Economics of Traceability for Mitigation of Food Recall Costs

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ABSTRACT

We develop conceptual and process simulation models to determine the probability of a recall and predict its size. We compare the costs of recalls with and without traceability for a ten year planning horizon by simulating the expected recalls caused by *Escherichia coli* O157:H7 contamination for ground beef produced at one plant. As the costs of implementing a traceability system are not available, we calculate only the direct costs savings by the use of traceability. Results suggest that for a ten year period the value of traceability is about $263 million, and that the cost saving increase with the shelf life of the product. Additionally, improved quality control measures at each stage of production appear to be substitutes for traceability, but under some circumstances may serve as complements. As improved cost parameters and uses of information systems become more standardized, our models can be adapted so to simulate alternative costs/values for traceability and, therefore, support firms and policy makers´ decisions.

JEL classification: C15, D81, L15, L66, M11.

Keywords: Traceability, Food Recalls, Quality Controls, Risk Assessment and Modelling.

1. Introduction

High profile incidences of food recalls caused by adulteration or pathogen outbreaks have contributed to public and private initiatives aimed to improve quality controls and traceability in food supply chains. Ollinger et al. (2004) estimated that between 1996 and 2000, U.S. meat and poultry processors spent $380 million a year and $570 million in long term investments to comply with U.S. Department of Agriculture's 1996 Pathogen Reduction/Hazard Analysis and Critical Control Point (PR/HACCP) regulation. They also estimated that processors spent an additional $360 million in long term food safety investments not included in PR/HACCP regulation. This is consistent with more recent research showing that the food industry has responded to food safety crises by installing quality assurance systems and traceability beyond requirements of public regulations (Trienekens and Zuurbier, 2008).

The U.S. private sector has voluntarily adopted a diversified and significant capacity to trace food without government regulation, motivated by the desire to improve product recalls (Golan et al., 2004). Charlier and Valceschini (2008) show that the private sector still has economic incentives to voluntarily implement more stringent traceability in food chains in which specific sanitary risks exist. Based on case study illustrations of European meat and poultry firms, Buhr (2003) identifies the crucial role played by traceability in improving firms' direct ability to limit the depth and size of product recalls when testing procedures or intervention strategies fail. According to Kramer et al. (2005), most major meat processors in the U.S. have been involved in a recall at some point in time, and spend considerable funds to prevent and respond quickly to future occurrences. However, none of these analyses provides a method for firms to evaluate the potential value of investing in traceability.

To be effective for recalls, a traceability system must be able to backward trace to identify the source of a food defect, and forward trace to find all other products subsequently

affected by the defect (Jansen-Vullers et al., 2003). Therefore, a traceability system may allow for faster and more precise withdraws of defective product units from the supply chain and also result in earlier identification of the need for a recall, possibly mitigating costs for firms and health risks for consumers.

Traceability can also reduce anonymity and facilitate the allocation of liability in a supply chain. Pouliot and Sumner (2008) show how the probability by which suppliers will be held responsible for food safety failures increases, firms will seek to improve the safety and the general quality of their product. Resende-Filho and Buhr (2008) model how reduced anonymity by traceability can be used by slaughterhouses as an element of incentive mechanism and, doing numerical simulations, found that even low rates of successful tracking can induce improved practices by upstream suppliers in the cattle sector.

Firms may choose to invest in food safety and quality controls to reduce the frequency of food recalls rather than in traceability systems. Malcolm et al. (2004) consider the cost-effectiveness of pathogen reduction (PR) 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 et al. (1998) provide estimates for levels of pathogen reduction for specific technologies and their fixed and variable costs. Of interest for this article, they also study the effects of employing combinations of intervention technologies, recognizing that they were not necessarily additive. Unfortunately, none of these previous studies have explicitly considered the dynamics of a product recall and how improved ability to make recalls utilizing traceability might affect their costs, which constitutes the main objective of this article.

The present article focuses on the economic modelling of traceability as a tool to reduce size and depth of recalls caused by food borne pathogens, using the case of *Escherichia coli* O157:H7 in ground beef and hamburgers. To refine the potential economic

worth of traceability, this article develops a model which encompasses risk and uncertainty related to testing and quality assurance effectiveness, a sub-model of product flows which allows for the simulation of recalls which would occur if a contaminated product breaks through the quality assurance, and a simple cost sub-model of this recall. We use a process risk simulation (PRS) approach by which a recall is modelled as a simulation model that makes it possible 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 recall costs with traceability in place allowing for a more precise recall and without traceability provides estimates of how much could be invested in a traceability system to improve precision of recall.

2. Conceptual Model of Traceability for Recall

2.1. Case Observations

To define the recall process, we interviewed two U.S. firms which requested anonymity regarding their recall processes. One was a meat processing company and the other a cereal and bakery products manufacturing company. To further describe the recall process, we also rely on case studies of European meat processors (Buhr, 2003) and on research guidelines which must be followed in case of a recall, provided by the FSIS (2008).

