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ABSTRACT

Recently enacted food safety regulations require processors to meet product standards for microbial contamination in meat products. An analysis of the cost-effectiveness of several technological interventions for microbial control in beef and pork processing shows that marginal improvements in food safety can be obtained, but at increasing costs. The additional food safety intervention costs represent about 1% of total processing costs for beef and pork. Some interventions and combinations are more cost-effective than others.

Keywords: food safety, meat processing, regulation.

THE COSTS OF IMPROVING FOOD SAFETY IN THE MEAT SECTOR

Food safety regulations issued in July 1996 mark a new approach to ensuring the safety of meat and poultry products. The U.S. Department of Agriculture's (USDA) Food Safety and Inspection Service (FSIS) moved from a system of carcass-by-carcass inspection to an approach that relies on science-based risk assessment and prevention through the use of Hazard Analysis and Critical Control Point (HACCP) systems. Under the new regulations, the government requires meat processors to put a HACCP plan in place, to conduct periodic tests for microbial pathogens, and to reduce the incidence of pathogens. The new regulations shift greater responsibility for deciding *how* to improve food safety in the processing sector to processors themselves. Thus, the intent of this regulation was to promote more efficient resource allocation in food safety improvement (reducing inputs in control and/or improving food safety outcomes).

In addition to the need to improve the safety of food products to meet new federal standards, firms also have private incentives to improve both food safety and the shelf life of meat products. Currently, these private incentives are most apparent currently in growing export markets for meat products, but also occur through contracting of final product from large purchasers, such as ground beef for fast food restaurants (Seward). Thus, industry has both market and regulatory incentives to improve food safety, and to do so in the most cost-effective manner.

The demand for improved food safety has induced changes in methods used in meat processing for pathogen control. New technologies for pathogen control include both specific interventions or actions in the production process as well as new methods of managing process control (i.e., HACCP). The adoption of the new technologies allows the processing firm to achieve a safer food product through reduced pathogen levels. The challenge for the industry is to evaluate which set of interventions is the most cost-effective for achieving pathogen control.

In this paper we investigate the production function for food safety in meat processing in order to better understand the costs to meat processing firms of changing food safety levels. The motivation for doing this is to provide better information for the marginal benefit/cost analysis of food safety interventions. This is the type of information that is needed to assess the cost-effectiveness of the new food safety regulation, as discussed in Unnevehr and Jensen and in MacDonald and Crutchfield. The

FSIS impact assessment of the rule on food safety (USDA/FSIS 1996a) was limited by lack of information on the marginal costs of food safety production. Here, we specifically address: *a*) the structure of costs incurred by the firm in applying interventions to control food safety in meat processing; and *b*) new data on the cost and effectiveness of selected food safety interventions in beef and pork processing. The intent is to provide basic information on the cost frontier and, hence, marginal costs associated with improved pathogen control at the plant level.

The paper is organized as follows: in the next section we provide an overview of the HACCP based pathogen reduction regulation and previous estimates of the total cost of regulation. Next, we discuss the unique issues that pose difficulties for firms in evaluating the costs of pathogen reduction and control. Then, we review estimates of the relative cost-effectiveness of selected technologies available to beef and pork firms for pathogen control. And in the final section we offer some conclusions with respect to the firm's choice of technologies and implications for improvement in food safety.

HACCP Regulation and the Industry Costs of Improving Food Safety

Government intervention can take many forms, including direct regulation. How the regulation is specified has an effect on both the allocation decisions of the firm as well as the firm's costs and profits under the regulation (Helfand). The new FSIS rule regarding pathogen reduction combines both a process standard by requiring the adoption of a HACCP system and performance standard in setting allowable levels for *salmonella* and generic *E.coli* in products (Unnevehr and Jensen). According to Helfand, this type of combined standard theoretically encourages high levels of production but tends to reduce profits more than a simple performance standard.

In the case of microbial pathogens, performance standards are costly to monitor and enforce for many different pathogens. Thus, the combined performance/process standard represents an attempt to improve overall food safety without undue testing costs. Although there is no single indicator pathogen that can be used to evaluate the safety of products, testing for *salmonella* (by FSIS) on raw meat products is used to verify that standards for this microbial pathogen are being met; testing for generic *E.coli* (by the firms) on carcasses is used to verify the process control for fecal contamination (Crutchfield et al. 1997). HACCP systems that reduce these two pathogen may be assumed to result in overall improvements in food safety.

