Pathogen Reduction Options In Slaughterhouses and Methods for Evaluating Their Economic Effectiveness[1]

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Abstract

Foodborne pathogens cause millions of human illnesses annually, many resulting in death or chronic illnesses. Universal methods to evaluate microbial risks and their associated costs have yet to be developed. Typically, risk analysis and economic analysis have been carried out independently. In this paper, we link a risk analysis model based on typical slaughterhouse practices with a decision model to evaluate the cost effectiveness of various combinations of pathogen reducing technologies.

We describe technological change with regard to pathogen reduction in meat and compare the use, effectiveness, and the degree to which different control technologies have penetrated the market. We follow with the description of a cost-effectiveness framework for evaluating technology adoption and provide an illustration for generic *E. coli*. In particular, we show that some options appear in every combination of technologies that are not inferior in both the cost dimension and effectiveness, and should be preferred. The paper concludes with a discussion of the institutional (and other) barriers affecting the adoption and development of more effective technologies for pathogen reduction.

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I. Introduction

Medical costs and productivity losses for seven foodborne pathogens range from $6.6 billion to $37.1 billion annually in the United States (Buzby and Roberts, 1997). Foodborne pathogens cause an estimated 6.5 million to 33 million human illnesses annually with up to 9,000 deaths and an unknown number of chronic illnesses (CAST, 1994). Universal methods to evaluate microbial risks and their associated costs have yet to be developed despite a critical need. We suggest that cost-effectiveness analysis is a useful tool that can be used by plants in conjunction with risk analysis to gain insight into their need for pathogen reducing technologies.

We deal with risk analysis and slaughterhouse practices in this paper. In a previous farm-to-table risk assessment for *E. coli* O157:H7, Cassin *et al.* (1998) identified slaughterhouses as representing a potential source for contamination of hamburger. Unfortunately, a lack of data resulted in the treatment of the slaughterhouse as a “black box” and consequently they found minimal control opportunities there. Alternatively, Roberts, *et al*. (1999) developed a quantitative risk assessment model that attempted to look more closely at the specific control options available in slaughterhouses. An additional difference in their approach was a focus on generic *E. coli*.

Jensen, *et al*. (1998) evaluate improved food safety in the meat industry by comparing the costs and effectiveness of interventions using the mean pathogen reduction of technologies and combinations of technologies. The present work uses the probabilistic risk assessment (PRA) model of Roberts, *et al*. (1999) to evaluate the effectiveness of various technologies, thus accounting for non-uniformity of their effectiveness and develops a preliminary cost effectiveness framework. This framework can be used by the private sector in conjunction with the results obtained from the risk analysis to evaluate the cost-effectiveness trade-offs between technologies that individual plants might consider as they choose which pathogen reduction intervention strategy to adopt.

The paper is divided into five sections. Section one discusses technological change with regard to pathogen reduction in meat. Section two compares the use, effectiveness, and the degree to which different types of control technologies have penetrated the market. Section three discusses the adoption of these technologies and looks at various adoption scenarios. Section four develops a cost-effectiveness framework for evaluating technology adoption and provides an illustration for generic *E. coli*. The paper concludes with a discussion that identifies some of the institutional (and other) barriers affecting the adoption and development of more effective technologies for pathogen reduction.

II. Technologies Used in Slaughterhouses to Reduce Pathogens in Meat

The major steps in the cattle slaughtering process are shown in figure 1. At any one step, meat can become contaminated by exposure to pathogens in the air, equipment, cross contamination by workers, or contact with other contaminated carcasses. Alternatively, pathogens can be removed through the use of a variety of decontamination technologies. Over the years, numerous technologies have been developed to reduce the number of bacteria on the animal carcass in the slaughterhouse. These include organic acid washes, tri-sodium phosphate washes, steam vacuum systems, hot water washes, steam pasteurization, and chlorine sprays.

Irradiation is an additional technology, not currently in use for beef that may prove to be very effective in eradicating pathogens.[2] These technologies differ in cost and effectiveness.