The typical recall scenario includes plant managers, quality control specialists, and shipping/distribution and information technology sections. Both the meat processing company and the cereal and bakery products company used date/time product code with plant identification to define batch sizes of products that, for its purposes of recall standards, was viewed as sufficient for narrowing the recall window so that the total product loss exposure was minimized. Neither case had implemented a traceability system at the time of the interviews and neither firm knew the costs of recalls, they did, however, view the primary

costs as being the loss of product sales with the next highest costs being labour and transportation. Both considered some of the costs coincident with their ongoing quality control systems and any information systems they have put in place.

The third example of an actual recall situation came from site visits to European firms (Buhr, 2003). 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.

Related to recall issues, their veterinary services identified a salmonella problem in routine on-farm testing. They immediately sampled feed batches at the farm and through traceability databases 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 and 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 event, and estimated in this single instance it saved them over $100,000 in recalls and recovery costs.

Although these three case studies are too limited to produce parameters useful to develop models, they clearly suggest that the key to properly recall products is the effectiveness of the quality control systems in place, and that traceability or information

systems' value stems mainly from the fact traceability is a tool employed to improve the efficiency of the recall process through records management and verification. However, as part of quality control systems, the three 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 developed the following conceptual model and numerical simulations of recall utilizing quality control systems and information to increase the precision of recall.

2.2. Defining the Conceptual Model of Recall

The model application considers the cost of recalling meat contaminated with *Escherichia coli* and is primarily based on our conversation with the meat processor regarding their processes. The meat supply chain can be quite complex in this case. *E. coli* originates with the beef animal as the source. Cattle enter the slaughter chain and are fabricated into whole muscle cuts of further processed products. For whole muscle cuts a single cut is by definition associated with a single animal. However, in the case of processed meats, the product may contain meat from several animals. This cross contamination can rapidly increase the scale of recalls. The scope of modelling a recall in this multi-segment, multi-product supply chain is quite complex. However, we develop the key insights in this paper by simplifying the supply chain to include only the processing stage and the final consumer by assuming case ready products. Case ready products are fully packaged at a central plant and then distributed to retailers and ready for sale to consumers without any further fabrication or packaging.

For the *E. coli* case example, beef products often leave the plant before *E. coli* is detected or test results are available. As a result, we assume the need for a recall is only detected after some product has left the processor's control, implying that the discovery of a recallable situation is made at the consumer level. We recognize this as a simplifying assumption. For instance, items which are mislabelled or for which test results could be

completed before products are released may be recalled at the distribution or retail stage before the consumer is affected. In those circumstances the cost of recall would be much less.

At some break point in time (e.g., end of shift or end of day's operation) the plant is either completely sterilized or the processing line completely discharged, making recall events independent one to each other. In reality, it is likely that poorly operated or 'bad actor' plants may have multiple and correlated recalls through which we do not model. However, it is worth noting that traceability may provide added incentives for these bad actors to become a 'good actor' and our assumption of independence results in a conservative estimate of the potential value of traceability for recalls.

Factors such as the type of event (e.g., pathogen vs. foreign matter vs. mislabelling), the reliability of safety and quality controls, and the effectiveness of PR/HACCP processes affect the probability of occurrence, the size, depth and cost of recall. Other important but less obvious factors are the product dispersion and the number of traceable products in the supply chain at the time of a recall.

The product dispersion is affected by the unit size reduction in sales units. The traceable product is dispersed first to several stores and then further dispersed to consumers at the store level. 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, attained when each consumer 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.

The number of traceable products in the supply chain at any point in time depends on its rate of production, the shelf life of the product and its rate of consumption. Figure 1 illustrates the simple example by which each single day's batch of ground beef is a traceable

unit (hereafter TU) of product for a three week horizon and all product is consumed by week three (e.g., fresh ground beef has a shelf-life of about 10 to 21 days (source: American Meat Institute)) or disposed of by the consumer.

For TU_1 the probability of recall is initially truncated by zero and, if the consumer is the only detector of a defect (e.g., through illness), becomes positive only after the product has reached the store after week 1. During week 2, consumers begin to purchase TU_1 that will make the probability of a recall positive as some consumers may purchase for near immediate, at least within day, consumption. During the entire product consumption cycle of TU_1 another fourteen TU's (assuming an average of a 14 day shelf-life) will enter the consumption chain.

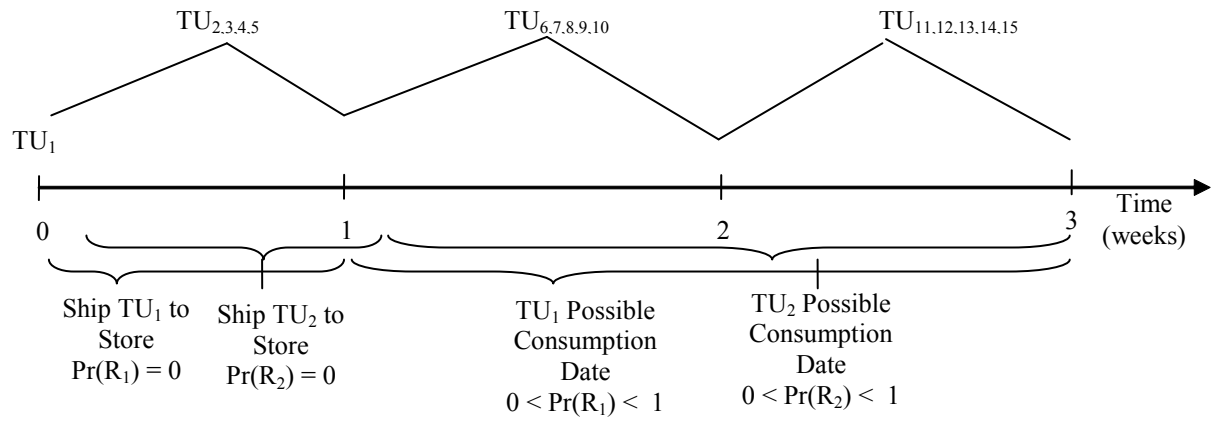

Figure 1. Traceable units' shelf-life timeline.

