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Evidence from the Meat Industry

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Tanya Roberts
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Abstract

Recent industry innovations improving the safety of the Nation's meat supply range from new pathogen tests, high-tech equipment, and supply chain management systems, to new surveillance networks. Despite these and other improvements, the market incentives that motivate private firms to invest in innovation seem to be fairly weak. Results from an ERS survey of U.S. meat and poultry slaughter and processing plants and two case studies of innovation in the U.S. beef industry reveal that the industry has developed a number of mechanisms to overcome that weakness and to stimulate investment in food safety innovation. Industry experience suggests that government policy can increase food safety innovation by reducing informational asymmetries and strengthening the ability of innovating firms to appropriate the benefits of their investments.

Keywords: Food safety, innovation, meat, asymmetric information, Beef Steam Pasteurization System, Bacterial Pathogen Sampling and Testing Program

About the authors

Elise Golan, Tanya Roberts, and Michael Ollinger are economists at the Economic Research Service, USDA. Elisabete Salay is the Director of the Interdisciplinary Center for Food Research (NEPA) and Associate Professor at the Food Engineering Faculty (FEA) of the State University of Campinas (UNICAMP), Brazil. Julie Caswell is a professor in the Dept. of Resource Economics, University of Massachusetts. Danna Moore is Assistant Director, Social and Economic Sciences Research Center, University of Washington.

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Large restaurant chains have created a market for food safety. By far the dominant drivers of food safety innovation in the meat industry are the stringent requirements on product safety and quality demanded by large fast food restaurants. By demanding safer products from their suppliers, these restaurants have successfully created markets for food safety. The success of these markets rests on the ability of these large buyers of meat to enforce standards through testing and process audits—and to reward suppliers who meet safety standards. Through contracts with these large buyers, meat processors are able to appropriate the benefits of their investments in food safety.

Branding helps firms appropriate benefits from food safety innovation. Branding also plays an important role in helping firms appropriate the benefits of safety investments. The major, name-brand fast food restaurants are able to appropriate some of the benefits of their investments in food safety because of their reputations for safe food. However, name-brand recognition is a double-edged sword: it allows consumers (and regulators) to identify and reward firms that produce high-quality, safe products, but it also increases their chances of identifying firms that are guilty of safety lapses. Branding reduces the chances of remaining anonymous in case of a foodborne outbreak, thereby further strengthening the incentives to invest in food safety.

International trade stimulates demand for safety and provides technological spillovers. International trade has played an important role in stimulating the demand for food safety, much the same way as large fast food restaurants. By demanding high safety standards in testing product for safety, and then paying premiums or guaranteeing sales for safe producers, foreign buyers fuel the growth of markets for food safety and stimulate safety innovation.

First movers appropriate the benefits of innovation and encourage diffusion. The first company to adopt a new technology can often appropriate the benefits of innovation. The Texas American Foodservice Corporation (Texas American), for example, did not patent its newly developed Bacterial Pathogen Sampling and Testing Program or seek any other sort of protection for the innovation. Its first mover advantage was sufficient to forestall pressure from competitors and to allow it to appropriate the benefits of the innovation. Not only did Texas American not seek protection for the innovation, it actually sought to disseminate the technology, arguing that anything that helps reduce the possibility of outbreaks associated with hamburgers is good for business. Another reason that firms may have an interest in sharing new technologies with their competitors and with government regulators is to influence the standard of care for the

industry. Setting a standard of care that is difficult to meet can help set a barrier to entry that benefits the first adopters.

Collaboration facilitates innovation and dissemination. The observation that the performance of the industry as a whole affects the reputation and profitability of all firms in the industry provides incentives for firms to collaborate to improve overall industry performance. In the two case studies presented here, the innovative process was dependent on collaboration. In each case, the technical and managerial expertise of the collaborators combined to facilitate the development of the innovation and ensure that it would be effective in a commercial setting. In addition to technical and managerial benefits, collaboration also provides important risk-sharing benefits.

Market conditions push large firms to innovate. The ERS survey indicates that large slaughter plants had much higher food safety technology ratings than smaller ones, suggesting that economies of scale, i.e., lower per unit costs for large plants over small ones, plays a major role in whether plants adopt capital-intensive food safety technologies. However, economies of scale do not sufficiently explain all differences. Two characteristics peculiar to the beef industry and food safety also play a role. First, large and small slaughter plants face different markets. Large plants tend to supply large, homogeneous markets with relatively elastic demand, while smaller plants tend to serve smaller markets with less elastic demand. To protect their markets, large plants may have more incentive than small firms to adopt food safety innovations. Another reason large firms may invest more in food safety than small firms do is that lapses in food safety have the potential to be more costly for large firms because they may involve larger amounts of product.

Foodborne disease outbreaks spur the demand for safety and innovation. The 1993 outbreak of *E. coli* O157:H7 was a seminal food safety event in the United States. This outbreak led to increased consumer awareness of food safety issues and triggered a spike in demand for food safety that is still being felt in the industry. For many consumers, news about foodborne illness outbreaks is their only information about food safety. As a result, the market is susceptible to large fluctuations after foodborne illness outbreaks, as consumers reassess their buying decisions.

Technological validation by third parties is as important as technological opportunity in driving innovation. The Steam Pasteurization System case study highlights an important observation about technological innovation for food safety: the design and fabrication of the technology may be secondary to technological validation in determining the ultimate success of an innovation. Not only is it difficult to measure pathogen control and technological efficacy, but even the best technology can be undermined by deficiencies in the overall safety system. The actual efficacy of the technology may vary greatly from plant to plant, depending on the characteristics of each plant's safety system. As a result, innovators may have a difficult time certifying or otherwise guaranteeing the efficacy of the technology for controlling pathogen contamination.