The Food Safety Inspection Service (FSIS) has historically used prescriptive approaches to food safety mandating the use of certain equipment and facilities. Recently they have begun to use performance-based standards for pathogen control. Thus, plants can select the strategy most effective for them, given their market conditions. Our study compares the effectiveness associated with five different technologies: dehiding, steam vacuuming, hot water final carcass wash, steam pasteurization, and irradiation. Table A gives estimates of cost from vendors, and effectiveness as determined by estimates derived from the literature under specific conditions,[3] and current status of adoption for each technology. Certain technologies, such as irradiation and steam pasteurization, are disproportionately expensive for small plants.

III. Adoption and Cost-effectiveness of Technologies

Whether or not a plant invests in existing food safety technologies or puts research efforts into developing new technologies depends on the expected return from the investment. For instance, recent sales of hamburger plants (*i.e.*, Hudson Foods) after the plants were found to have produced meat contaminated with *E. coli* O157:H7 indicates the high costs associated with a loss of reputation resulting from selling poor quality beef. (Jack in the Box paid a settlement of $15.6 million in 1995 for one child's illness in the 1993 outbreak [Seattle Times, 1997].) This threat of a loss in reputation suggests that some plants have an incentive to adopt technologies that will reduce the likelihood of being identified as a source of poor quality beef (Klein and Leffler, 1981).

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[2] Irradiation was approved by FDA in 1997 and in April 26 1999 FSIS published its proposed rule on the irradiation of meat and meat products.

Regulations, such as HACCP, can also result in firms investing in new technologies or implementing new methodologies so as to meet new pathogen-reducing standards. The lack of plants adopting certain technologies despite their effectiveness in pathogen reduction may be in part because they are not the most "appropriate" choice of technology based on their size, but also because there are not the proper market incentives in place such that companies are willing to adopt new technologies or invest in research for development of new technologies. Efforts need to be placed on developing institutional mechanisms such that Pareto-optimal solutions can be met with regards to food safety. Outcomes may not always be socially desirable. For instance, the benefits of adopting a certain technology may result in many small plants being "forced" out of business due to high information and transaction costs, economies of scale, variability in supply and demand, short versus long term effects, and outcomes that may be "efficient" but socially undesirable.

Not all plants have identical incentives for adopting pathogen-reducing technologies. First, owners of large firms with multiple plants have relatively strong incentives to invest in pathogen reduction technologies because an outbreak associated with one plant would reduce sales for the whole firm. Second, plants selling uncooked products have a stronger incentive to adopt pathogen-reducing technologies than plants selling cooked products (since the cooking kills pathogens). Third, plants selling to intermediaries that co-mingle beef from several sources have less of a chance of being identified as a source of pathogen contaminated meat than do plants selling to intermediaries with one supplier and, thus, have a weaker incentive to adopt technologies that reduce pathogens. Fourth, plants with higher growth in product demand may be more likely to adopt pathogen-reducing technologies because their long term profits are relatively higher than others (Libecap, 1992).

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[3] Effectiveness is defined as the range of reduction of generic *E. coli* from the carcass surface.

Plant capability to adopt various technologies results in different adoption costs for similar technologies. A plant with a stable workforce may realize greater benefits from worker training because it has a lower likelihood of losing training value due to worker departures than does a plant with high worker turnover. Additionally, plants with higher cattle slaughter throughputs have lower pathogen-reducing equipment costs per head of cattle than do plants with lower throughputs. Plants with sufficiently high hamburger volumes may choose to irradiate their meat while plants with lower volumes may either not irradiate or use a contract irradiator.

Another factor affecting technological adoption is economies of scale in the use of the technology. Economies of scale arise because of (1) the high initial implementation cost of meat and animal HACCP systems may be a hurdle for small plants with limited capital, and (2) large plants already are operating under some form of quality management system comparable to HACCP while many small plants have to implement HACCP from scratch (Ngange and Mazzaco, 1998). Ngange and Mazzaco (1998) suggest that improving HACCP methods will cost small plants 29%-62% more than large plants.