The use of HACCP as the basis of pathogen control in plants has basically two components, as previous studies have recognized. The first component is the pure process control aspect of training, monitoring, record keeping, and testing, which has been the focus of previous estimates of the costs of the regulation to industry (Roberts, Buzby, and Ollinger). The second component is the cost of specific interventions to reduce pathogens. Plants incur these costs in order to meet pathogen reduction goals; hence, these costs need to be considered as costs of the pathogen reduction regulation (MacDonald and Crutchfield). Relatively little is known about the second set of costs, in part because there is uncertainty regarding how much new technology will be needed to meet specific pathogen reduction targets. Earlier forms of the FSIS regulation mandated that each firm would have to introduce at least one antimicrobial technique in the production process, but this requirement was abandoned in favor of allowing firms greater flexibility in meeting performance standards.

Roberts, Buzby and Ollinger provide a summary of the costs for the meat and poultry industries estimated by the FSIS (both preliminary and revised) and by the Institute for Food Science and Engineering (IFSE) at Texas A&M. The annual costs of process control under HACCP consisted of planning and training, record keeping, and testing. The revised FSIS regulation estimated costs for these recurring process control efforts to be $75 million; IFSE estimated these costs at $953 million. One source of the difference in the estimates was a very high estimate of testing costs from IFSE. They assumed that industry would have to incur costs over and above the required tests for *E.coli*, simply to monitor performance of their HACCP systems. The wide variation in estimated costs of implementing HACCP shows the inherent uncertainties and wide range of possible assumptions (e.g. the number of critical control points).

Regarding the second major component, process modification costs, FSIS reported an estimated range of $5.5 to 20 million (Roberts, Buzby and Ollinger). The modification cost estimates, however, are very uncertain because the extent of necessary modifications to meet performance standards is unknown. The original FSIS and the IFSE cost estimates did not include these costs explicitly. The later, revised, FSIS estimates include explicitly costs for out-of-compliance beef and pork plants to adopt steam vacuum systems and for poultry plants to adopt antimicrobial rinses (Roberts, Buzby and Ollinger). As we discuss below, the steam vacuum technology is only one of several potential interventions in beef and pork. Currently steam vacuums are widely used in beef processing, but are not commonly used for pork. Thus, none of the past cost estimates provides much information to support the choice of any particular performance standard based on marginal cost/benefit analysis. Furthermore, there is little available information to guide choices faced by meat processing firms in adopting different technologies for pathogen control. Therefore, we explore sources of new cost information below, but first we discuss firm-level issues in identifying cost-effective means of pathogen control.

Issues in Evaluating Costs of Pathogen Control

There are several aspects of the food safety problems in meat processing plants that are unique and that differ from other aspects of product quality control. Understanding these aspects leads us to view food safety control within the context of the production process and to be aware of the limitations of focusing on a single technology or stage in the production process.

First, microbial pathogen control in the slaughter and processing environment involves control of hazards of various types. Some hazards are brought into the plant with the animals (many pathogens such as *salmonella* live in the enteric systems of animals); other hazards contaminate product through worker or other environmental contamination (such as *staphyloccocus* or *listeria*). Some hazards grow (multiply) on product; others do not multiply. Identification of the sources and levels of hazards can be complex and costly.

Second, microbial pathogen control involves control of biological processes that are closely related to the production process in meat plants. The process of slaughter, evisceration, and chilling carcasses provides opportunity for carcass contamination and cross-contamination. Presence or growth of pathogens can be affected by temperature, environment (e.g., acidity), physical pressures (e.g., washing), and time of year or day during which processing occurs. Thus, a HACCP system recognizes the need for control and monitoring throughout the production process. Pathogen reduction efforts at different intervention points, often at Critical Control Points (CCPs), affect the level of pathogens at that point in the process, but they can also reduce subsequent hazards. A simple example would be whether a hot water carcass rinse is applied before or after evisceration.

Third, and related to the last point, intervention technologies are often used in combination for pathogen control. Although the simplest assumption is that controls are additive, combinations of technologies often result in pathogen reduction that is nonadditive, as we will discuss below. Thus, evaluation of alternative interventions would ideally include evaluation of combinations of interventions or use of interventions at different points in the process. A simple example would be whether to combine a hot water rinse with an antimicrobial spray. This interconnectedness of process interventions means that HACCP planning is likely to have an indirect benefit through improved management of the entire production process or use of monitoring data (Mazzocco).

Fourth, technologies are not often pathogen specific: that is, control of contamination from one pathogen often affects or controls other pathogens as well (although this is not always the case). Generic *E. coli* is associated with fecal contamination of product, and its presence is likely to be an indicator of other associated contamination (or the potential for contamination) in the production process.

Furthermore, there is some (but not complete) overlap between the microbes that reduce shelflife and those that pose a hazard to human health. Thus safety and quality are jointly produced through certain production processes (e.g., chilling carcasses). Attributing costs of interventions to specific firm goals and benefits may therefore be problematic, which means that it may be difficult to identify the marginal costs of food safety improvement alone. In spite of the difficulties mentioned in this section, we examine the costs of specific technologies in the section that follows with an effort to account for the problems to the extent possible with available data.