The drivers of food safety innovation highlighted by the ERS survey and the case studies suggest four areas where government policy may be well targeted for stimulating food safety innovation:

- Strengthening appropriability (the ability to control and exploit the benefits from innovation) through safety information,
- Strengthening appropriability through increasing the costs of food safety failure and the benefits of success,
- Providing flexibility in the choice of food safety technology, and
- Investing in the scientific infrastructure and supporting research on safety testing.

In general, government policy targeted at overcoming asymmetric information problems in markets for food safety will go a long way toward establishing incentives for efficient investment in food safety innovation.

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Food Safety Innovation in the United States

Economic Theory and Empirical Evidence from the Meat Industry

Elise Golan, Tanya Roberts, Elisabete Salay, Julie Caswell, Michael Ollinger, and Danna Moore

Introduction

The last decade marked a period of extensive innovation in the science and regulation of food safety in the United States. New production technologies, supply management systems, detection methodologies, regulatory approaches, and surveillance networks are improving the safety of the Nation's food supply. Improved food safety is in turn lowering the incidence of foodborne illness in the United States. Data from the Centers for Disease Control and Prevention show a 23-percent overall decline in bacterial foodborne illness in the United States from 1996 to 2001 (CDC, 2002).

Despite this progress, bacterial contamination and large recalls are still making news. Unprecedented recalls of hamburger patties in 2002 because of pathogen contamination indicate that control programs have yet to be reliably successful. Can producers do more to efficiently control pathogen contamination? What motivates producers to invest in food safety innovation? How can policymakers and regulators best target policy to increase efficient food safety investment?

The drive for food safety innovation has come from a number of sources. The food industry, consumers, and lawmakers have all played a part in stimulating the development and adoption of food safety innovations. In some cases, lawmakers or consumer organizations have prodded industry into making improvements to food safety. In other cases, food manufacturers have pioneered new methodologies to improve the safety of their products, often producing foods that exceed government safety requirements. When industry successfully innovates to produce safe foods, a win-win situation arises, with the innovating firm, consumers, and government all benefiting from improved food safety.

In this report, we investigate the factors that motivate firms to invest in food safety innovation and identify government policies supporting such motivation. We begin with an overview of the economic literature on innovation in which we examine the core drivers of innovation in the economy. We then conduct a theoretical analysis of the strength of these core drivers for motivating investments in food safety innovation. We hypothesize that the core drivers of innovation are relatively weak for food safety. We test this hypothesis with evidence from a recent survey of U.S. meat and poultry slaughter and processing plants and two case studies of food safety innovation. We find that industry has developed a number of mechanisms for overcoming weaknesses in the food safety incentive structure and for stimulating food safety innovation. We build on industry experience to suggest government policies that may best support food safety compliance and innovation.

Part I. Theory: The Economics of Food Safety Innovation

Food Safety Innovation Boosts Social Welfare

Innovation is all the scientific, technological, organizational, financial, and commercial activities necessary to create, implement, and market new or improved products or processes (OECD, 1997). Innovation takes two forms: product innovation and process innovation.

A *product innovation* is the development and commercialization of a product with improved performance characteristics (OECD, 1997). Product innovation tends to expand consumer choice. More product choice allows more consumers to find products that better match their particular tastes and preferences, thereby expanding consumer welfare. This welfare-increasing effect of product innovation is not guaranteed, however. Product innovations that become the industry or regulatory standard may ultimately reduce, not increase, product differentiation and consumer welfare. For example, some cities prohibit sales of unpasteurized milk, thereby reducing choice through the elimination of raw milk markets.

A *process innovation* is the development or adoption of a new or significantly improved production or delivery method (OECD, 1997). Process innovations may be technological or organizational, involving changes in equipment, human resources, working methods or any combination of these. Process innovation tends to make production more efficient. With diffusion, some or all of these efficiency gains may be passed on to consumers in the form of lower prices. Social welfare is improved through lower prices and more efficient use of resources.

The distinction between product and process innovation for food safety is not clear cut because food safety process innovations often lead to safer foods, not just the same level of safety at less cost. Pasteurized milk, juices, and eggs, ultra-high temperature (UHT) milk, and irradiated spices and meat patties encompass technological innovations that have made standard food products safer. Even such processing changes as properly refrigerated trucks, lot coding, lay-date stamping on eggs, pathogen testing, and instant-read thermometers all lead to safer final products, blurring the line between process and product innovation.

Imitation plays an important role in ensuring that the benefits of innovation, whether product or process, are maximized. Imitators, those firms that adopt and adapt innovations pioneered by other firms, help ensure that the choice and efficiency gains of innovation are realized. Product innovations that are widely marketed have a bigger impact on consumer choice than those with limited market exposure. Process innovations that are widely adopted or account for a large share of industry output have a larger impact on industry efficiency and consumer welfare than those with limited use.

Widespread diffusion of food safety innovation not only increases choice and economic efficiency, it also saves lives and improves health. In 1999, the U.S. Centers for Disease Control and Prevention estimated that annually, one in three Americans become ill from a foodborne illness, one in 700 are hospitalized, and one in 60,000 die (Mead et al., 1999). The human toll is mirrored by an economic one. USDA's Economic Research Service estimates that the annual economic cost of five foodborne illnesses[1] is approximately $6.9 billion per year (ERS, 2001). Innovation and the adoption and diffusion of food safety improvements will help combat foodborne illness and improve the quality of life for all Americans.