Economic theory suggests that plants will use the least-cost combination of technologies to achieve pathogen reduction that meets their market needs. To assess the relative value of these technologies, the net reduction obtained from applying combinations of technology options in a single large steer/heifer plant is computed. The plant is assumed to have no improved technology installed. Three technology adoption strategies are proposed: improved dehiding, steam pasteurization, and irradiation. Seven strategies (either singly or in combination) are possible. A second case provides an illustration of the effect of scale economies for a single technology across the industry; different adoption levels of irradiation are examined for large, medium, and small plants.[4]

IV. Cost-Effectiveness of Pathogen Reduction Options

As noted by McDowell, *et al.* (1995:120) "food safety managers are faced with the problem of assembling a "portfolio" of mitigation techniques to obtain some desired level of safety (or maximizing safety for a given cost)." To evaluate the overall effectiveness of reducing pathogens in the output of the plant, we use an earlier probabilistic risk assessment (PRA) model (Roberts, Malcolm, and Narrod, 1999). Please see Appendix A for a more detailed description of the model.

Briefly, PRA quantitatively addresses the uncertainty and variability surrounding risk increasing and decreasing events**.** In our model, each step in the slaughterhouse either increases or decreases the pathogen load on a carcass by an amount drawn from a probability distribution representing the range of contamination (in the case of contamination events) or the range of effectiveness (in the case of decontamination technologies). By cycling the model through a large number of iterations, a probability distribution is obtained for the contamination level of quarter pound hamburgers. The model is run for the baseline case, (i.e., no improved technologies are present) producing the cumulative distribution function (cdf), F_0. Including one or more pathogen reduction technology and running the modified PRA model results in a second

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[4] For this case, the effectiveness of different levels of irradiation adoption is evaluated. Three situations are considered that take into account that plants facing lower costs are likely to adopt technology before plants with higher costs. In situation L, 0% to 100% of large plants adopt irradiation, with no medium or small plants included. In situation M, 0% to 100% of medium plants adopt irradiation, with 100% of large plants adopting, and no small plant. In situation S, 0% to 100% of small plants adopt, with 100% of large and medium plants adopting.

cdf, F_1, typically shifted to the left. This shift reflects the degree to which pathogens are reduced in the final product, in this case raw hamburgers weighing ¼ pound (See Figure 2).

From a risk assessment standpoint, what is of interest is not the expected value of hamburger contamination but rather the frequency with which hamburgers posing some level of risk occur. Focus is on the right-hand tail of the distribution, rather than the mean value. To evaluate the effectiveness of technology adoption strategies, a risk tolerance threshold is selected. The change of expected pathogen frequency above the threshold compared to the baseline model represents the effectiveness of the adoption strategy. This is expressed as:

$$DP(\textit{hamburger contamination above threshold}) = (F_1(\textit{Threshold}) - F_0(\textit{Threshold}))$$

The difference $F_1 - F_0$ represents the change in the probability that a hamburger is above the risk threshold.

Figure 3 shows how four hypothetical strategies might be compared. Strategy D can be excluded since strategy B dominates D in the sense that B is both more effective and less costly. Choices of adoption strategies can be limited to non-dominated Strategies A, B, and C. For the three technologies described in the previous section, there are seven possible combinations (S, D, I, DS, DI, SI, DSI).

Figure 4 shows the cost per pound of each option in large steer/heifer plants on the X-axis. On the Y-axis is the difference of percentage of hamburgers above threshold compared to the no improved technology case. The risk threshold selected is 10,000 generic *E. coli* per hamburger (Threshold 4). There are four non-dominated combinations of options; these are joined by a dotted line. Every non-dominated choice contains improved dehiding. Notice the synergy in combining steam pasteurization with improved dehiding procedures - the reduction in contamination is much more than the sum of the two processes. This analysis supports the “multiple hurdle” approach commonly used by the food industry for pathogen control.

Results for the case of industry-wide irradiation adoption are shown in Figure 5. The marginal change in effectiveness per unit cost is much greater for situation L (large plants) than situation M (medium-sized plants), and likewise greater for situation M than situation S (small plants). This difference between plant sizes is less pronounced when the risk threshold is higher at level 5 (100,000 generic *E. coli* per hamburger).