If there is no traceability, the probability of a recall equals the probability of the TU among those still in the consumption chain that has the highest probability of causing a consumer to get sick. The recall will also need to include all TU´s in the chain at the time of a recall event. Thus, the value of traceability is created by its potential to identify the TU responsible for a recall which would make it possible to pull only the products within that distribution. The probability of a recall with or without traceability will eventually return to zero as the TU's are cleared from the supply chain.

Shelf-life may vary depending on product perishability, storability (e.g., freezing vs. fresh), and even on the consumer's conscientiousness in disposing of past due product. However, the longer the shelf-life the more of all TUs are likely to be in the chain at any point in time which will increase the value of the precision of traceability.

3. The Risk Assessment Simulation Model of Traceability and Recall

We apply our conceptual model of recall to a numerical simulation approach to illustrate and quantify the potential benefits of traceability related to recall. To accomplish this we first parameterize a model of probability of recall which provides the technical basis for traceability. Second, we provide a descriptive model of the dissemination of product which determines the size of recalls. Third, we develop the cost function for recalls. Fourth, we conduct numerical simulations including assumptions about the adoption of traceability with improved precision on traceable products and the implications for various scenarios. Our objective is to provide insights into how key parameters such as dispersion of product, shelf-life of product and type of contamination affect the value of traceability through the reduction of the cost of recalls.

3.1. Modelling the Probability of Recall

Our case simulation relies on the process of production of ground beef that can be contaminated by *E. coli* O157:H7. The motives for our choice are twofold: the contamination of ground beef by *E. coli* is the second most common reason for recall of meat products in the U.S. (USDA/FSIS, 2007), and it was possible for us to adapt a model originally used for risk assessment of *E. coli* O157:H7 illness from ground beef (Cassin et al., 1998). The model that Cassin et al. (1998) term a Process Risk Model (PRM) combines the biological/microbial growth rates and characteristics of *E. coli* O157:H7 with a stylized representation of a ground beef production process including cattle entering the process with quality control parameters that can be varied.

The probabilities of exposure to *E. coli* O157:H7, P_E, and illness from dose D, $P_I(D)$, are generated by two mathematical sub-models. The first one models the behaviour of *E. coli* O157:H7 through cattle production, meat processing, grinding, storage (post-processing), and consumption to estimate exposure that is a measure of hygienic quality of the system. The second sub-model uses the exposure estimate, P_E, to determine the probability of illness from a dose, $P_I(D)$, which is a physiological response of the consumer. Table 1 provides a simplified flow of the structure of the model and identifies the probability distributions used for each key stochastic process to the modelling of the aggregate result of the probability of recall (P_R).

Table 1. Key Factors of *E. coli* O157:H7 Process Risk Management in Ground Beef.

Factor	Probability Distribution	Units
Production		
Concentration of *E. coli* O1557:H7 in Faeces	Custom Probability Distribution Function: Beta (2.7, 250)	log_{10}CFU/g
Prevalence of *E. coli* O157:H7		percent
Processing and Grinding		
Carcass Cross Contamination	Uniform(2, 3)	
[numerous factors of bacterial growth omitted for brevity]		----
Probability of *E. coli* O1557:H7 in Fresh Ground Beef (P_{FGB})	Function of Prior Probabilities	percent
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 Probability Distribution Function	Celsius
Concentration in Cooked Ground Beef (C_{CKGB})	Function of Prior Probabilities Poisson(10^{Cckgb}*Mass of Hamburger Ingested)	Log_{10}CFU/g
Consumption		
Ingested Dose of *E. coli* O1557:H7 (D)	Lognormal(μ=84, σ=48)	CFU
Mass of Hamburger Ingested (m_I)	----	grams
Probability of Exposure to *E. coli* O1557:H7 (P_E)	As Given by Equation (1)	percent
Dose Response		
Probability of Illness from Exposure to One Organism ($P_I(1)$)	Beta (0,267, exp(Normal(5.435, 247))	percent
Probability of Illness from Dose, $P_I(D)$	Beta Binomial Model as Given by Equation (2)	percent

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

Following the process of Cassin et al. (Table 1; a), cattle are the primary source of contamination by *E. coli* O157:H7 and are slaughtered in an abattoir that supplies 5 kg vacuum packages of carcass trimmings to a retail outlet that grounds them on-site and sets them out for sale in packages containing from 300 g to 1000 g of fresh ground beef.

Organism growth and cross contamination occur during processing, grinding, packaging and storage (Table 1, b). The retail outlet employs pathogen reduction procedures characterized by hand trimming of visible defects followed by spray washing with plain water, and also influence the microbial growth by altering the time length and the temperature during the storage of the ground beef patties (Table 1, c).