Appropriability, Market Demand, and Technological Opportunity Are Key to Innovation

How can policymakers and regulators encourage food safety innovation to improve public health and expand social welfare? Why do some policies succeed in stimulating food safety innovation for some firms but not for others? To begin to answer these questions, we first turn to the general economics literature. Economists and business analysts have spent well over half a century investigating the questions of "What drives firms to innovate?" and "What differentiates innovating from non-innovating firms?"

[1] The five pathogens included in the ERS estimate are *Campylobacter*, *Salmonella* (nontyphoidal serotypes only), *E. coli* O157:H7 and non-O157 STEC, and *Listeria monocytogenes.*

A starting point for much research on innovating behavior is Schumpeter's work on growth and innovation (Schumpeter, 1934 and 1942). His assertion that large firms operating in concentrated markets are the best engines of technological progress motivated early innovation researchers to focus their investigations on the role of firm size and market concentration. Only relatively recently have researchers expanded the investigation to examine other factors, eventually identifying appropriability (the ability to control and exploit the benefits from innovation), market demand, and technological opportunity as the core drivers for innovation and technological change. In this section, we outline how these core drivers of innovation operate in most industries and then examine their operation in the food industry for food safety innovation. For more complete reviews of the innovation literature, see Freeman (1994), Cohen (1995), and Stoneman (1995). Pray and Fuglie (2000) examine the literature on the drivers of innovation in agriculture.

Appropriability

Appropriability, the ability to control and exploit the benefits from innovation, plays a key role in driving investment in innovation. Only if firms expect to be able to reap the benefits of an innovation will they have an incentive to innovate. This principle was articulated by Schumpeter when he argued that the expectation of ex-post market power is an important inducement to innovation (Schumpeter, 1942).

Early researchers, including Schumpeter, argued that bigger, diversified, oligopolistic firms are typically in a better position to appropriate the benefits of innovation than smaller, specialized, firms without market power. This is more likely to be the case when the most efficient mechanism for appropriating the benefits of innovation is through a firm's own output. However, when other means of appropriation are as effective, then size, degree of diversification, and ex-ante market power are joined by other firm and industry characteristics in predicting a firm's potential for appropriating the benefits of innovation—and therefore, for predicting which firms will invest in innovation.

Supply chain management, patents, branding, marketing, customer service, secrecy, early sale of innovative rights, and first-mover advantage all provide varying degrees of protection from competition and help firms appropriate the benefits of innovation. Firms that successfully develop any of these appropriation mechanisms will be better able to capture benefits from innovation, and therefore have more incentive to innovate, than firms that are unable to create these mechanisms. Firms may use any of these mechanisms. In their survey of American firms (the first comprehensive survey of appropriability conditions in the U.S. manufacturing sector), Levin et al. (1987) found that 80 percent of surveyed firms regarded investments in complementary sales and services as an effective means to protect returns to innovative investments. Many of the firms in the Levin et al. survey stated that a head start and the ability to move quickly down the learning curve were more effective means of appropriation than patents. Peculiarities of the industry, firm, and even the type of innovation interact to determine the most efficient means of appropriation and the firms that are most successful in establishing them.

The importance of appropriability in motivating innovative activity extends to every manager and worker in the firm or plant. Managers and workers who are able to appropriate some of the benefits of innovative activity will be more likely to initiate and engage in such activity. Subtle firm-level characteristics such as the organization of product development, information processing capabilities, and internal organization may have a strong effect on the appropriation structure within the firm and the incentives of individual workers to engage in innovative activity. This observation echoes one made by Schumpeter in his discussion of the delusory effect of hierarchical management systems on managerial initiative. He argued that managers who do not have some control over the product of their labor will lose the incentive to innovate.

Demand

The view that market demand has an almost exclusive pull on innovation was staked out by Schmookler in his work on the determinants of technical change (Schmookler, 1962 and 1966). He argued that demand determines the rate and direction of inventive activity because rational, profit-seeking firms are responsive to economic incentives. Schmookler argued that there is a general pool of knowledge and technical capability, and that only those industries driven by market demand are motivated to dip into the pool and adapt technologies to their own purpose. Market demand provides the incentive to firms to innovate and adapt technologies.

To test Schmookler's hypothesis, researchers have primarily examined intermediate products, demand for

which is derived from estimates of final demand and the downstream production technology. Though Schmookler's own empirical investigation found that demand played a major role in driving innovation (Schmookler, 1966), subsequent researchers have not duplicated this result. In general, the empirical evidence has not identified demand to be a key determinant of innovation (Cohen, 1995).

Though demand may not directly spur innovation, researchers have suggested two principal ways in which demand conditions may influence innovative activity. First, the size of the market may influence innovation because even if innovative activity is scale neutral, the benefits of innovation are proportional to the size of the market. In other words, holding constant the cost of innovation, more innovative activity would be expected in the larger market or in the market expected to grow more rapidly.

Second, the elasticity of demand may also play a role in determining the level of innovation. Kaimen and Schwartz (1970) demonstrated that the gains from process innovation are larger when demand is more elastic. Process innovation lowers production costs, thereby shifting out the supply curve. Movements of the supply curve result in larger quantity changes and smaller price changes, the more elastic the demand. As a result, process innovation triggers larger increases in producer surplus when demand is more elastic. The effect of demand elasticity on the gains from product innovation is less straightforward. Market structure and the degree to which consumers view the new and old products as substitutes determine gains from product innovation more than do existing demand elasticities. (For an introduction to this literature, see Carlton and Perloff, 1994.)

Technological Opportunity

Contrary to Schmookler's position, the "technology-pull" hypothesis posits that the direction and rate of technological change is determined not by demand, but by the suitability of the technology to a particular industrial application. In general, the empirical evidence tends to support this hypothesis, finding that cost and applicability of design are as important as, or more important than, demand considerations (Cohen, 1995).

