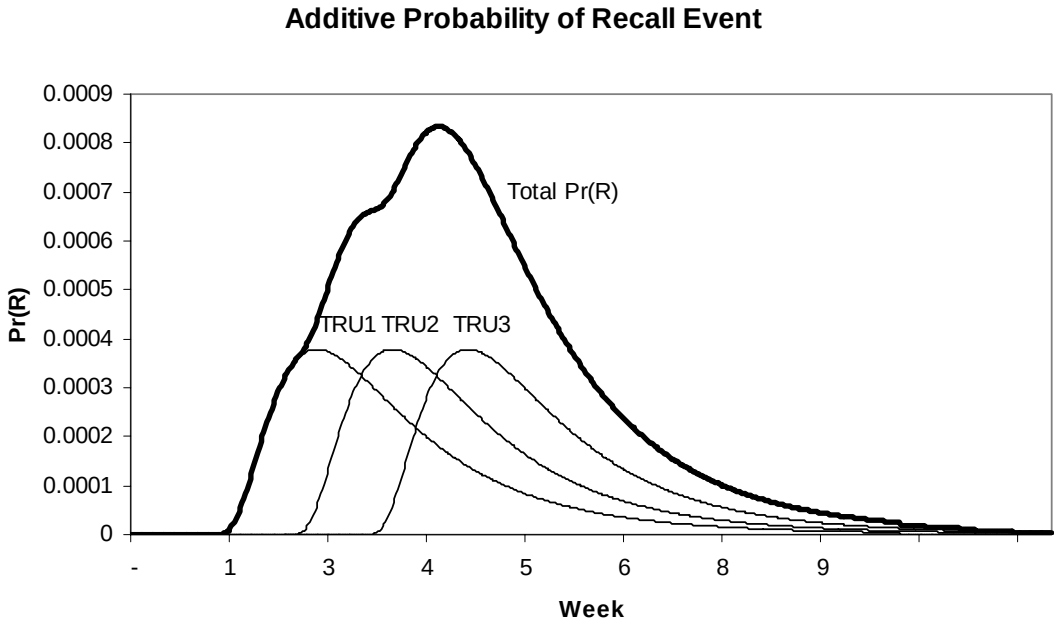

Figure 3. Effect of multiple TU's on recall probability and size of recall.

The total probability is truncated by zero if the product does not leave the plant. The probability reaches a static maximum at a point determined by the product life duration and number of TUs which fit within that product life cycle. If the plant ceased production the probability of a recall would eventually return to zero as the pipeline cleared. This graphical illustration clearly shows the value of traceability – in this situation with multiple TU's in the marketplace at any one time, the firm which could potentially identify the TU responsible would only need to pull the products within that distribution while a lack of traceability would require recall of all products within the product life chain.

Defining the Conceptual Model of Recall: Defining the Costs of Recall

As described earlier, Thomsen and McKenzie and Salin and Hooker have addressed the issue of the stock valuation implications of recalls. Jarrell and Peltzman (1985) also find that the capital market penalizes producers of both recalled drugs and autos far more than direct costs via company's stock price value (indirect cost). Indeed, the higher are the frequency, size and duration of product recalls the greater is the company's indirect cost. Following Fox and Hennessy (1999), a general expression defines indirect cost as an economic loss function $L(.)$ in the probability of occurrence, expected size and duration of a product recall as follows:

$$(2) \qquad L(\Pr(R),S)=H(\Pr(R), S, G(S))$$

where $H(.)$ denotes an increasing monotone and convex function in all of its arguments. These function's characteristics models the fact that economic loss is hypothesized to monotonically increase but at a non decreasing rate on probability, size and expected duration of a product recall. Note that S denotes the actual size of the product recall and $G(.)$ is a function mapping S into the duration space.

Shiptsova, Thomsen and Goodwin use a similar approach to modeling recall for estimating impacts on producer welfare. However, they are not as complete in their description of recall. They simply assume that recall is a function of the probability of recall and the retail value (price * quantity recalled) of the product multiplied by a factor of three which they gained from interviews of industry sources and they utilize historical data of quantities of recalls to estimate this value. Since we are simulating the economic value of traceability it becomes necessary to model the process of recall. Our approach recognizes that recall size will depend on dispersion as well as number of units in the chain. In discussions with industry, it became evident that recall costs were highly dependent on the product type involved. For example, individually

packaged dry goods such as cereal have very low recall costs, similar to the reverse costs of distribution and stocking plus the product cost. However, in cases of ground beef which may be repackaged at stores, blended and repackaged, the recall cost could be large, including product that in fact was not contaminated (a type II error).