The key variable determined at the end of post processing is the concentration of *E. coli* O157:H7 in cooked ground beef during post-processing phase (Table 1; c), $C_{CKGB.}$ This is determined by the equation: $C_{CKGB} = C_{FGB} + G_{RTL} - I_{CKG}$, where C_{FGB} is the concentration of *E. coli* O157:H7 in fresh ground beef, G_{RTL} is the growth of *E. coli* O157:H7 during retail storage and I_{CKG} is thermal inactivation from cooking ground beef and are obtained in the first sub-model. Note that in the Process Risk Model developed by Cassin et al. (1998), C_{FGB}, G_{RTL}, I_{CKG}, P_I(D) and D are all random variables defined as functions of other parameters and random variables in the model, which makes the probability of a recall per day of production, P_R, also a random variable.

The probability of exposure to *E. coli* O157:H7, P_E, that is the probability that $D > 0$, is given by:

$$P_E = P_{FGB}(1 - \exp(-10^{m_I C_{CKGB}})) \quad (1)$$

where P_{FGB} is the probability of contamination of *E. coli* O157:H7 in fresh ground beef (FGB) as a result of what happens in the processing and grinding phases (see Table 1; a and b), and m_I is the mass of hamburger ingested by an adult (Table 1; d).

The probability of illness from dose, $P_I(D)$, is also a random variable. While dose levels increase the risk of illness, it is not necessarily deterministic that ingestion will cause illness. This is considered a second sub-model because it is independent of all processes in the supply chain but is simply determined by the immunological status of the individual which can be affected by age, pre-existing conditions, nutrition, and other physiological factors, given by:

$$P_I(D) = 1 - (1 - P_I(1))^D \quad (2)$$

where $P_I(1)$ denotes the probability of illness from exposure to one *E. coli* O157:H7 organism.

The testing of raw material and in line sampling might be useful in determining whether a process meets quality standards. But *E. coli* O157:H7 detection is not a good candidate for verifying quality control because *E. coli* is not uniformly distributed, its number is usually too low for quantitative recovery, and rapid and inexpensive methods for its recovery are not readily available (Food Directorate, Health Protection Branch, Health Canada, 2000). Our assumption is that *E. coli* O157:H7 contamination in ground beef is discovered only after at least one unit of the product has reached a consumer and a consumer has become ill. Therefore, we use the probability of at least one adult individual getting sick by exposure to a dose of *E. coli* O157:H7 given by equation (3) as the probability of a recall per day of production, P_R.

$$P_R = P_E P_I(D) \quad (3)$$

where P_E denotes the probability of exposure to *E. coli* O157:H7, and $P_I(D)$ is the probability of illness from dose, D (Table 1, d and e). The fact a recall occurs after the product has reached consumers increases the costs of recall dramatically because of the 'last mile problem' by which the recall will need to rely on public announcements to make people aware and dispose of the recalled product (Fritz and Schiefer, 2009).

Finally, we model the need for a recall as a Bernoulli probability function with outcomes 0 and 1, in which 1 implies the need for recall with probability P_R as given in equation (3), and 0 implies no need for recall with probability $(1 - P_R)$, and with $0 < P_R < 1$. The Bernoulli probability function enters the simulation model in a Microsoft Excel® spreadsheet by means of the function RiskDiscrete({1, 0},{P_R, $(1- P_R)$}) of the Palisade's @Risk® software add-on.

3.2.*Modelling the Size of Recall*

Without the ability to trace products, the incidence of an illness as described above would result in recalling all products in the supply chain on that date. The only products not recalled would be those that had been consumed. However, if there is traceability, then only those products identified as being the cause of the illness would need to be recalled. This quantity would then depend on the amount of that product remaining in the chain that is not yet consumed and its stage in the chain. This section describes the model structure to address this aspect of recall.

In our model, the day's production which is to be recalled, given the prior that there is a need for recall, is drawn from a discrete uniform distribution based on the number of days of shelf-life. This is implemented using Palisade's @Risk® function, RiskDuniform({1, 2,…, (shelf-life – 1)}), where (shelf-life - 1) means that we assume that it is impossible for a product in its very last day of shelf-life to be responsible for a recall. In so doing, we are also imposing the restriction that only one day's batch can be the cause of a recall within the shelf-life window. This does remove the possibility of serial correlation in recall, which would mean that given a recall in a day's batch, it may imply a condition that is creating the need for recall (unsanitary practices, for example) could raise the probability of following days' recall. However, give the extremely low probability of recall occurrence this is a negligible effect.

Shelf-life in our model is essentially 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 is, the more precise is traceability relative to an untraceable supply, where traceability precision is one minus the percentage of the total product in the chain that needs to be recalled at the time of a recall.

3.3. Modelling the Costs of Recall

There are two possible types of costs associated with recalls; direct and indirect costs. Direct costs are associated only with costs such as notifications of recalls, logistics to retrieve product and the loss of product sales that are recalled. Indirect costs are due to factors such as a loss of consumer confidence which could result in an overall decline in demand for a firm products or even a reduction in a firm's stock price.