Cost-effectiveness of Different Technologies for Pathogen Control

Meat processing plants consider alternative interventions for microbial pathogen control. Some technologies may be considered for specific pathogen reduction; others are less targeted in their effect. In general, however, the food safety control is best viewed from a plant/system perspective. As such, modifications to the process either through changed methods with existing technology, or the addition of new technologies, effect marginal improvements (i.e., incremental improvements) to the final product (or product at the completion of processing).

For firms, the costs of improved food safety include both costs of implementation (e.g., design of plan and training) and ongoing costs of inputs used to control microbial pathogens in the plant process. Most plants are continually engaged in process evaluation and quality improvement, but HACCP may require additional new management or employee training efforts.

The recurring operating costs that a meat processing plant is likely to incur in order to achieve higher levels of food safety, and meet new food safety regulations, are both variable and fixed costs. The variable costs include those associated with different quality inputs (including live animals), labor costs, operational costs of equipment (electricity, water, other utilities, and labor), sampling and testing, other supplies, ongoing training, and managerial costs. Fixed costs include investments in new capital equipment and plant (with appropriate depreciation to represent the costs of services from the equipment) as well as costs associated with any plant and process reconfiguration.

Foodborne pathogens enter the food supply at any point in the process from the farm level to final consumption. However, because many foodborne pathogens live in the enteric systems of animals, the pathogens may first enter into the food chain during the initial processing in slaughter plants. Current interest among industry, government and scientists in discovering how to prevent or eliminate pathogens at this point in the process has generated both new technologies and new studies. This emerging information regarding use of different technologies enables us to look at the economic dimension of the production process for food safety more closely.

The major stages of the production process for beef and pork include: incoming animals; pre-evisceration; post-evisceration; and packing and fabrication. Each stage can involve monitored CCPs and some microbial control processes or technology. Our analysis below focuses on the first three stages of processing, which are basically stages related to animal and carcass handling. We evaluate several different technologies of control in terms of their effect on reducing pathogens and their costs.

In the past few years, several new and existing technologies have been more widely adopted and adapted for pathogen reduction in the meat packing industry. This section presents cost curves for pathogen reduction in beef and pork, constructed from the best currently available data. These cost curves show how steeply marginal costs increase as pathogens are reduced, how costs of pathogen reduction may compare with overall costs of processing, and which intervention(s) may be most cost-effective.

Data regarding costs of equipment and inputs required for operation were obtained directly from input suppliers of new technologies.[1] Comparable operating and depreciation costs were constructed for all technologies with assumed prices for energy, water, labor, and capital. These cost estimates are representative of large plants in the packing industry, i.e. pork packing plants processing 800–1200 carcasses per hour and beef packing plants processing 250–300 carcasses per hour. Most of the technologies considered require capital investments that would be harder to justify for medium or small plants.

Data regarding pathogen reductions associated with different technologies were more difficult to obtain, and were drawn from selected published studies by meat scientists. Two issues confound comparability among pathogen reduction studies. First, some studies observe pathogen levels in plants, which are generally low, and therefore observed reductions are also small. Other studies innoculate carcasses with high levels of pathogens in order to observe measurable and significant reductions following interventions. Second, few studies consider all possible combinations of interventions that a plant might consider, including the use of interventions at different points in processing. We chose two studies (Phebus et al. and Dickson) that were most easily adapted to construction of a cost diagram.

Beef

For beef, possible interventions include steam pasteurization, trimming, hot water washes, steam vacuum, and sanitizing spray. Steam pasteurization is a relatively new technology that utilizes a cabinet that steams the entire carcass. Trimming refers to cutting away any visible fecal contamination on the carcass. Hot water washes refer to rinsing the carcass with hot water. A steam vacuum can be used to remove contamination from particular areas of the carcass and can be adopted at many different points during processing. A sanitizing spray using an antimicrobial solution such as lactic acid can be applied to a carcass to reduce pathogens. Combinations of technologies may be used, and trimming followed by hot water wash is most common in commercial facilities (Phebus et al.).

A study by Phebus et al. reports pathogen reductions for three pathogens (*escherichia coli*, *salmonella typhimurium*, and *listeria monocytogenes*) and for several different combinations of technologies on innoculated sides of beef. Of the interventions considered, steam pasteurization achieves the greatest reduction when used alone, followed by trimming and steam vacuum, with the use of hot water washes alone a distant fourth (table 1). Combinations of technologies are clearly more effective than the use of individual technologies, and the two combinations using four out of five technologies were observed to be the most effective in reducing pathogens.