The existence or growth of scientific knowledge encourages innovation through a number of avenues. First, the cost of undertaking a science-based innovation may decrease as scientific knowledge increases. A strong scientific base focuses innovative activities in the most productive direction, reducing the costs of trial and error. Second, a strong scientific base may provide a rich pool of potential technologies, thereby increasing the likelihood of finding a technology efficiently suited to a firm's or industry's specific objectives. Third, a strong scientific base may actually increase a firm's or industry's set of objectives, decreasing innovation costs by expanding the set of problems with solutions.

The development of technologies is often completely divorced from demand considerations—though applications triggered by initial technological breakthroughs are often motivated by demand conditions. In many cases, a major innovation triggers a series of smaller innovations tailored to the specific needs of a particular firm or industry (Walsh, 1984). For example, the scientific research behind the harnessing of electron beams, x-rays, or gamma rays was not motivated by the demand for pathogen control in food processing. However, demand for food safety has motivated the application of irradiation technologies for controlling pathogens and improving the safety of a variety of foods. Irradiation technologies have been developed to control pathogens and fungi in spices and dried vegetable seasonings, to delay ripening and sprouting in fresh fruits and vegetables, and to control pathogens and extend shelf-life of raw meats and meat products (ERS, 2003).

Changes in Appropriability, Demand, and Technological Opportunity Vary the Costs and Benefits of Innovation and Imitation

As outlined above, the theoretical and empirical economics literature points to appropriability, market demand, and technological opportunity as the key factors affecting the costs and benefits of innovation. The strength of these factors helps to tip the balance toward innovation for some firms and away from innovation for others. Strong appropriability mechanisms, large potential markets, elastic demand, and innovations that are easily adaptable to firm-specific applications all increase the benefits of innovation, tipping the innovation cost-benefit calculus toward innovation. Table A-1 illustrates how these three factors condition a firm's innovation cost-benefit calculus.

Appropriability, market demand, and technological opportunity also play key roles in a firm's decision to

Table A-1—Economic literature suggests three main drivers of innovation and imitation

	Innovation	Imitation
Appropriability	+ The stronger the ability of innovators to appropriate the benefits of innovation, the higher the likelihood of innovation	- The stronger the ability of innovators to appropriate the benefits of innovation, the lower the likelihood of imitation
		+ The stronger the ability to appropriate the benefits of imitation, the higher the likelihood of imitation
	+ The higher the likelihood that firms will be forced to bear costs of food safety failure, the higher the likelihood of innovation	+ The higher the likelihood that firms will be forced to bear costs of food safety failure, the higher the likelihood of imitation
Size and shape of demand		
Size	+ The larger the market, the stronger the incentive to innovate	+ The larger the market, the stronger the incentive to imitate
Elastic demand	+ The more elastic the demand, the stronger the incentive to invest in process innovations	+ The more elastic the demand, the stronger the incentive to invest in process imitation
Technological opportunity	+ The greater the technological opportunity, the lower the cost of innovation and the greater the incentive to innovate	+ The greater the technological opportunity, the lower the cost of imitation and the greater the incentive to imitate

imitate (adopt a technology developed by someone else in the industry). These three factors influence the costs and benefits of imitation—though not always in the same direction as they influence innovation. Column 3 in table A-1 illustrates how these three factors stimulate or dampen a firm's incentive to imitate.

When innovating firms have strong appropriability mechanisms, the cost of imitation rises, tipping the cost-benefit calculus away from imitation. For example, the cost of imitation is higher when an innovation is patented. Mansfield et al. (1982) found that of 48 firms interviewed, the median estimate of the increase in the cost of imitation due to patents was 11 percent on average. In their survey of American manufacturers, Levin et al. (1987) found that the relative cost of duplicating an innovation was higher for patented than for unpatented process and product innovations. Any innovation appropriability mechanisms that make it more costly for imitators will dampen the extent of imitation.

Potentially large markets and demand elasticities have the same influence on imitation as they have on innovation. Imitators will reap more benefits from investments to duplicate process innovations in large markets with elastic demand.

Technology spillovers from innovating firms reduce the amount of resources imitating firms must spend on R&D activities. Technologies that are easily adaptable to firm-specific characteristics reduce the cost of imitation. Innovative spillovers increase the speed of the diffusion of innovation and increase consumer welfare. Spence (1984) dubs this the efficiency effects of spillovers.

The dynamics of the firm's innovation and imitation incentives reflect constantly changing information regarding the costs and benefits of innovation and imitation—and the extent of appropriability, technological opportunity, and market demand. Firms are constantly adjusting to new information and updating their innovation and imitation strategies. The simple cost-benefit seesaw described in table A-1 is influenced by a stream of new information that can tip the balance without any actual change in the underlying cost-benefit structure.

Market Failure Distorts the Incentives for Food Safety Innovation and Imitation

Though there is no reason to suspect that technological opportunity has been exhausted for food safety innovation, appropriability and market demand seem relatively difficult to establish for food safety. As a result, the incentives for food safety innovation are less than in

industries with large markets and effective mechanisms for appropriating the benefits of innovation. However, weak appropriability may hasten the diffusion of innovation, thus amplifying the consumer benefits of any innovation that does take place. In this section, we examine the logic behind these observations.

Information Asymmetries Erode the Appropriability of Food Safety Innovation

It may be difficult for producers to appropriate the benefits of food safety innovation because improved food safety is a difficult attribute for consumers to detect. For the most part, food safety is a credence attribute. Credence attributes are those that consumers cannot evaluate even when they use or consume the product (Darby and Karni, 1973). Consumers cannot usually determine before purchase, or even after consumption, whether a food was produced with the best or worst safety procedures, or whether a food poses a health risk. For example, consumers are unable to distinguish between raw ground beef contaminated with *E. coli* O157:H7 and uncontaminated ground beef.