Although a firm would clearly like to consider the total direct and indirect costs of recall, for our purposes, the issue of traceability affects the direct costs of recall. Hence, our following models only rely on the direct costs of loss of product, and reverse logistics costs of recalling products. This clearly ignores a very interesting question regarding traceability's impact on indirect losses such as stock valuations. Will the market penalize a company with traceability greater for having a recall or will it penalize it less? It could be hypothesized to be penalized more since in previous articles on traceability it is viewed as a quality improving technology.

A Risk Assessment Simulation Model of Traceability and Recall

Although we have described the conceptual nature of the problem, a numerical simulation approach is used to simulate potential benefits of traceability related to recall. This requires a four step process as described conceptually (1) to parameterize a probability of recall model which provides the technical basis for traceability, (2) to provide a descriptive model of the dissemination of product which determines the size and scope of recalls, (3) to develop a cost function for recalls and (4) to conduct numerical simulations including assumptions of the adoption of traceability with improved precision on traceable products and the implications for various scenarios. The objective is to provide insights into how key parameters such as dispersion of product, shelf-life of product and type of contamination event affect the value of traceability through reduced recall costs.

Probability of Recall: Modeling the Contamination and Production Process

The heart of traceability is its application to a process of production. As such it is necessary to define the production process itself and the factors which may, result in the need for traceability. In practice, these factors can be negative or positive. Negative factors might include bacterial contamination, introduction of foreign materials, or mislabeling. Positive factors could be the ability to identify credence attributes. However, the case simulation focuses on the case of E.coli in ground beef. This is done for two reasons (1) it is the second most common reason for recall (FSIS, USDA) of meat products and (2) we were able to adapt a model developed by Cassin et al. and originally used for risk assessment of E.coli illness from ground beef. The model they term a Process Risk Model (PRM) combines the biological/microbial growth rates and characteristics of E.coli with a stylized representation of a ground beef production process including cattle entering the process with quality control parameters that can be varied. This model is used as the primary driver of our case illustration affecting the probability of recall, as their final parameter is the probability of consumer illness. For a complete description of this very detailed model, see Cassin et al. Table 1 provides a summary of the key terms of Cassin's model to describe the probability of recall and the probability distributions of the microbial contamination and quality control process. Although the table is truncated for brevity, it clearly shows the process of the contamination from major factors including: feces on the carcass, the growth rate of the bacteria, and several control variables (cooking temperature, storage temperature, etc.) and finally, the dose response relationship which provides the final estimate of the probability of illness dependent on all other prior factors. This probability of illness that is also defined as Pr(R) is what we will use to trigger recalls for our simulation.

Table 1. Key Factors of E.Coli Process Risk Management in Ground Beef

Factor	Probability Distribution	Units
Production		
Concentration of E. coli O1557:H7 in contaminated feces	Created by Cassin et al.	$Log_{10}CFU/g$
Prevalence of E. coli O157:H7	Beta (2.7,250)	Percent
Carcass Cross Contamination	Uniform(2,3)	-
[numerous factors of bacterial growth omitted for brevity]		
Probability of H7 in Fresh Ground Beef	*Function of prior probabilities*	*%*
Post-Processing		
Time in Retail Display	Triangular(4,48,96)	Hours
Storage Temperature	Triangular (4, 10, 15)	Celsius
[other omitted growth factors]		
Internal Temperature of Cooked Ground Beef	Custom Distribution	Celsius
Concentration in Cooked Ground Beef (ccgb)	*Function of prior probabilities*	*$Log_{10}CFU/g$*
Consumption		
Ingested Dose of E. Coli	Poisson(10^{ccgb} * mass ingested)	CFU
Mass Ingested	Lognormal (84,48)	Grams
Dose Response		
Probability of Illness from Dose (Pr(*R*))	*Beta binomial model*	Percent

Source: Cassin et al. (1998)
Note: CFU denotes Colony Forming Units of bacteria.