Results of previous studies (Jarrell and Peltzman (1985), Wang et al. (2002), Shiptsova et al. (2002), Thomsen and McKenzie (2001), Salin and Hooker (2001)) suggest that indirect costs of food recalls that would include stock value decreases as investors respond to adverse events like recall, and the potential reduction in demand and sales of other products through consumer aversion are negligible and quite difficult to quantify in reliable terms. As a consequence we focus only on the direct cost of recall which includes product loss, retrieval, destruction and reverse logistics. We recognize though that our conceptual model clearly ignores an interesting point 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?

Estimates of the direct costs of recall from industry are difficult to obtain because they are commingled with other ongoing costs. However, USDA, Economic Research Service estimates the food marketing cost on a consumer price basis and reported that the consumer

expenditure on farm foods was $661.1 billion in 2000. Of this $537.8 billion was marketing costs, including approximately $75.6 billion for advertising and transportation. Considering advertising as a proxy for recall notification, and transportation as a proxy for transportation needs in case of a recall, we estimated that approximately four percent of the food marketing cost is toward advertising or recall notification in our case. Transportation and fuel costs would be directly related to the quantity recalled and total ten percent of the food marketing costs. Based on all this, the total direct cost of recall, $C(Q_R)$, is defined as:

$$C(Q_R) = P_r Q_R + 0.04 P_r Q_R + 0.10 P_r Q_R = 1.14 P_r Q_R \quad (4)$$

where P_r denotes the retail value of ground beef, and Q_R is the quantity of product to be recalled. Although these numbers clearly differ from any particular case, in simulating the base case of recall without traceability to recall with traceability we can still develop insights on the two alternatives.

The overall simulation model structure is provided in Figure 2. For simulations, any of the variables in the boxes can be adjusted to evaluate the impact on the overall cost of recall which is the value of implementing traceability.

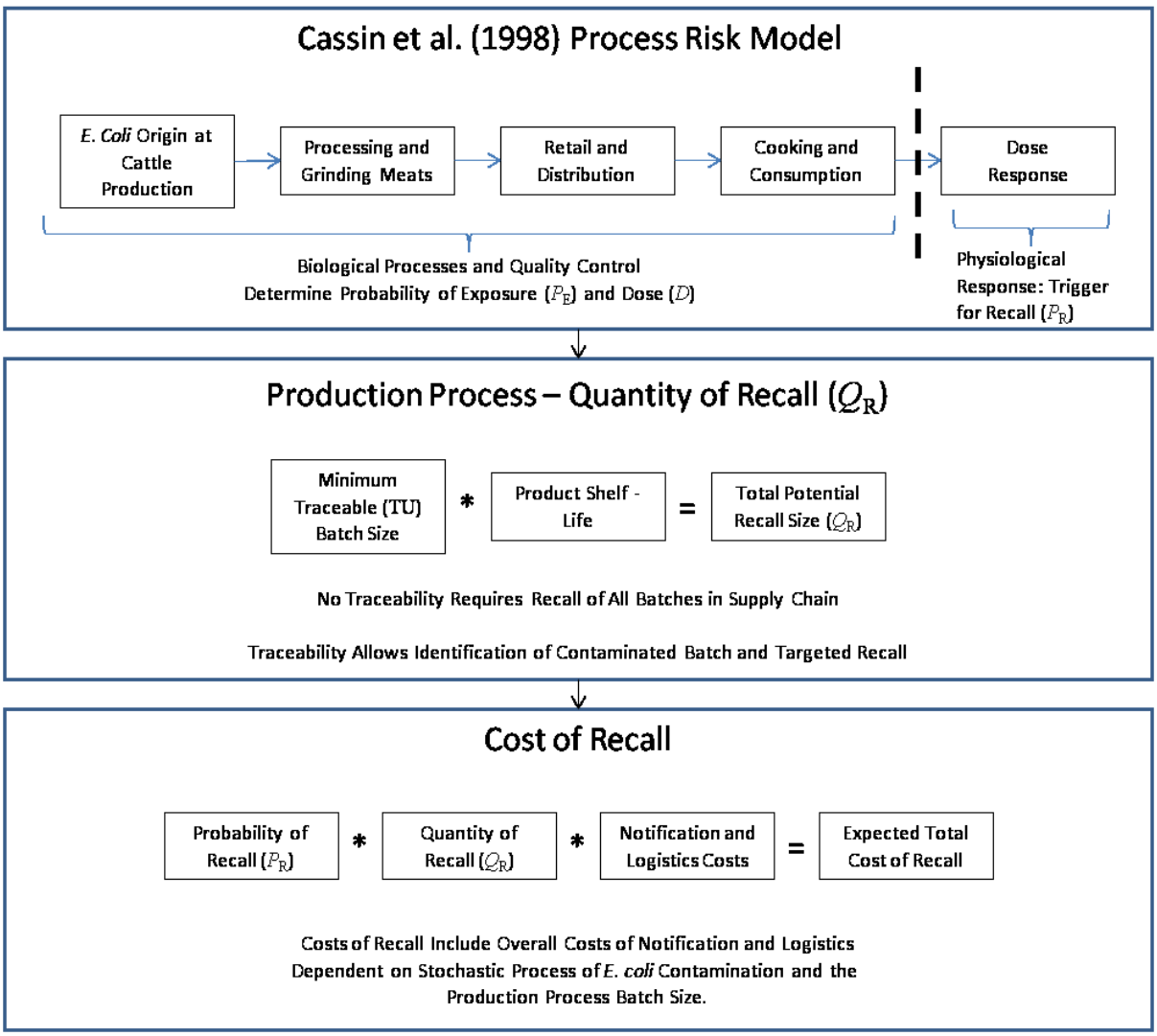

Figure 2. Overview of three components of simulation model.