Because consumers cannot detect food safety, they may be unwilling to pay a premium for "safer" food. Consumers may worry about fraud and the possibility that some foods marketed as safer products are actually standard or even sub-standard products. In fact, firms producing low-safety foods may have an incentive to market their products as high-safety; they could charge high-safety prices, and because of their cost cutting, have greater profits than high-safety producers. If this incentive were left unchecked, the market would be dominated by low-quality products with little or no product differentiation (Akerlof, 1970). In this case, consumers would be correct in assuming that all products were of low quality unless proved otherwise.

In some cases, food producers themselves may be unaware of the safety characteristics of individual products. For example, poultry producers do not typically have information on whether a specific package of chicken thighs is contaminated with *Salmonella*. Producers do know, however, what safety procedures are maintained in their plants and whether their procedures surpass, meet, or fall below industry standards. As a result, although producers do not have complete information, they have more information than consumers about product safety. Firms with poor safety records may try to take advantage of the fact that consumers lack full information about firms' safety records and market their products as if they had been produced with the best safety technologies.

Producers have developed a number of approaches for overcoming problems associated with marketing credence attributes and for assuring consumers that attributes such as safety actually exist (for a review of this literature, see Golan, Kuchler, and Mitchell, 2000). For food safety and quality, one of the most common approaches is to establish a brand name associated with high standards. Connor and Schiek note the advantages of this strategy (1997, p. 348):

> In consumers' minds the brand names identify the main attributes of the product and are a guarantee of consistent or minimum quality. Brands are preferred by consumers to unbranded products because they reduce the uncertainties concerning product performance, quality, and value associated with food purchases.

Third-party quality verification is another approach used by firms to overcome consumer skepticism regarding credence quality attributes. Third-party entities offer a wide variety of inspection services to verify that a firm's production standards or quality content are as advertised. Third-party certifiers inspect traceability systems to verify the existence of credence process attributes such as organic, fair trade, dolphin-safe, no child labor, and earth-friendly. Third-party certifiers also inspect production facilities and bookkeeping records to verify that firms have adhered to safety standards. Some third-party certifiers provide testing services to verify that pathogen contamination or other safety problems are under control.

A growing number of food manufacturers are insisting on third-party safety certification from their suppliers. Traceability documentation, lab results, and detailed safety inspections are becoming increasingly important in contracts among food processors (Golan et al., 2003). To date, most consumers do not demand this type of information from food suppliers, and firms do not typically supply this information to their consumers. Since this information exists, particularly for high-quality firms, it is puzzling that producers do not use it to advertise their good safety records and appropriate more of the benefits of their safety investments. One reason may be that in advertising their good safety records, and disclosing the poorer safety records of their competitors, firms also disclose general food facts that may frighten consumers. Consumers may not react positively to claims like "our *Salmonella* count is

50 percent less than the leading brand." Firms may decide that though such advertising could differentiate them from poorer quality producers, any overt mention of safety risks could work to their disadvantage and to the disadvantage of the industry as a whole.

In addition, firms may want to avoid specific safety guarantees that could expose them to additional liability. Food safety is not easy to guarantee, particularly in the case of pathogen contamination. Even the most careful producer could experience a safety problem. Deviations from planned procedures, uncertainty regarding input contamination, equipment malfunction, personnel factors, pathogen grow-back, and sampling variability all contribute to the potential for safety breaches (Bisaillon et al., 1997; Bogetoft and Olesen, 2003; Roberts et al., 2001; Sofos et al., 1999).

Firms may also shy away from advertising or establishing other appropriability mechanisms if there is value in some level of anonymity. If appropriability systems increase the probability that a firm will be identified in the case of food safety problems and be exposed to liability, then the firm may have an incentive to forgo appropriating the benefits of a good safety record and to remain anonymous. The benefits of branding, third-party verification, specific quality claims, and other appropriability mechanisms may not outweigh the costs of being more easily linked to a food product in the case of safety problems.

Not only does the ability to remain anonymous dampen the incentive to establish appropriability (and to innovate), it also reduces the threat of punishment in the case of safety lapses, thus further dampening the incentive to innovate. The complex diets of most consumers, the long incubation periods of many foodborne pathogens, incomplete lab analyses of intestinal illnesses, and the fact that the food evidence is usually destroyed (eaten) all reduce the chances of identifying producers of unsafe foods (Buzby et al., 2001). Firms are often able to avoid the negative consequences of safety lapses, including fines, recalls, bad publicity, or litigation because consumers and government regulators are unable to identify the source of foodborne illness. The incentive to invest in food safety is reduced because the probability of detection and punishment in the case of safety failures is less than one.

All in all, the problem of asymmetric information in the market for food safety has the potential to reduce incentives to invest in food safety innovation. The difficulty of advertising and differentiating food on the basis of safety attributes reduces the ability of firms to appropriate the benefits of safety innovation, thereby reducing producers' incentives to invest in safety innovation. Producers' incentives to invest to overcome appropriability constraints are in turn damped by the fact that anonymity is valuable in the case of food safety problems. As a result, the amount of food safety and food safety innovation supplied by the market is likely to be lower than the socially optimal amount.