Modeling the Size of Recall

The 'probability of illness from dose' essentially gives the probability of recall. The most critical factor of the recall process then is the description of product flows. This flow has two major components, the number of traceable units in the chain at any given time which may be subject to recall, and the dispersion of those units. Our simple model assumes only two stages after the processor; a retailer and the consumer. If one considers the process model, it is clear that only the product not consumed is recallable. In reality a recall may include distribution and retail. Our assumption is that the costs of recall to any depth of the chain is similar and that the

primary cost of recalling retail versus at distribution is a multiplier effect by number of retail outlets distributed to.

The flow of product is also affected by the shelf-life of product in the case of perishable meats. A recall event is described by a discrete distribution with domain composed by zero (no recall need) and one (need for recall), respectively with probabilities of occurrence (1-Pr(*R*)) and Pr(*R*). In the need for a recall, assuming a constant rate of consumption of all products and no traceability, all product in the supply chain and still available for recall will be recalled, unless there has been a recall in which products have been pulled within the shelf-life period. However, with traceability and the ability to define the day's batch, a recall event still means that any of the subsequent days' batches still in the chain could be the culprit. So, although the total stock on the day in the chain might be 100, there could be 10 of batch 1 left, 20 of batch 2 left, 30 of batch 3 left and so on… so taking the day's batch when the event occurred would not be accurate, but rather taking the day's batch that was accountable within that recall day. This has been done by creating a second random variable to select the day's production which is to be recalled given the prior that a recall has occurred. A discrete uniform distribution based on the number of days of shelf-life is adapted for this purpose.

In our model, the term shelf-life is critical. It essentially is the measure of the precision of a recall in the sense that the shelf-life of the product directly affects the percentage of the total product in the chain that needs to be recalled at the time of a recall. Therefore, the longer the shelf life we use in our model, the more precise is traceability relative to an untraceable supply. Note that we define traceability precision as one minus the percentage of the total product in the chain that needs to be recalled at the time of a recall. In this respect the model is flexible in that

rather than recalling food, it could be analogous to a reverse recall of products used as inputs such as cattle or feed.

Costs of Recall

As indicated earlier, the costs of recall are broken into two components: the direct costs of loss of product, retrieval, destruction, etc. and the indirect costs. The indirect costs would include potential reduction in demand and sales of other products through consumer aversion or share value decreases as investors respond. However, Salin and Hooker found little evidence for supporting stock market return reductions, and similarly Thomsen et al. found only minor reductions (1-3%) for Class I (the most serious) recalls. Given this data it might suggest that indirect costs associated with a reduction in volume of recall might be negligible. However, it is worth considering the other direct costs of recall. Again, estimates from industry are difficult to obtain because they are commingled with other ongoing costs. USDA, Economic Research Service estimates the food marketing cost on a consumer price basis. For example, in 2000 USDA reported that the consumer expenditure on farm foods was $661.1 billion. Of this $537.8 billion was marketing costs, including approximately $75.6 billion for advertising and transportation. Advertising is used as a proxy for recall notification and news requirements and transportation is used as a proxy for transport due to recall. Using these analogies it is estimated that approximately 4 percent of the consumers' expense is toward advertising (or recall notification in this case). Transportation and fuel costs would be directly related to the quantity recalled and total 10 percent of the consumer's expenditure on food. The cost function is described by:

(3) $$C(R) = P^*Q_R + .04\ P^*Q_R + 0.10\ P^*Q_R$$

where P is the retail value of ground beef, and Q_R is the quantity of product recalled.

Simulations of Traceability Applied to Recall

The above models were combined and simulated using Palisade's @Risk software add-on in a Microsoft Excel spreadsheet. The risk analysis was conducted predicated on the assumption of a 10 year planning horizon. Therefore, approximately 2,500 days (average working days) of production were simulated in each run. Each of these 10 year horizons were then iterated until they converged to generate a distribution of expected quantities of recall and costs of recall based on the prior assumptions. This was done because the risk nature of recalls is one of extreme events – there is the possibility of very limited recalls, and also the probability of very large recalls happening very infrequently. The model is simulated under two broad categories (1) assuming that there is no traceability which remains the baseline, and (2) assuming there are means of tracing products after they leave the firm. The broad traceability assumption is then varied on key parameters. Thus, the simulations show that depending on the nature of the contamination event and the precision of traceability (shelf-life) the value of traceability is altered. Estimates of the maximum value that a firm might invest in traceability are based on its benefit over having no traceability. Table 2 shows the key parameter estimates used to conduct the simulations for a single beef plant producing ground beef.