4. Simulations of Traceability Applied to Recall

We combined the models for the probability, size and cost of recall and simulated them using Palisade's @Risk® software add-on in the Microsoft Excel® spreadsheet. The risk analysis assumed a 10 year planning horizon, which gives approximately 2,500 working days of production in each simulation run. Each of these 10 year horizons were then iterated until they converged to generate stable distributions of quantities and costs of recall based on prior assumptions. We proceed this way because the risk nature of recalls is one of extreme events, which means that the frequencies in which very limited and very large recalls

(extreme events) happen are very low. Table 2 shows our assumptions and values for the key parameters we 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 ($P_{\mathbf{r}}$)	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 (P_{R})	varies	$0 < P_R < 1$	Cassin et al. (1998)
Time Horizon	10/2,500	years/days	Selected Horizon
Shelf-life	14	days	American Meat Institute (AMI)

Following our conceptual framework as shown in Figure 1 and based on Table 2 values, each day's product is a 990,000 pound batch of ground beef and constitutes a potential traceable unit (TU). We adopt a constant rate of consumption of 1/shelf-life so that, for example, at the end of the first day of the second week after the production of the first TU, 990,000(1 - 1/shelf-life) of product will remain in the chain. From the start of

production it takes thirteen days for the total quantity of ground beef in the chain to reach its steady state level of 6,435,000 lbs. This steady state level would remain assuming a constant production and consumption level until a recall occurs. Because we assume a one week lag between production and the start of consumption, there is no chance of a recall event during the first seven days of our 2,500 day time horizon.

The model is simulated for two main scenarios (i) the base scenario, assuming that there is no traceability, and (ii) the traceability scenario that assumes there are means of tracing products after they leave the firm. Under the first scenario, when there is a need for a recall the firm recalls all products in the chain so that in the day after the recall there will be only 990,000 lbs of ground beef in the chain. Under the second scenario, the firm recalls only the quantity of the TU that is identified as responsible for the recall. The broad traceability assumption is also varied on key parameters to illustrate 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. Figure 2 shows a sample schematic of the simulation model.

The Process Risk Model (PRM) developed by Cassin et al. (1998) is iterated first to obtain the probability of illness (triggering a recall) for inclusion in the recall model. The PRM model was iterated until the convergence criterion of less than a 1.5% change in the probability of a recall per day of production, P_R, was achieved. Remember that the probability of recall is the probability of at least one adult individual getting sick by exposure to a dose of *E. coli*, calculated according to equation (3). This same procedure was repeated 100 times to obtain a series of results of P_R.

We used the Best Fit® feature of @Risk® to fit a distribution to P_R that was best represented by the exponential distribution with mean 0,0027473 and domain between

-0,0000012695 and infinity. This exponential distribution enters the simulation model by means of the function RiskExpon(0,0027473; RiskShift(-0,0000012695)) of the Palisade's @Risk® software add-on.

The exponential distribution is a distribution of extreme values so that returns are heavily skewed towards zero which is necessary feature in simulating returns to traceability based on extreme events of recall. For illustration, the recall and cost models were simulated with P_R following the fitted exponential distribution, and with P_R as the mean of the series of result of P_R. Figures 3 and 4, and Table 3 show distributions and results of the value of traceability for these two cases. Note that Figures 3 and 4 show the probability of illness which is modelled as a Bernoulli function of the probability of recall, P_R. These demonstrate that while the mean value of traceability is approximately the same for the two cases, Figure 3 is a more realistic pathway, in that if no recall occurs, the value of traceability is zero but there is a low probability that a very high cost event could occur. As this demonstrates, when modelling the value of traceability for recall, careful consideration must be given to the behaviour of the underlying production process and the risks associated with a recall.