V. Discussion

We have illustrated a way of linking technology evaluation with quantitative risk assessment models. The benefits of doing so are that it enables plants to see more clearly the trade-offs between technologies and pathogen reduction given their costs. As can be seen from the portfolio of adoption strategies, technologies differ in relative cost and effectiveness.[5] Some of these choices may be superior to others in terms of pathogen reduction, but more costly to certain plants based on their size of operations. For the case of irradiation, the analysis shows that the higher the risk threshold, the less the advantage of expensive, highly effective technologies. The method reveals complementarity between technologies that is unlikely to be discovered by other methods

Some factors may prevent the widespread adoption of these technologies even if they are shown to be effective. Plants may not adopt some technologies, despite their effectiveness in

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[5] It should be recognized that we only evaluated a few technologies, whose efficacy may be improved over time through adaptive research by individual plants. (For example, increasing the time of exposure and temperature can increase steam pasteurization effectiveness.) Also, new scientific improvements in faster, cheaper tests for more pathogens increase the ability to ascribe liability to plants producing contaminated food. For example, the use of pulsed field gel electrophoresis (PFGE) as a DNA "fingerprinting" method to match strains of pathogens found in patients with that found in food may increase plants’ concerns over liability in the future and affect the rate of adoption of pathogen reducing technologies.

pathogen reduction, because there are not the proper market incentives for adoption or investment in research for development of new technologies. Possibilities include:

- The consequences of scale economies associated with each technology.
- Assignment of liability to certain pathogens.
- Uncertainty associated with effectiveness of technology.
- Uncertainty associated with consumer acceptance of irradiated foods

The failure to adopt new technologies may also arise from the inability of the market to properly signal the importance of food safety. Unwillingness to invest in new technology to improve food safety by the private sector is due to incomplete markets, which may be exacerbated by the failure of the market to properly signal consumer demand to producers (Hirschorn, *et al.*, 1999). The existence of these strong market failures may also result in insufficient incentives for the private sector to adopt the technology once it is developed, and until these incentives are in place companies or plants may not be willing to invest in food safety research (Fuglie, *et al.*, 1999). Until then, private sector research will tend to be biased toward those commodities, technologies, or research areas that have patentable technologies, large markets, or expanding demand. It can also be assumed that the technologies plants adopt will be biased in this direction.

Purvis and Outlaw's (1995) work on environmentally sound technologies found that the adoption of technologies to meet compliance obligations was fundamentally different from the adoption of production-enhancing technologies.[6] The reason for this is that "a large portion of the costs associated with the adoption of compliance technologies is the cost of capital investment (thus sunk costs) which are required" (Norris and Thurow, 1997:6). Plants in part are

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[6] This argument has been used for environmental technologies and environmental compliance, but the same argument could be used for food safety technologies.

reluctant to adopt such technologies because they do not necessarily receive immediate pay-offs for the adoption of the technology to offset investment costs (ibid).

The main benefits of adopting food safety technologies are avoiding possible costs from fines, recalls, or liability issues associated with foods having high pathogen levels. Some plants recognizing the need to find alternative ways to reduce pathogens have put research and development efforts into developing alternative technologies. Excel has worked in conjunction with Frigoscandia to test a steam pasteurization process for their plants (Unnevehr and Roberts, 1997). By being the first movers in this area they assumed a risk, because the higher costs associated with the implementation of a process to improve food safety may not result in compensation in terms of increased prices or increased sales (Nganjea and Massaco, 1998).

Table A: Available Technologies

Technology	**Plant Size**[4]	**Cost Range (per head)**	**Effectiveness Range**[5]	**Plants Using Technology**
Dehiding[1]	All	\$0.01-\$0.10	90-99%	20%
Steam vacuuming	Large	\$0.01-0.02	50-80%	100%
Hot water/ final carcass wash[2]	Small	\$3.58	50-80%	100%
	Medium	\$0.42	50-80%	100%
	Large	\$0.28	50-80%	50%
Steam pasteurization[2]	Small	\$3.58 - \$7.05	90-99%	0%
	Medium	\$0.42 - \$0.78	90-99%	0%
	Large	\$0.28 - \$0.46	90-99%	50%
Irradiation[3]	Small	\$12.30	99-99.5%	0%
	Medium	\$3.90	99-99.5%	0%
	Large	\$3.82	99-99.5%	0%