The costs of these interventions for beef are also shown in table 1, and their derivation is presented in table 2. Fixed costs of new equipment are highest for steam pasteurization and lowest (zero) for trimming. These fixed costs were amortized over a 10-year period assuming a 10% interest rate. Variable costs were estimated for use of energy, water, and labor. Trimming and steam vacuum are labor intensive; steam pasteurization is energy intensive; and rinses are water intensive. Technologies that use water must also incur costs of disposing of effluent, and these are highest for rinses. Total variable costs are lowest for steam pasteurization and highest for rinses.

Total costs per carcass show that sanitizing sprays are highest at 41 cents per carcass, followed by water rinses (37 cents), steam vacuum (34 cents), steam pasteurization (27 cents), and trimming (17 cents). Total costs per carcass are included in table 1 for comparison with pathogen reductions. The highest costs are for the intervention combinations 10 and 11 in table 1. The most expensive technology combination costs five to six times as much as the cheapest intervention. However, care must be taken in interpreting the highest cost combinations as our cost estimate for sanitizing sprays is the least reliable.

Figure 1 shows cost per carcass graphed against pathogen reductions (the reduction in the mean log 10 values of the bacterial numbers observed on the carcass, measured as the CFU/cm^2) for Salmonella Typ. for beef. The pattern is similar for other pathogens evaluated (see table 1).. The graph shows clearly that greater pathogen reductions are associated with higher costs of intervention. If the results from the Phebus study apply to actual application of technologies in cattle packing plants, it appears that there are a set of least cost or "frontier" technology combinations that provide the most cost-effective pathogen reduction in beef. The plotted lines trace out a step cost function connecting the lowest cost points. This discrete function represents both average and marginal costs of achieving particular levels of pathogen reduction. Firms cannot choose costs and pathogen reduction from a continuous cost function, but rather must choose among the limited set of technology combinations and resulting reductions that are available.

Technologies numbered 1, 2, 5, and 10 are observed on the least cost line. Those numbered 4 and 7 may also be cost-effective substitutes, given the variance in observed pathogen counts and their close position to the least cost line. Trim alone (2) or trim and water rinse (5) appear to be quite cost-effective, and as these are in use in most plants, it appears that the industry has ascertained this. Use of the newer steam pasteurization technology alone (1) is also on the least cost line, but does not achieve as much pathogen reduction as trim and water rinse combined (5). Combining steam pasteurization with trim, wash, and sanitizing spray (10) gives greater reductions in *salmonella* (or *listeria)* reduction, but these reductions in pathogen counts nearly double the costs. Thus, adding this new technology to existing interventions may or may not be profitable, depending upon pathogen reduction standards and actual pathogen levels in plants.

Pork

Similar interventions are possible in pork processing, but data are limited regarding pathogen reductions for combinations of technologies. Interventions available for pork include carcass wash, sanitizing sprays, steam vacuum, and carcass pasteurizer. The carcass wash is a cabinet that provides a hot water rinse to the carcass. This can be applied either pre- or post- evisceration. Sanitizing sprays, most often acetic acid, are used post-evisceration. Steam vacuum is used to remove contamination from specific parts of the carcass, and may be utilized at different points in the process. Steam pasteurizers have been developed in Canada for hog carcasses, but have not yet been adopted in the United States.

Comparable data are available from Dickson for reductions in total aerobic bacteria and total enterics for water rinses at different temperatures and with or without sanitizing sprays; data regarding the carcass pasteurizer are available from Gill and Jones (table 3). In the Dickson study, carcasses were innoculated with relatively high levels of pathogens, whereas they were not in the Gill and Jones study. The Dickson study shows that higher reductions occur as water temperature increases and as rinses are combined with sanitizing sprays, and that reductions are generally to one-half of the initial levels. The Gill and Jones study shows that the carcass pasteurizer virtually eliminates the lower levels observed during processing.

Costs of interventions in pork processing are presented in table 4. Fixed costs are highest for pasteurizers and much lower for other interventions. Variable costs are also high for pasteurizers, due to their high energy costs. Total costs per carcass are thus highest for carcass pasteurizers (which may explain why they have not been adopted yet in the United States). Total costs range from 5 cents per carcass for washes at 55 degrees C to 16 cents per carcass for pasteurizers.

Available studies regarding pathogen reduction in pork processing do not provide enough information to evaluate all of the potential interventions or combinations of interventions. The Dickson study provides information to examine the cost curve for water rinses at different temperatures and in combination with sanitizing sprays. Table 3 shows how costs vary for these different intensities of intervention. Costs increase as more energy is used to heat water and as sanitizing sprays are added, and the range of costs varies from 3 cents per carcass to 20 cents per carcass. Figure 2 shows the relationship between cost per carcass and reductions in total enterics. The data came from table 3. As was the case in beef, greater pathogen reductions in pork are associated with higher costs.