Table 2. Key Parameter Assumptions for Baseline Recall Simulation

Variable	Mean Level	Units	Source
Beef Plant Capacity	4,400	Head/day	Cattle Buyer's Weekly, Top 30 Beef Packers 2001
Product Share Ground Beef	30	Percent	AMS, USDA, Carlot Summaries
Average Carcass Weight	750	Lbs	AMS, USDA, Weekly Cattle Summary
Ground Beef Production	990,000	Lbs/day	Calculated
Retail Price of Ground Beef	1.54	$/lb	BLS, Retail Meat Prices
Recall Notification Costs	4	Percent of product value of recall	Derived from ERS, USDA, Cost of Food Marketing
Recall Logistic Costs	10	Percent of product value of recall	Derived from ERS, USDA, Cost of Food Marketing
Probability of E.Coli Contamination Event on Any Given Day (Pr(R))	varies		Cassin et al. Model
Time Horizon	10/2,500	Years/days	
Shelf-life	14	Days	

A simplifying assumption is made that two recalls do not occur within a 14 day period which could potentially reduce the total quantity of recall over the ten years. After repeated simulations and given the extremely low probability of two recalls occurring close together, the error of this assumption was well below five percent of the total value.

Figure 4 shows a sample schematic of the simulation model.

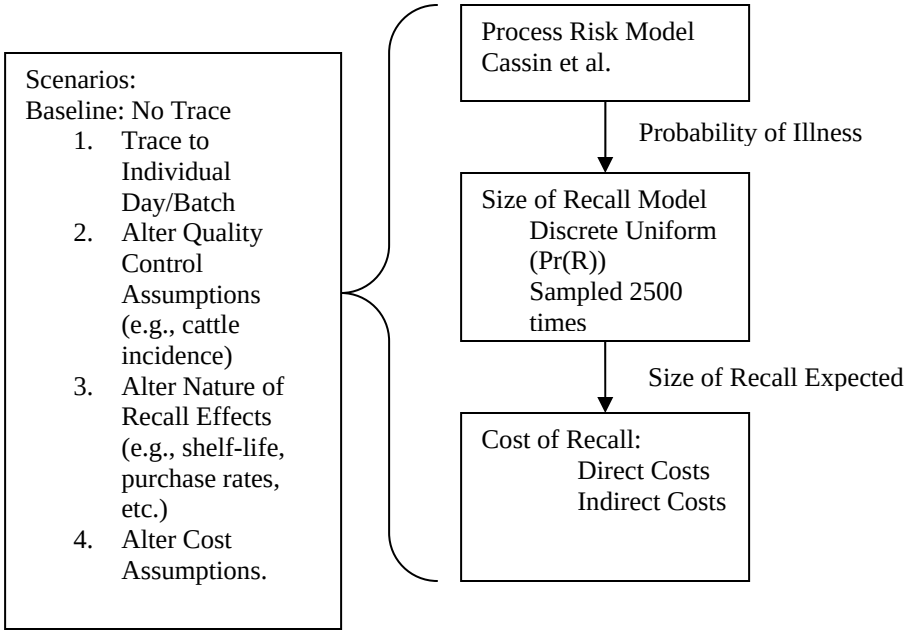

Figure 4. Overview of Simulation Model and Scenarios

The first step is to iterate the Process Risk Model developed by Cassin et al. to obtain the probability of illness to be included in the recall model because this is the event that triggers a recall. Cassin's model was iterated until the convergence criterion of no more than a 1.5% change in the mean value was obtained. This same procedure was repeated 100 times so to obtain a series of results for Pr(*R*). Rather than using the mean of the series of result of Pr(*R*), we used the Best Fit feature of @Risk to fit a distribution to the probability of illness or Pr(*R*). The probability of illness was best represented by the exponential distribution, which is a distribution of extreme values. In fact, this shows a critical point in simulating investment in traceability, the returns are actually heavily skewed towards zero. For an illustration of this point, the recall and cost models were simulated in one case allowing the probability of illness to be modeled as an exponential distribution and in the other case to be included as the mean of the series of result of Pr(*R*). Table 3 shows the results of this simulation, and Figures 5 and 6 show the distributions of the value of traceability.