1. Source: HACCP training costs are used as a rough proxy for the cost associated with training workers in improved dehiding methods. Unnevehr (1999) personal communication on average estimates of HACCP training for workers from four hog slaughter plants. From these estimates, adjustments are made for throughput in beef slaughter plants.
2. Source: USDA estimates based on industry and manufacturer estimates.
3. Source: Estimates based on Morrison (1997). Costs assume that whole carcasses are irradiated.
4. Large plants – 101-400 head/hr; Medium plants – 41-100 head/hr; Small plants – 0-40 head/hr
5. See Roberts, Malcolm, and Narrod (1999) for references on the effectiveness of the technologies and see Appendix A of this paper for the distributions used in this analysis.

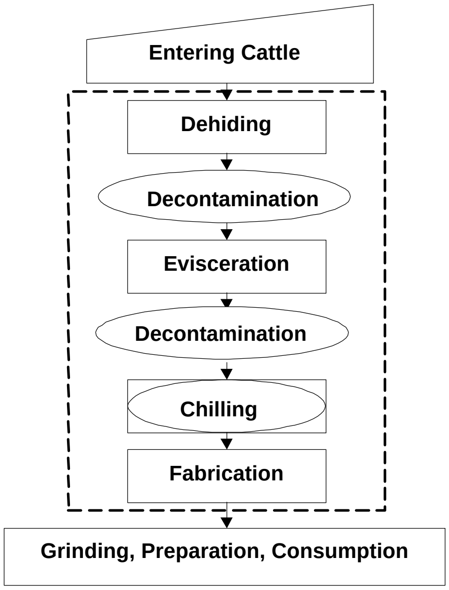

Figure 1: Steps in the ground beef production process (boxes represent contamination, ovals represent decontamination)