The Nature of the Product May Dampen Demand for Food Safety

Consumers also play a role in slowing the development of markets for food safety and in dampening incentives to invest in food safety. Skeptical, discerning consumers are not the norm when it comes to food safety attributes. Most consumers are unaware of the specifics of food production—and many may prefer to stay that way. For example, Kuchler (2001) argues that consumers do not really want to know the content of most processed meat and, as a result, labels indicating that a product contains "meat" are preferable to more specific labels indicating what meat actually is, such as the official "Muscle tissue of cattle, sheep, swine, goats, or equines which is skeletal or found in the tongue, diaphragm, heart, or esophagus with or without accompanying or overlaying fat, bone, skin, sinew, nerve, or blood vessel which are not separated during dressing" (USDA, FSIS, no date).

Whether they do not want to know or just do not have the time to learn, consumers do not know very much about how food is produced or about food safety. In the United States, both marketplace behavior and survey results indicate that most consumers are not very knowledgeable about food content or production practices. Throughout the 1990s, surveys found that only 30 to 40 percent of consumers in the United States were aware of the use of biotechnology in food production and most were unaware of general food production techniques.

The low level of consumer knowledge about food safety makes it difficult to gauge the size and depth of the market for food safety. The low level of knowledge may also contribute to the susceptibility of this market to large perturbations after foodborne illness outbreaks: well-publicized outbreaks may be many consumers' sole source of safety information. In fact, dramatic and highly publicized outbreaks have often driven sharp increases in demand for

safety, at least in the short run. In Europe, a number of high-profile scares, including those involving Bovine Spongiform Encephalopathy (BSE or mad cow disease) and dioxin-contaminated feed have triggered increased demand for food safety. In the United States, the 1993 outbreak of *E. coli* O157:H7 in Jack-in-the-Box hamburgers led to a dramatic decrease in demand and the company lost around $160 million in the 18 months following the outbreak (Roberts et al., 1997).

If the size and intensity of consumer demand have the same impact on food safety innovation as they do on innovation in other industries, then the rather nebulous and episodic demand for food safety probably dampens incentives to invest in food safety innovation.

Asymmetric Information Helps Spur Imitation and Technological Spillover

Asymmetric information problems may ultimately amplify the benefits of food safety innovations by providing innovating firms with an incentive to share new technologies with their competitors. A food safety problem in one firm or one segment of an industry has the potential to discredit a whole industry because consumers cannot distinguish safe and unsafe product and producers. For example, the BSE outbreak in the United Kingdom dampened beef markets around the world, not just markets where producers used feed containing mammalian protein. As a result, safe producers have an incentive to try to raise the safety level of the whole industry. The desire of safe firms to protect themselves from negative publicity means that spillovers could be large in food safety. This observation may help explain why the American Meat Institute, the National Chicken Council, the National Cattlemen's Associations, and other industry groups support food safety research activities and information dissemination.

The same incentive does not exist in other markets. For example, faulty brakes on one brand of cars do not hurt business for other brands of cars. A car brand with an innovative new braking system has no incentive to share the discovery with its competitors in order to bolster the reputation of the industry. However, because of asymmetric information problems in markets for meat safety, massive recalls of hamburger, for example, shake consumer confidence in the whole industry. Hamburger-borne disease outbreaks hurt everyone in the industry, and innovation to reduce such outbreaks helps everyone in the industry—including the innovating firm. In the hamburger industry, and many other food industries, negative spillovers provide an added incentive to innovate and disseminate innovation.

Firms also have an incentive to share new technologies with their competitors and with government regulators to influence the standard of care in the industry. In some cases, standards of care that are difficult to meet can help establish a barrier that benefits the firms that first adopt such standards. First adopters gain larger market shares (and maybe market power) if the expense of new technologies forces some producers out of business. Even if all firms eventually adopt the technology, first adopters will benefit from limited competition during the period when their competitors are installing the new technologies. Such benefits may help explain why the large meat and poultry slaughter and processing plants generally have supported stricter food safety regulation.

Imitative spillovers of innovations are prevalent in the food processing industry. Levin et al. (1987), in their survey of American firms, report that many in the food processing industry found patents ineffective because they often did not withstand legal challenges. Eleven of 130 industries in the Levin et al. survey, all from the food processing and metalworking sectors, reported that no mechanism of appropriating the returns from product innovation was even moderately effective.

Part II. Empirical Investigation: A Closer Look at Food Safety Drivers in the Meat Industry

The theoretical literature suggests that failure in markets for food safety may dampen two of the primary drivers of innovation: appropriability and market demand. Because safety is a credence attribute, firms may have difficulty appropriating the benefits of food safety innovation—and given the graphic nature of many safety attributes, even firms with the safest records may have little incentive to disclose their records, if it means raising consumer concerns about food safety. In addition, firms may actually avoid establishing appropriability, if it also entails an increased likelihood of facing liability when food safety problems arise. On the demand side, consumers are largely unknowledgeable about food safety practices and tend not to demand product differentiation on the basis of food safety.

With little incentive for safety disclosure on the part of firms, and episodic demand from consumers, it is almost surprising that any firms invest in improved food safety and continue to innovate to improve food safety. Yet they do. How do they overcome the disincentives discussed above?

To investigate this question, we turn to evidence from the meat industry. The meat industry is an important industry in which to investigate these questions for three reasons. First, though our meat products are some of the safest in the world, food safety remains a critical issue within the industry. Meat and poultry are estimated to be responsible for more than 40 percent of human illnesses associated with four common pathogens (USDA, 1996, p. 733). The meat industry has also experienced a number of large, well-publicized recalls and has been at the heart of some of the Nation's most tragic foodborne illness outbreaks (see box "The 1993 Jack in the Box Restaurant *E. coli* O157:H7 Outbreak").