Table 3. Comparison of Simulation with Distribution of Illness Versus Point Estimate

Variable	Minimum Value	Mean Value	Maximum Value
	Results with Exponential Distribution of Illness		
Quantity Recalled Without Traceability	0	81,022,500	572,715,000
Quantity Recalled With Traceability	0	6,236,486	46,812,860
Cost of Recall No Traceability	0	$284,855,700	$2,013,528,000
Cost of Recall With Traceability	0	$21,925,990	$164,582,800
Value of Traceability	0	$262,929,700	$1,848,946,000
	Results With Point Estimate of Illness		
Quantity Recalled Without Traceability	12,870,000	78,965,500	167,310,000
Quantity Recalled With Traceability	848,571	6,091,417	14,496,430
Cost of Recall No Traceability	$45,247,830	$277,623,700	$588,221,800
Cost of Recall With Traceability	$2,983,374	$21,415,960	$50,965,960
Value of Traceability	$40,772,770	$256,207,800	$546,454,600

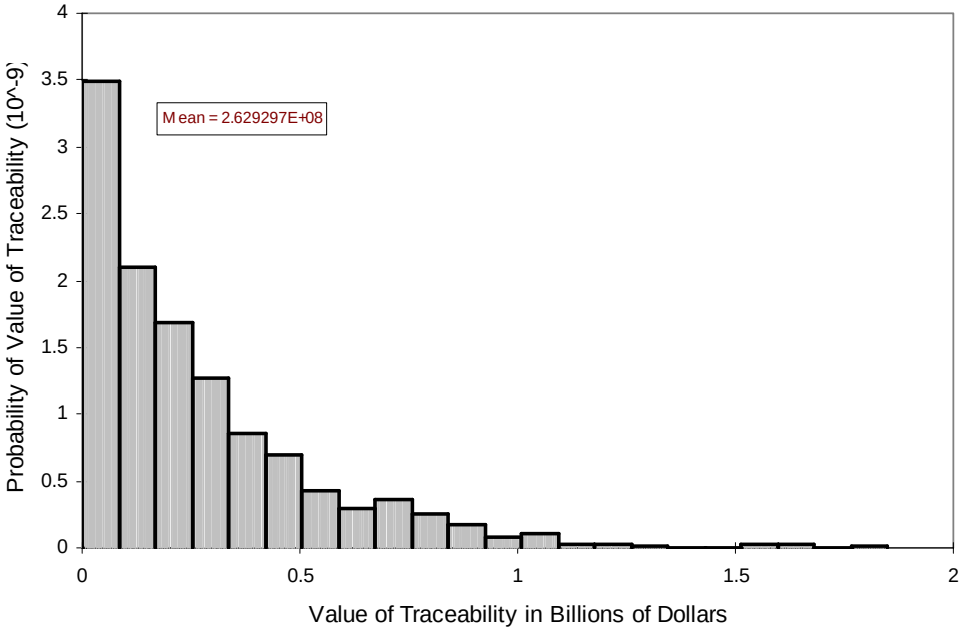

Figure 5. PDF of the Value of Traceability with Exponential Distribution of Illness