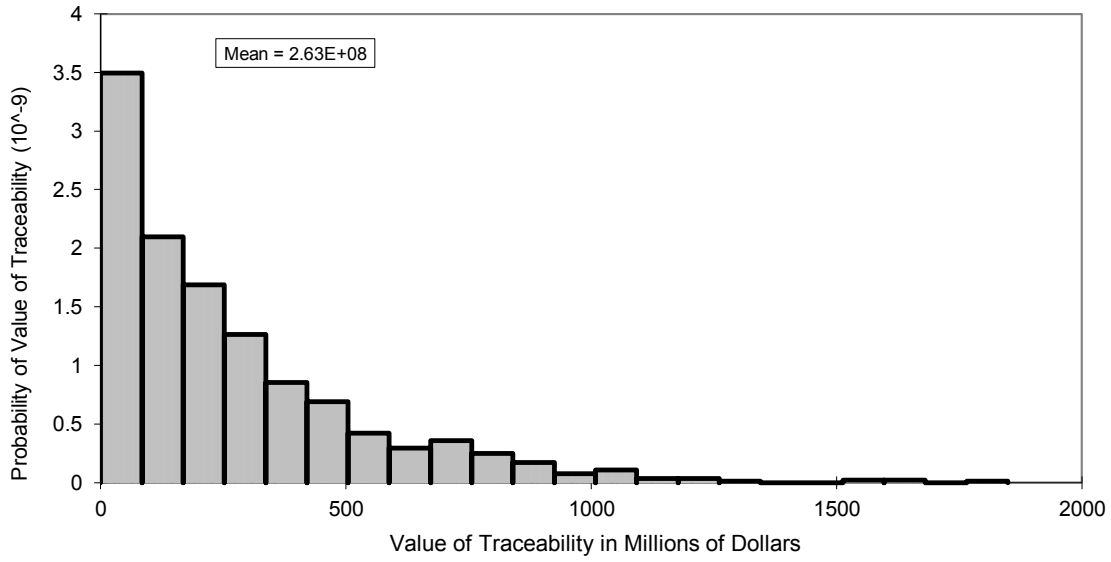

Figure 3. PDF of the value of traceability with exponential distribution of illness.

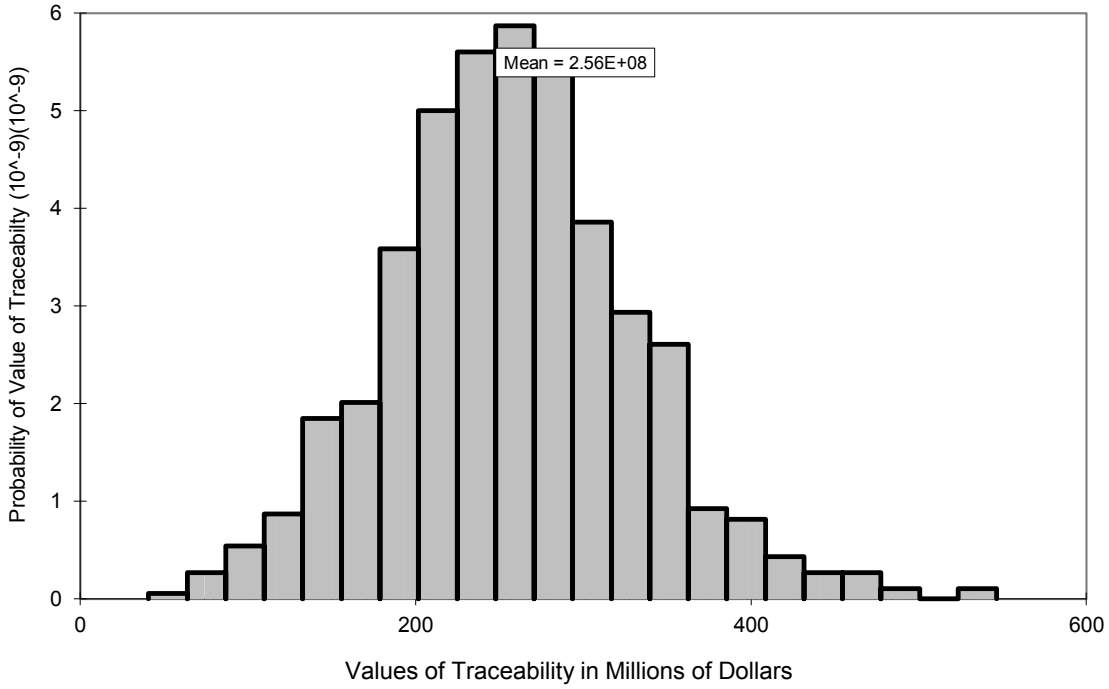

Figure 4. PDF of the value of traceability with point estimate of probability of illness.

Table 3. Comparison of simulation when the probability of recall/illness follows an exponential distribution versus when the probability of recall/illness is point estimated as the mean of the series of result of P_R.

Variable	Minimum Value	Mean Value	Maximum Value
	Results with P_R following an Exponential Distribution		
Quantity Recalled without Traceability (lbs)	0	81,022,500	572,715,000
Quantity Recalled with Traceability (lbs)	0	6,236,486	46,812,860
Cost of Recall without 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	$262,929,710	$1,848,946,000
	Results with P_R as the mean of the series of result of P_R		
Quantity Recalled without Traceability (lbs)	12,870,000	78,965,500	167,310,000
Quantity Recalled with Traceability (lbs)	848,571	6,091,417	14,496,430
Cost of Recall without Traceability (lbs)	$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

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 ten year period of beef plant operations as defined in Table 2 for the case of *E. coli* O157:H7 contamination. The total expected value of traceability in this case is about $263 million. For comparative purposes, the total value of ground beef produced over this period given the above baseline is about $3.8 billion, so that a break-even expected investment in

traceability could be about seven percent of the total value of sales of ground beef or, approximately, eleven cents per pound of ground beef produced. Given our assumptions, this value represents a risk adjusted value of traceability in the case of *E. coli* contamination. But the greater importance is the model development that enables firms to incorporate parameters for their own circumstances and evaluate the potential value of traceability for mitigation of recall costs.