Second, controlling pathogen contamination in meat production, particularly ground meat production, is a challenging task. Pathogens can be introduced and or amplified at many stages along the production, processing, and retailing chain (Roberts, Ahl, and McDowell, 1995). Farm inputs may bring pathogens onto the farm, and production practices on the farm may increase pathogen numbers, as well as expose food animals to new pathogens. Transportation may cause stress in animals, increasing shedding and the spread of pathogens. Slaughtering procedures may spread pathogens among animals, carcasses, and cuts of meat. Processing and product fabrication may encourage the growth of existing pathogens and introduce new pathogens through worker handling, ingredients, poor temperature control, and the water used in processing. Hamburger production, in which scraps of meat are ground into a homogeneous product, introduces the potential for integrating pathogens throughout the product. The transportation of meat products to wholesale/retail operations may result in pathogen growth, cross-contamination of products, or introduction of new pathogens. How foods are stored and displayed affects pathogen growth through temperature control, possibilities for cross-contamination, and length of shelf-life. How food is handled in the kitchen affects the probability that pathogens multiply or cross-contaminate other products. Hamburgers that are not thoroughly cooked may harbor pathogens in the interior of the patty.

The challenge of controlling pathogens in meat production makes the industry particularly fertile ground for food safety innovation: the potential for killing or controlling pathogen growth exists at all or most points along the production chain. This potential, along with technological and methodological advances in pathogen control, contributes to making the meat industry particularly interesting for a study on food safety innovation. The development of new tests for microbial pathogens has created additional options for detecting unwanted pathogens associated with meat. Improved analytical tools for risk assessment, new processes and equipment to kill pathogens, as well as new procedures and management systems to control pathogens, have all led to reduced levels of pathogen contamination and greater efficiency in pathogen control at many different stages in the meat production chain.

The third reason the meat industry is an important industry in which to examine food safety innovations is its size and diversity. The Food Safety and Inspection Service of USDA (FSIS) and State inspection agencies monitor about 2,500 establishments that process meat or poultry products as their primary business activity.[2]

[2] Together, FSIS and State agencies monitor over 9,000 plants producing meat and poultry products. However, the vast majority of these plants have other businesses that are much larger than their meat and poultry operations. The Bureau of the Census identifies a little more than 3,000 manufacturing plants producing meat and poultry products. Of those plants, we estimate that only about 2,500 have meat or poultry manufacturing as their primary line of business.

The 1993 Jack in the Box Restaurant *E. coli* O157:H7 Outbreak

In 1993, a Seattle pediatrician noticed an unusual spike in the number of children with bloody diarrhea. He alerted Washington State health officials about a possible foodborne disease outbreak. Within a week of documenting the diarrheal disease outbreak, health department investigators identified *E. coli* O157:H7-contaminated hamburgers from Jack in the Box restaurants as the cause. In all, 73 Jack in the Box restaurants in the States of Washington, Idaho, California, and Nevada were involved in the outbreak and recall. Seven hundred people became ill and four children died. Epidemiologists at the Centers for Disease Control and Prevention concluded that the outbreak resulted from errors in meat processing and cooking (Bell et al., 1994).

Epidemiologists had been following *E. coli* O157:H7 since 1982, when the pathogen was first linked to human illness in a two-State outbreak associated with hamburgers from McDonald's (Bryan et al., 1994). They soon discovered that the *E. coli* pathogen had interacted with *Shigella*, a well-known, virulent pathogen, to develop the ability to produce the toxin causing the human illnesses. In 1985, epidemiologists documented *E. coli* O157:H7 as the leading cause of acute kidney failure in children, and in 1992 they concluded that it was the most common bacterial cause of bloody diarrhea.

The 1993 Jack in the Box *E. coli* O157:H7 outbreak marked an important turning point in epidemiologists' approach to *E. coli* O157:H7 and infectious disease in general (Editor, 1993). Before the outbreak and the full-blown emergence of *E. coli* O157:H7 as a foodborne pathogen, many epidemiologists had predicted that the discovery of sulfa and penicillin would eliminate infectious diseases as a public health problem.

Repercussion from the outbreak—and the newly recognized public health threat—were widespread. Within the 18 months following the outbreak, the Jack in the Box company lost approximately $160 million in reduced sales and other costs (Roberts et al., 1997). These costs included those associated with the company's voluntary recall of all hamburger meat from their restaurants. They also included legal costs. A number of ill customers and parents of ill or dead children filed suits against Jack in the Box and its parent company, Foodmaker, Inc. All cases were settled out of court, with one family receiving over $15 million for a child who was brain damaged. Stockholders also filed suit against the company for court costs and lost sales due to adverse publicity.

The Federal Government responded to the Jack in the Box outbreak in several ways. President Clinton signaled the importance of the outbreak by sending the Secretary of Agriculture to testify before the Washington State legislature. The Food and Drug Administration (FDA) raised the recommended internal temperature for hamburgers cooked in restaurants to 155º F. USDA's Food Safety and Inspection Service (FSIS) initiated several programs after the outbreak: a safe-food-handling label with instructions for consumers on packages of raw meat and poultry sold in supermarkets, an information campaign alerting school children to eat hamburgers cooked well-done, and tests for *E. coli* O157:H7 in raw ground beef prepared in federally inspected establishments and in retail stores. FSIS also changed the status of *E. coli* O157:H7, declaring it an adulterant in raw ground beef. As a result of the outbreak, the Centers for Disease Control and Prevention (CDC) obtained additional funding for its FoodNet program to identify foodborne pathogens causing intestinal illness. The outbreak also accelerated efforts to modernize Federal requirements for food safety using the Pathogen Reduction and Hazard Analysis and Critical Control Point (PR/HACCP) system (see box "Pathogen Reduction and Hazard Analysis and Critical Control Point Program, p. 14").