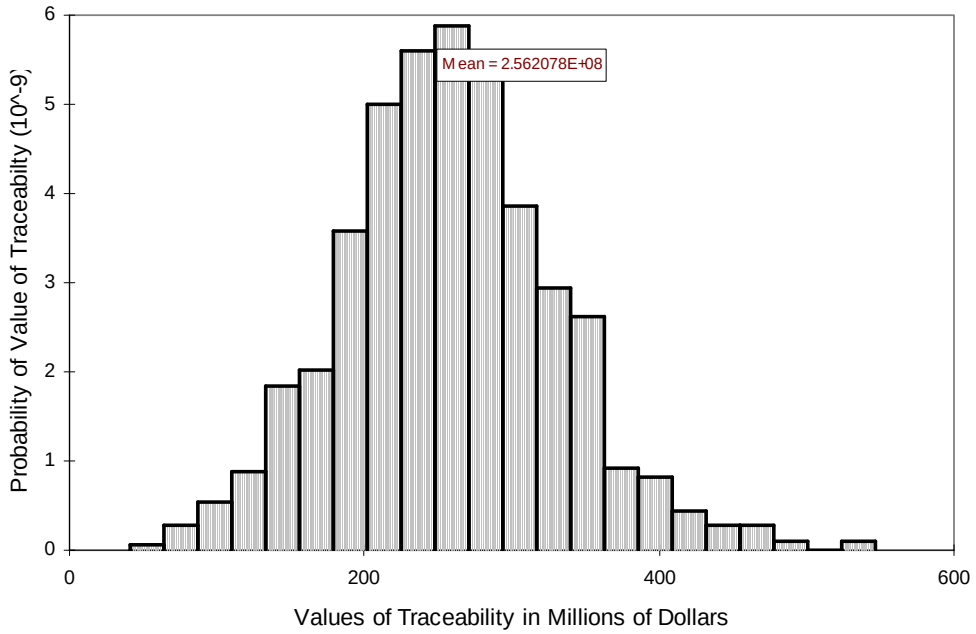

Figure 6. PDF of the Value of Traceability with Point Estimate of Probability of Illness

Clearly, the use of the exponential distribution results in the incorporation of the extreme values which may be generated for recall as well as the potential for no recall given the low probability of illness and would result in a dramatic undervaluation of the value of traceability for recall purposes in the case of E.coli. The importance of this is that when modeling the value of traceability for recall, careful consideration must be given to the behavior of the underlying production process and the risks associated with a recall event.

The results of the baseline simulation are shown in the upper block of Table 3. The results are interpreted as the value that traceability is expected to return in saved recall costs over a 10 year period of beef plant operations as defined in Table 2 in the case of E.coli contamination. The total value of traceability in this case is $262,929,700. For comparative purposes, the total value of ground beef produced over this period given the above baseline is $3,811,500,000 so

that a break-even expected investment in traceability could be about 7 % of the total value of sales of ground beef, or approximately eleven cents per pound of ground beef produced.

A second simulation is run to evaluate the implications of extending shelf-life on recall. Recall that in our current analysis, the shelf-life is determined by the number of days over which the product must be consumed. However, as a generalization, shelf-life is a proxy for the precision of traceability or the percentage of the total product in the chain at the time of a recall that is likely to remain in the supply chain. Because the model randomly selects for a particular day to recall meat when traceability exists, the model exhibits greater precision with traceability (in other words a smaller proportion of product must be recalled.). This concept is highly generalizeable to, for example, the reverse case of increasing precision of finding an input (such as steer, etc) which may have affected the product. As modeled in this article, the precision is a linearly additive event, but only because we have assumed that the product decay (consumption and replenishment) is a constant rate per day. We could alter this to include assumptions about purchasing patterns. For example, if a store rotates its stock, it likely moves older product to the front of the case, so that at the start of a new product's shelf life, the consumption rate is slow, but then increases as the older products are removed from the case and then finally decreases again. However, because there is a random selection criterion for the recall, the linear selection is a very close approximation to all other assumptions. The results for the simulations considering respectively 14 and 28 day shelf-life are reported in Table 4.

Table 4. Comparison of Simulation Alternate Shelf-lives (precision of traceability)

Variable	Minimum Value	Mean Value	Maximum Value
	Results With 14 day shelf-life		
Quantity Recalled Without Traceability	0	81,022,500	572,715,000
Quantity Recalled With Traceability	0	6,236,486	46,812,860
Cost of Recall No Traceability	0	$284,855,700	$2,013,528,000
Cost of Recall With Traceability	0	$21,925,990	$164,582,800
Value of Traceability	0	$262,929,700	$1,848,946,000
	Results With 28 Day Shelf Life		
Quantity Recalled Without Traceability	0	168,878,100	1,296,370,000
Quantity Recalled With Traceability	0	6,319,642	48,898,930
Cost of Recall No Traceability	0	$593,734,900	$4,557,725,000
Cost of Recall With Traceability	0	$22,218,340	$171,916,900
Value of Traceability	0	$571,516,500	$4,385,808,000