To further demonstrate the usefulness of the model we ran a second simulation to evaluate the implications of extending shelf-life on recall only considering P_R follows an exponential distribution. Shelf-life gives the number of days over which the product must be consumed and that only one recall may occur during a shelf-life window. Therefore, shelf-life determines 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. As modelled here, 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 (lbs)	0	81,022,500	572,715,000
Quantity Recalled with Traceability (lbs)	0	6,236,486	46,812,860
Cost of Recall without 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	$262,929,710	$1,848,946,000
	Results with 28 Day Shelf-life		
Quantity Recalled without Traceability (lbs)	0	168,878,100	1,296,370,000
Quantity Recalled with Traceability (lbs)	0	6,319,642	48,898,930
Cost of Recall without 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	$571,516,560	$4,385,808,000

As expected, the mean value of traceability increases for the 28 day shelf-life by about double the 14 day shelf-life case. But the mean 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 because the steady state level of product in the supply chain (13,365,000 lbs) approximately doubles for the 28 day shelf-life. With traceability, the firm is still able to detect and recall only a selected day's product or TU

remaining which illustrates that for production systems with greater shelf-life or more products in the supply chain, traceability carries a greater value.

A final set of scenarios demonstrates that the value of traceability is also closely related to the type of problem traceability is being applied to, in this case bacterial *E. coli* O157:H7. Improved quality control measures at each stage of the production process (e.g., farm, processing, and retail) were simulated using PRM model of Cassin et al. (1998) as the basis. For the farm, a simulation of a reduction in the *E. coli* contamination level in the faeces was performed. For the processor, improved decontamination processes were simulated, and at retail a simulation originally conducted by Cassin et al. (1998) 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	\$262,929,710	\$1,848,946,000
Reduced Faecal 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 Temperature Control (20% lower maximum and average)	\$0	\$250,227,600	\$1,664,225,000

In the case of reduced faecal 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, our 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. Although intuitively appealing, the results in Table 5 should not be interpreted as relative because the effective change in each quality control measure is not necessarily equivalent. It does however highlight the risk implications of the nature of recalls. For example the maximum value relative to the mean of reduced faecal contamination is quite large whereas the maximum value of improved decontamination is small relative to the mean. This can illustrate where the maximum risk exposures are and may differ from a ranking of mean exposure. Hence, failure to account for the correct stochastic nature of the contaminating event and its quality control interventions can result in incorrect investments.

The results for the set of scenarios simulations in Table 5 seem to indicate that quality control systems and traceability are substitutes because investing in quality control reduces the value of traceability. However, we cannot necessarily make this a conclusion because we do not have a good comparison of the cost of the control system. Offsetting the costs, we also cannot include the value of improved information for identifying the source of the quality control failure that might help to improve quality controls leading to a complementary relationship. As evidence of this potential complimentarily of quality control and traceability, studies by Alfaro and Rábade (2009) in the Spanish vegetable industry and Bulut and Lawrence (2008) in the U.S. beef industry each show this result. Again, however, the importance of this research is that the simulation model allows prospective investors to evaluate the potential trade-offs in intervention and traceability by obtaining data on the costs and efficacies of the two technologies.

5. Conclusions

Several previous studies have addressed the value of traceability on a descriptive basis. Traceability is a diffuse technology including adaptation of physical processes, data

collection, and recording and information management. 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 vs. mislabelling).

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. To provide insights into the value of traceability, we create a process simulation model for recall with traceability by using parameters for *E. coli* O157:H7 contamination in ground beef and a simulated 4,400 head per day processing plant that produces 990,000 lbs/day of ground beef. We also consider that this plant incurs four percent and ten percent of product costs of recall due to recall notification and logistic costs in an event of a recall.

Our baseline scenario results indicate that a break-even expected investment in traceability can be about seven percent of the total value of sales of ground beef, or approximately $0.11 per pound of ground beef produced. We also demonstrate how the precision of recall (simulated by differences in shelf-life) enhances the value of traceability.

Our process simulation model for recall allows for the assessment of adopting improved quality control at various stages to investigate the potential substitution effect between quality control systems and traceability value. For instance, we simulated a set of scenarios to investigate how the value of traceability is related to quality control measures at each stage of the production process (e.g., farm, processing, and retail). At first sight, our results suggested that improvements in quality controls may be a substitute for traceability

and vice versa. However, we did not include costs of improved quality control, nor were we able to include learning effects that traceability may provide to improve quality control systems. These phenomena could very well, as suggested by the literature, result in a complementary relationship. Never-the-less, by obtaining appropriate cost and learning effects data our model could be used to investigate this effect by those considering investment in new traceability technologies.

Our process simulation model enables firms and policy makers to simulate alternative costs/values for traceability from a recall perspective. Therefore, 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. However, there are limitations and significant opportunities for future research. First, we could not find a reasonable estimate of the cost of implementing traceability because it is not a contained technology but rather a systems process. Therefore, we could not evaluate the cost-benefit of traceability, only providing a 'break-even' valuation. Secondly, because we assume *E. coli* is identified only upon consumption, unfortunately an all too real method, we did not simulate the value of detection at other stages in the chain such as at the retail stage. In this case we would need an intermediate model that better evaluates the dispersion effect of products. That is as product moves closer to the consumer it tends to become more dispersed in the supply chain and more difficult to recover. Therefore, early detection would actually affect the logistic and notification costs of the recall.

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