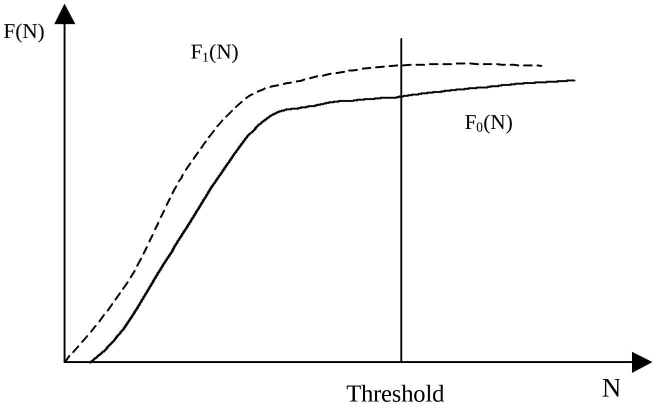

Figure 2: Cumulative distribution of *E. coli* levels in raw hamburgers

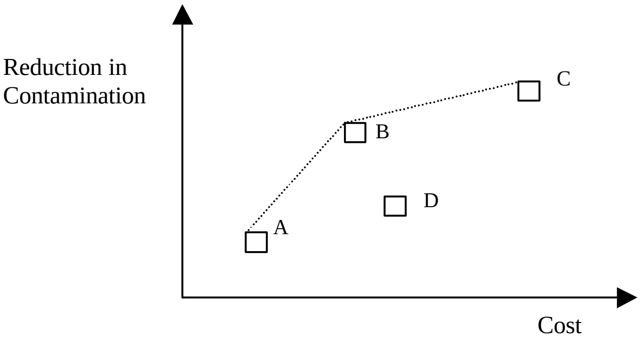

Figure 3: Comparison of Adoption Strategies

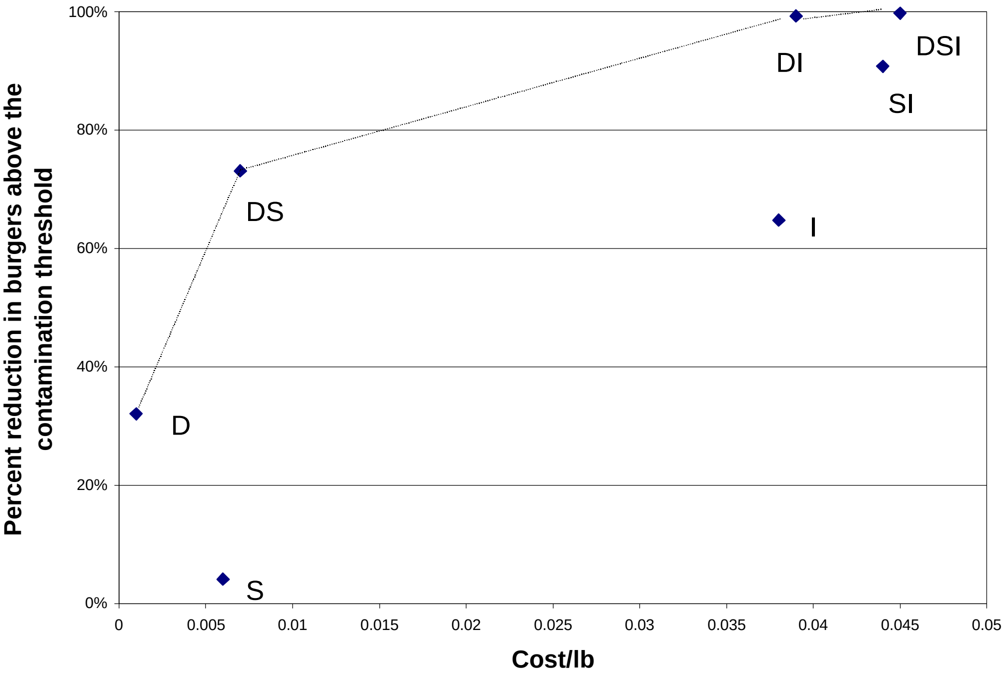

Figure 4: Trade-off curve for combinations of three technology adoption strategies in large steer/heifer plants (D = improved dehiding, S = steam pasteurization, I = irradiation)