As expected, the mean of the value of traceability increases for the 28 day shelf-life by about double the 14 day shelf-life case. Note that the means values for cost of recall and quantity of recall with traceability are about equal in both cases, while the mean quantity of recall for the non-traceable system approximately doubles. This is because the steady state level of product in the supply chain is approximately double with the longer shelf-life, but with traceability, the firm is still able to select and recall only a selected day's product remaining. This result illustrates that for production systems with greater shelf-life or more products in the supply chain, traceability carries a greater value. More importantly, this illustrates the increasing cost of greater precision desired from traceability.

A final set of scenarios, demonstrates that the value of traceability also is closely related to the type of problem traceability is being applied to, in this case bacterial E.coli. Improved quality control measures at each stage of the production process (farm, processing, and retail) were simulated using Cassin's model as the basis. For the farm, a simulation of a reduction in the E.coli contamination level in the feces was performed. For the processor, improved decontamination processes were simulated, and at retail a simulation originally conducted by Cassin et al. of improved temperature quality control of the retailer was used. Table 5 provides a summary of these results, including only information on the value of traceability.

Table 5. Comparison of Simulation Alternate Quality Control Mechanisms for E.Coli.

Quality Control Trait	Minimum Value	Mean Value	Maximum Value
	Value of Traceability		
Baseline (14 Day Shelf-life)	$0	$262,929,700	$1,848,946,000
Reduced Fecal Contamination (75% improvement)	$0	$ 143,453,000	$1,151,334,000
Improved Processor Decontamination (75% improvement)	$0	$200,667,000	$439,799,000
Improved Retail Temp Control (20% lower maximum and average)	$0	$250,227,600	$1,664,225,000

Although intuitively appealing, these should not be interpreted as relative results because the effective change in each quality control measure is not comparable. Also, this simulation seems to illustrates that there may be a substitution effect between quality control systems and the value of traceability. However, as mentioned by our case study interviews, both firms utilized mock recalls as a way to identify problems in their quality control system. Therefore, the possibility must also be considered that traceability may improve information as to the source of the quality control failure and, therefore, play a complimentary role in achieving some of the quality control benefits identified in Table 5. In the case of reduced fecal contamination of the carcass, the

value of traceability is quite low, as an economic decision, a firm investing in improved carcass quality would find it beneficial only to invest in traceability up to about $0.06/lb compared to $0.11/lb without the improved quality control. Therefore, the process model developed for recall would allow for the assessment of adopting or investing in improved quality control at various stages or in traceability which could improve detection and removal of product from consumption. It becomes clearer that in the case of traceability as a method for product recall, that its productive value depends not only on the recall value, but also on the potential to identify quality control problems and therefore reduce the chances of a recall.

Conclusions

Several previous studies have addressed the value of traceability on a descriptive basis. However, traceability is a diffuse technology including adaptation of physical processes, data collection, recording and information management. For example date-time codes on products are a form of traceability already adapted by many processors for recall purposes which can be easily implemented and at low costs. Alternatively, some European firms have adopted systems which allow for tracking individual meat cuts. Given this diffuse technology, addressing a question such as what is the value of traceability for recall, depends on factors including the nature of the production process, the nature of the distribution of products, and the characteristics of the attributes which may cause recall (bacterial vs. foreign matter, etc.). From interviews of U.S. food manufacturing firms, it is also clear that they view traceability as a means to support their quality control systems, but that the quality control system itself is the basis for reduced recall. However, at this point firms were only beginning to implement improved information systems so it was difficult to determine what the net effects might be. Never-the-less, this article created a process simulation model for recall which allows for the introduction of traceability by

using the case of E.coli in ground beef manufacturing. The model allows for a consideration of the trade-offs between quality control and traceable recovery systems as well as assessing the potential for complementarities if the traceability system identifies the source of contamination. This enables firms and policy makers to simulate alternative costs/values for traceability from a recall perspective. As improved cost parameters and uses of information systems become more standardized, it may provide a useful basis for analyzing the value of both quality control systems and the value of information.

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