The least cost line connects technologies numbered 2, 4, 3, and 7 for total enterics (figure 2). Use of water rinses alone (2, 4) seems to be more cost-effective for lower levels of pathogen reduction, although the combination of lower temperature rinses and sprays (3) is cost effective for total enterics at slightly higher levels of pathogen reduction. The least cost means of achieving the very highest pathogen reductions is the use of the sanitizing spray with the highest water temperature (7), but this more than doubles the cost over the use of highest temperature water rinses alone. Thus, addition of a sanitizing spray to existing water rinses may or may not be profitable, depending upon the desired pathogen reduction and the actual pathogen levels in the plant.

Comparison with Overall Processing and HACCP Costs

Costs of intervention per carcass are small in comparison to total costs of processing in large plants. Melton and Huffman estimate the 1988 value-added packing costs for beef at around $.06 per pound. Adjusted to current (1996) dollars, the value-added costs are estimated to be $67 per carcass. So for beef, intervention costs of between $.20 and $1.50 per carcass would represent an increase of less than 0.3% to 2% in costs. Because the $1.50 cost estimate is uncertain and could be too high, the costs of intervention for beef are likely to be 1% or less of total processing costs (not including the cost of the live animal).

For pork, Melton and Huffman estimate the value-added packing costs to be $.10 per pound for 1988; in current dollars, this would be $30 per carcass. In comparison, Hayenga estimates that large hog packing plants today have variable costs of $22 per carcass, and fixed costs of $6 per carcass, for a single shift, large plant. He estimates total costs to be $28 for a single shift and $23 for a double shift operation. In either case, the additional costs of 20 cents for hot water rinses and sanitizing sprays represent an increase of less than 1% (0.7-0.9%). Thus, these new technologies for large plants represent a relatively small potential increase relative to other determinants of cost variation in the industry, such as scale or number of shifts.

On a per pound (dressed weight) basis, costs of the pathogen reduction technologies considered above are in the range of $0.00014 to $0.00106 per pound for pork, and $.00025 to $0.00201 per pound for beef. Crutchfield et al., using the final FSIS cost estimates, report that total costs for implementing the HACCP rule requirements will be $0.00006/lb. for large beef firms and $0.00003/lb. for large hog firms; on a carcass weight basis this would be about $.04 per carcass for beef and $.0056 per carcass for hogs. These costs represent all of the costs of implementing HACCP, of which process modifications were only assumed to be a small part. FSIS assumed that half of pork and beef plants would adopt steam vacuums to achieve additional pathogen reductions, and that these would cost about $.08 per carcass. Our estimates show that total costs of steam vacuum are $.09 per carcass for hogs and $.19 per carcass for cattle. FSIS did not consider the costs of any other potential interventions. Thus, if more plants adopt the technologies considered above, the costs of pathogen reduction could be higher.

Another technology for reducing risk of foodborne illness from meats is irradiation. The federal government is currently evaluating changes in regulation to allow its use for red meat. Estimates for costs added for irradiation of ground beef product are between 2 and 5 cents per pound (McCafferty; Morrison, Buzby, and Lin). Hence, irradiation is a relative costly technology. It is likely that irradiation would be used in combination with other technologies and irradiated products will be differentiated in retail markets.

Conclusions

Demand for safer meat products and new food safety regulations have led to the development of new technologies for pathogen control through improved process and product controls. To date, there has been relatively little information on the cost-effectiveness of various technologies for improved food safety. Estimates based on recent data on various technologies and their costs indicate costs to be in the range of $0.20 per carcass for hogs, and between $0.20 and $1.50 per carcass for beef. These costs represent about 1% of packing costs, although the pathogen control costs may be higher if other costs of monitoring and testing are included. These costs, however, are observed at relatively high levels of pathogen reduction and control.

It is clear that the cost function is upward sloping for microbial pathogen reduction in the meat industry. Greater pathogen reductions can only be achieved at higher cost, and thus both firms and regulators must consider how to achieve improved food safety cost-effectively. Firms seem to be using the most cost-effective combinations currently. Although most plants operate at levels where expected pathogen reduction would be expected to be relatively smaller (to the left side of the figure), additional reductions will require the adoption of newer, more expensive technologies. If our data are representative, these additional reductions could double the costs of interventions to reduce pathogens.

We caution that these results are preliminary in several senses—more studies of pathogen reduction under plant conditions are needed; new technologies are emerging to control pathogens; and they represent only part of the costs of a full HACCP system that includes monitoring and verification. Some interventions appear to dominate and will be more cost-effective. But, their effectiveness in real world situations is still unclear. Plants may obtain their own information about cost-effectiveness based on internal review; however, that information is only available post-adoption. Therefore, much experimentation will be necessary; industry should evaluate new options carefully and may want to foster more public research to compare and fine-tune technologies.