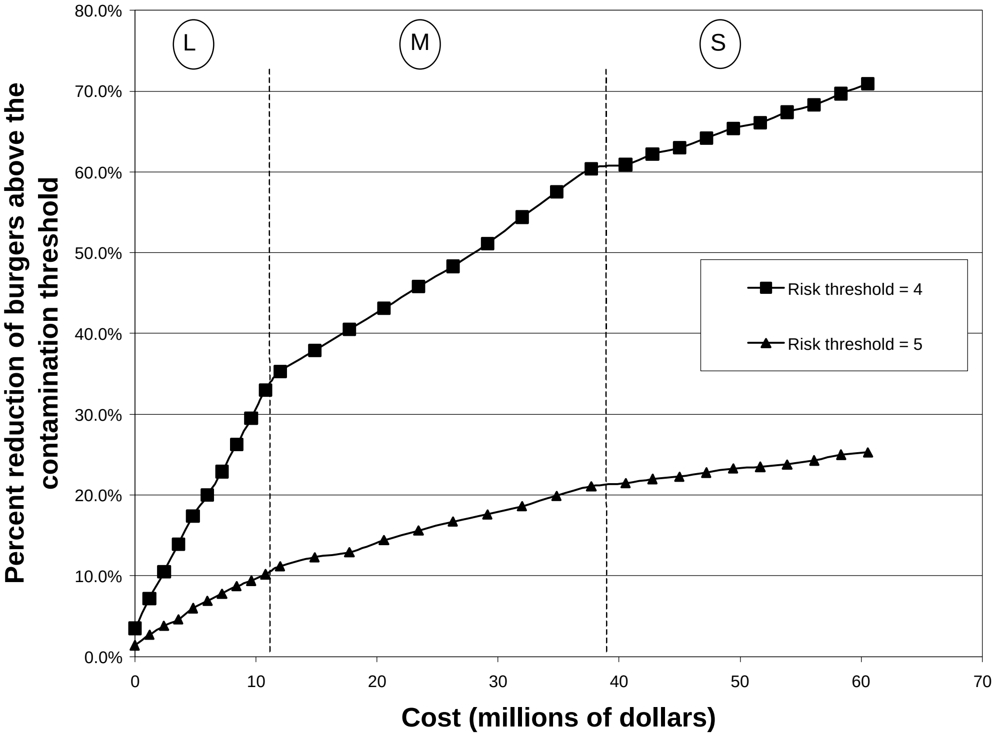

Figure 5: Effectiveness of irradiation under increasing adoption

Section L: range of costs and effectiveness for 0% to 100% of large plants
Section M: range of costs and effectiveness for 0% to 100% of medium plants and 100% of large plants
Section S: range of costs and effectiveness for 0% to 100% of small plants and 100% of large and medium plants

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APPENDIX A.

The slaughter plant is modeled as a simplified version of the process described above. The four steps included are dehiding (d), steam pasteurization (s), chilling (c), and fabrication (f). Monte Carlo simulation is used to compute the average contamination level per combo bin (X). In each iteration of the model, this value (expressed as $\log_{10}$ CFU) is determined by the net contribution of the four steps:

$$X = d + s + c + f$$

The average number of contaminants per hamburger (expressed as $\log_{10}$ CFU) is given by:

$$N = \log_{10} ((A * SA * (\%SA) * 10^{X})/8000)$$

where A is the number of animals contributing to a 2000 pound combo bin, SA is the surface area of the animal, %SA is the percentage of the surface area that ends up in the combo bin. There are 8000 quarter-pound burgers per combo bin. Multiple iterations of the model produce a probability distribution of N. Most of the steer/heifer carcass becomes steaks and other cuts and only 20% ends up as trim going into hamburger or other ground products. In contrast, only a few select roasts of the cow are left intact with 80% of the carcass destined for grinding (Duewer, 1999). For steer/heifers, an estimated 75% of the surface area (54,000 cm^2) contributes to ground products (McAloon, 1999). On average 20 animals contribute in a steer/heifer plant.

A. Dehiding. The computation begins by assigning a level of generic *E. coli* in $\log_{10}$ CFUs reported by Gill (1999) on the hindquarters during hide removal. *E. coli* levels after dehiding are modeled by a normal distribution.

B. Steam Pasteurization. The next step modeled is the effectiveness of carcass decontamination before going into the chiller. Both steam pasteurizers and hot water washes have highly variable applications. Some plants with process control can consistently achieve a 2 $\log_{10}$ CFU reduction of generic *E. coli.* (Gill, 1998).

C. Chilling. Studies of plants have found great variability in their ability to control their chilling operations (Gill and Bryant, 1997). Typically carcasses are chilled for 18-48 hours after slaughter. Either contamination or decontamination may occur during chilling.

D. Fabrication After chilling, the carcasses are fabricated into steaks, roasts, etc. and the remaining trim goes into ground beef. Gill's (1999) analysis of a group of plants suggests that plants which have good control of plant sanitation, temperature, and cross-contamination, often experience no increases in generic *E. coli* while plants with poor process control may have increases up to 5 $\log_{10}$ CFU.

The values used in the model for plants are summarized in Table B. The values include an unspecified mix of the variability and uncertainty that can occur within slaughter plants.

Table B: Slaughter Plant Model Variables and Ranges

Process	Distribution*
Dehiding (d) - Typical	Normal(2.27,0.5)
Dehiding (d) - Improved	Normal(0.23,0.5)
Steam Pasteurizing**(s)	Normal(1.5,0.5)
Chilling** (c)	Normal(-1,1,0)
Fabrication**(f)	Normal(0,0.5)***
Irradiation	Normal(3.0,0.5)

* Values given as $\log_{10}$ CFU of generic *E. coli*/cm^2 of carcass surface. The Normal distribution parameters are mean and standard deviation for changes in $\log_{10}$ CFU/ of generic *E. coli*/cm^2

**change in $\log_{10}$ CFU of generic *E. coli*/cm^2 of carcass surface

***Only positive values allowed