Figure 1: Salmonella Typ. Reductions for Different Technologies in Beef

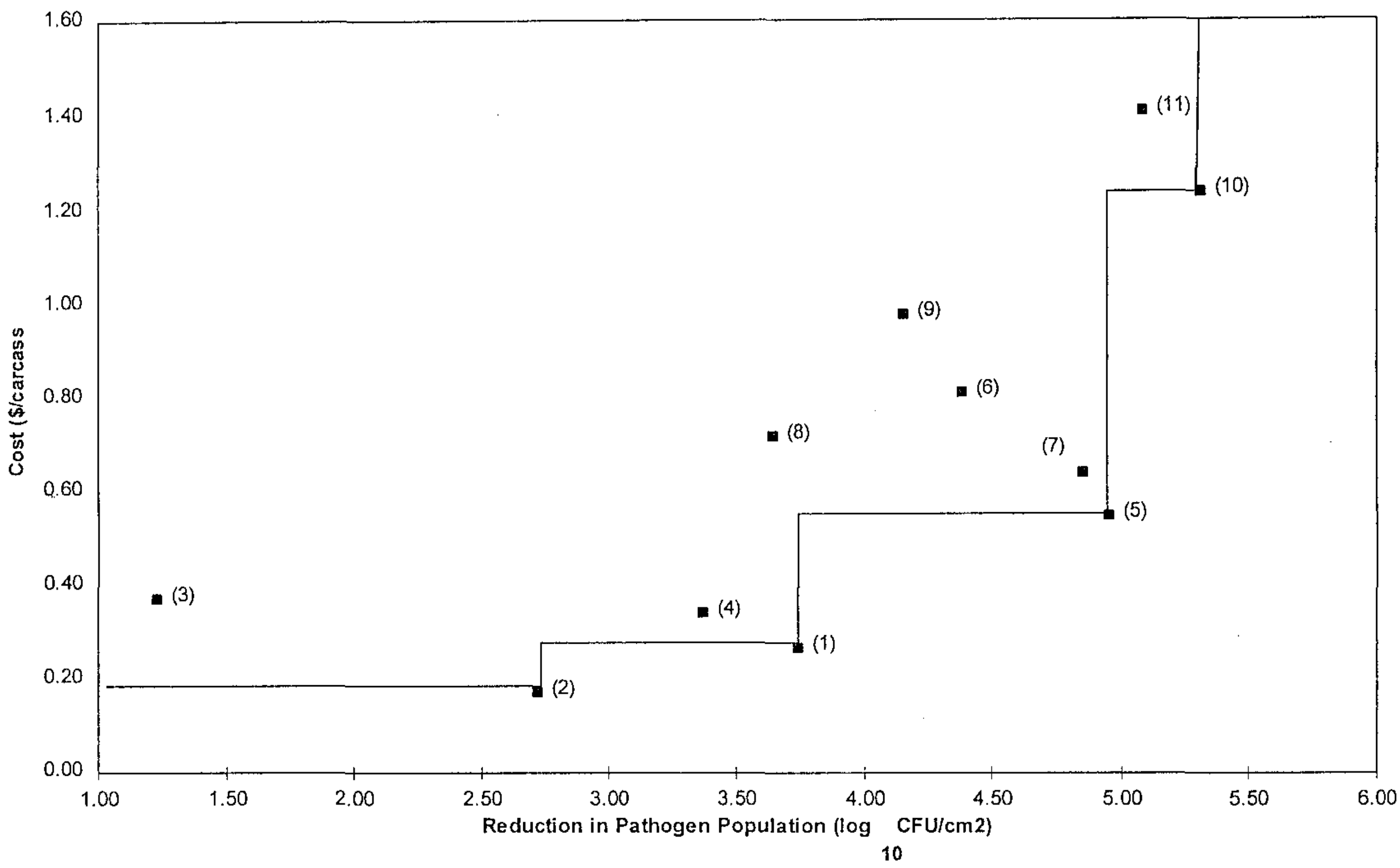

Figure 2: Total Enterics Reduction for Different Technologies in Pork

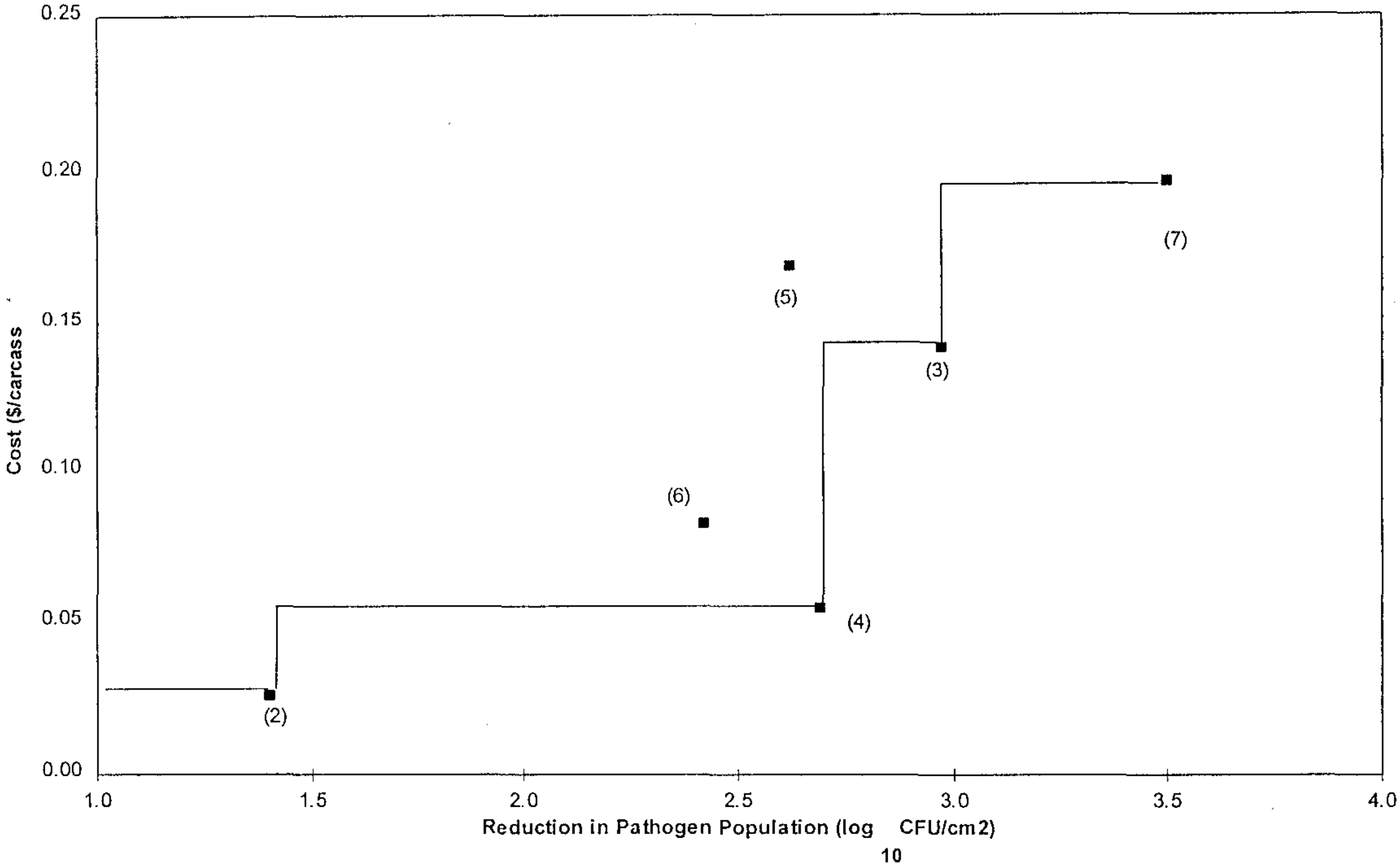

Table 1. Mean Pathogen Reduction of Different Technologies for Beef Carcasses ($\log_{10}$ Counts)

Type of Microorganism	(1) Steam pasteurization	(2) Trim	(3) Hot water wash (80°c)	(4) Steam Vacuum	(5)	(6)	(7)	(8)	(9)	(10)	(11)
					Combination of Decontamination Treatments[a]						
					TWc	TWS	WS	VW	VWS	TWLS	VWLS
Escherichia Coli											
Before Treatment	5.05	5.14	5.17	5.07	5.19	5.24	5.18	5.27	5.20	5.05	5.20
After treatment	1.52	2.04	4.42	1.96	0.48	0.80	0.96	1.74	1.41	0.91	0.55
Total reduction	3.53	3.10	0.75	3.11	4.71	4.44	4.22	3.53	3.79	4.14	4.65
Salmonella typhimurium											
Before treatment	5.15	5.27	5.19	5.20	5.26	5.31	5.24	5.35	5.24	5.31	5.27
After treatment	1.41	2.55	3.96	1.83	0.31	0.93	0.39	1.71	1.09	0.00	0.19
Total reduction	3.74	2.72	1.23	3.37	4.95	4.38	4.85	3.64	4.15	5.31	5.08
Listeria monocytogenes											
Before treatment	5.38	5.26	5.27	5.37	5.52	5.57	5.46	5.56	5.49	5.51	5.51
After treatment	1.94	2.72	3.99	2.04	0.56	1.01	1.06	2.07	1.65	0.44	0.50
Total reduction	3.44	2.54	1.28	3.33	4.96	4.56	4.40	3.49	3.84	5.07	5.01
Costs											
300 carc./h ($/carcass)	0.27	0.17	0.37	0.34	0.55	0.81	0.64	0.72	0.98	1.24	1.41

[a]S=Steam Pasteurization, T=Trim, W=Water Rinses, V=steam Vacuum, L=Lactic Acid Rinse
Source: Phebus et al. (1997)

Table 2. Fixed, variable, and total costs of different technologies: beef

	Steam Pasteurization[a]	Water Rinses for Cattle[a]	Trim[b]	Steam vacuum[c]	Sanitizing Spray[d]
Fixed Costs		($/carcass)			
Nominal cost equipment	750,000	250,000	0	87,500	250,000
Installation	275,000	45,000			
Freight	7,000	7,000			7,000
Spare parts	30,000	5,000			
Total	1,062,000	307,000	0	87,500	257,000
Medium term fixed costs per carcass[e]	0.14403	0.04164	0.00000	0.01780	0.0348
Variable Costs					
Water	0.00855	0.05400	0.00000	0.00074	0.0003
Electric	0.01530	0.00375	0.00000	0.01463	0.0222
Effluent	0.00863	0.05460	0.0000	0.00557	0.0003
Natural gas	0.05655	0.18615	0.00000	0.00000	0.3360
Labor[f]	0.03333	0.03333	0.17333	0.30333	0.0108
Solution	NA	NA	NA	NA	0.0050
Total variable cost per carcass[e]	0.12236	0.33183	0.17333	0.323537	0.3748
Total Costs					
Total costs ($/carcass)	0.26639	0.37347	0.17333	0.34207	0.4096

[a]Frigoscandia Inc.
[b]For trim it is assumed that four full-time workers perform this activity. Costs of materials are not included.
[c]Jarvis Co. steam vacuum for cattle assumes the use of seven vacuums operating simultaneously during the slaughter process.
[d]Our best estimates. We assumed that the cost of the santizing spray was the same as for water rinses.
[e]Based on plant processing 300 carcasses per hour, 16 hours a day, 260 days a year. A 10-year depreciation period and a 10% annual interest rate are assumed.
[f]Labor utilization parameters were provided by Jarvis Co. for steam vacuum. The others are our estimates.

Table 3. Mean Pathogen Reduction of Different Technologies in Hog Carcasses($\log_{10}$ Counts)

Type of Microorganism	(1) Carcass Pasteur.[a]	(2) Water Rinse (25C)[b]	(3) Water Rinse (25C) and Sanit. Sp.[b]	(4) Water Rinse (55C)[b]	(5) Water rinse (55C) and Sanit. Sp.[b]	(6) Water rinse (65C)[b]	(7) Water rinse (65C)[b] and Sanit. Sp. [b]
Total Aerobic Bacteria							
Before treatment	2.38	4.5	4.5	4.5	4.5	4.5	4.5
After treatment	0.39	3.49	2.25	2.64	2.25	2.06	1.76
Total reduction	2.0	1.0	2.2	1.9	2.3	2.4	2.7
Total Enterics							
Before treatment	2.7	4.1	4.1	4.1	4.1	4.1	4.1
After treatment	0.0	2.7	1.1	1.4	1.5	1.7	0.6
Total reduction	2.7	1.4	3.0	2.7	2.6	2.4	3.5
Cost							
1200 carc./h($/Carcass)	0.16	0.03	0.14	0.05	0.17	0.08	0.20

[a]Gill (1996). The samples were taken from parts other than the anal area of the carcass. The samples were taken during the plant operation, and were not contaminated intentionally.

[b]Dickson (1997). In this experiment the carcasses were intentionally contaminated.

Table 4. Fixed, variable, and total costs of different technologies: pork

	Hog Carcass Wash[a]	Sanitizing Spray System[a]	Carcass Pasteurizer[b]	Steam Vacuum[c]
Fixed Costs		($/carcass)		
Nominal cost equipment	10,900	32,900	200,000	12,500
Installation	12,000			
Freight	7,000	7,000		
Spare parts	2,281			
Total	32,181	39,900	200,000	12,500
Medium term fixed costs per carcass[d]	0.00655	0.00812	0.04069	0.01270
Variable Costs				
Water	0.00140	0.00008	0.00021	0.00003
Electric	0.00052	0.00557	0.00174	0.00063
Effluent	0.00141	0.00008	0.00021	0.00024
Natural gas	0.04201	0.08402	0.11004	0.00000
Solution	NA	0.00500	NA	NA
Total variable cost ($/carcass)[d]	0.04804	0.09746	0.11491	0.06948
Total Costs				
Total costs per carcass	0.05459	0.10557	0.15559	0.08220

[a]CHAD Co.
[b]Stanfos Inc.
[c]Jarvis Co.
[d]Based on plant processing 1200 carcasses per hour, 16 hours a day, 260 days a year. Medium term fixed costs use a 10-year depreciation period and a 10% annual interest rate.

ENDNOTES

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