The outbreak united parents of those children who had become ill in the outbreak to create the first consumer activist group devoted to food safety, Safe Tables Our Priority (STOP). STOP has been a very visible lobbying group for safer food at congressional and USDA hearings, at professional conferences, and in the media (for example, see Eskin et al., 2003).

The 1993 outbreak also spurred the beef industry to fund research. The Washington Beef Commission supported research on techniques for detecting *E. coli* O157:H7 in hamburger (Bell et al. 1994) and the National Cattlemen's Beef Association (NCBA) set up a task force to fund research on how to reduce *E. coli* O157:H7 in cattle and slaughterhouses, as well as how to establish testing and sampling programs to detect the pathogen. The interventions developed by the NCBA have a high rate of adoption by the industry (Smith, 2003). The NCBA spends an average of $2.5 million on food safety research and technology each year (Voldseth, 2002). In early 2003, NCBA helped form a new committee, the Beef Industry Food Safety Council (BIFSCo), with representatives from all segments of the beef industry. BIFSCo's mission is to develop industry-wide, science-based strategies to solve the problem of *E. coli* O157:H7 and other foodborne pathogens in beef (Beef Food Industry Safety Council, 2003).

These establishments can be grouped into five categories: producers of cooked or otherwise further processed products with no slaughter operations; raw meat processors with no slaughter operations; and cattle, hog, and poultry slaughter plants. Some slaughter plants engage in a wide range of processing, and some cattle slaughter plants slaughter animals other than cattle, including hogs, sheep, and goats.

The main products of cooked meat processors include roast beef and other cooked meats, luncheon meats and frankfurters, bacon and other smoked products, pepperoni and other fermented products, and raw meat products. Raw meat processors with no slaughter operations produce mainly ground beef and pork, fabricated cuts, and other raw products. Carcasses and hamburger and other boneless beef are the chief products of cattle slaughter plants while carcasses and cooked and other further processed products are the main outputs of hog slaughter plants. Poultry plants, in contrast to hog and cattle slaughter, sell mainly cut-up products (about half of their output) and products processed beyond cut-up (about a quarter of their output).

In 1997, the meat and poultry industry supplied about $110 billion of output. Cattle and hog slaughtering was by far the largest sector, accounting for about half of industry output. Poultry slaughter and processing amounted to about $31 billion in sales, while cooked and raw meat processors without slaughter operations accounted for the final quarter of industry output. Cattle and hog slaughter plants were also more numerous than poultry slaughter plants, with 1,400 plants and over 140,000 employees. Poultry slaughtering had about one-third the number of plants, but, due to the much larger size of its plants, employed about 225,000 workers in 1997. There were also a large number (about 1,300) of raw- and cooked-meat processors but they employed only about 90,000 workers (Bureau of the Census, 1999 a, b, and c).

The cattle slaughter industry, the focus of the case studies, had an output of about $28 billion in 1997, the vast majority of which was supplied by the 300 federally inspected plants (USDA, FSIS, 1999). The industry has become increasingly concentrated in the last three decades, with its four-firm concentration ratio (the share of the industry's output held by the four largest producers in the industry) exhibiting a dramatic increase from 1963 to 1992 (table A-2). The growth of large cattle slaughter plants during this period is also striking. Table A-3 shows that the percent of animals slaughtered in large plants grew from 12 percent in 1977 to 65 percent in 1997 (MacDonald et al., 2000). Eighty percent of steers were slaughtered in large plants in 1997. Table A-4 shows that over the 1977-92 time period, large plants' share of industry value of shipments grew from 31 percent to 72 percent (MacDonald et al., 2000).

Large cattle slaughter plants differ from small plants in more than just the volume of production. They also vary with respect to the diversity of inputs and outputs, with smaller plants processing a more diverse set of animals and products than large plants. A recent survey of cattle slaughter plants found that smaller plants slaughtered hogs and other animals such as sheep and goats while larger plants slaughtered only cattle

Table A-2—Four-firm concentration ratios, value of shipments basis

	Slaughter industry			
Year	Cattle	Hogs	Chickens	Turkeys
1963	26	33	14	23
1967	26	30	23	28
1972	30	32	18	41
1977	25	31	22	41
1982	44	31	32	40
1987	58	30	42	38
1992	71	43	41	45

Source: MacDonald et al. (2000).

Table A-3—Percent of animals slaughtered in large plants

	Slaughter classes (size cutoff[1])					
Year	All cattle (500,000)[1]	Steers (500,000)[1]	Heifers (1 million)[1]	Cows/bulls (150,000)[1]	Hogs (1 million)[1]	Sheep/lambs (300,000)[1]
1977	12	16	nr	10	38	42
1982	28	36	nr	15	59	73
1987	51	63	31	20	72	84
1992	61	76	34	38	86	74
1997	65	80	60	62	87	75

[1]The size cutoff, in parentheses, refers to the minimum number of animals slaughtered annually in the large plant category.

Source: MacDonald et al. (2000).

Table A-4—Large plants' share of industry value of shipments[1]

Year	Slaughter industry			
	Cattle	Hogs	Chickens	Turkeys
1963	31	66	d[2]	d[2]
1967	29	63	29	16
1972	32	62	34	15
1977	37	67	45	29
1982	51	67	65	35
1987	58	72	76	64
1992	72	86	88	83

[1]Large plants are defined as those with more than 400 employees.
[2]Data cannot be disclosed, in order to retain respondent confidentiality.

Source: MacDonald et al. (2000).

(table A-5). Smaller plants also processed more meat into further processed products than did larger plants. Larger plants preferred to sell trim products to other processors for further processing (table A-6).

To investigate drivers of safety innovation in the meat industry, we first examine recently completed survey data of U.S. meat and poultry slaughter and processing plants. These data reveal the characteristics of firms that do and do not innovate or adopt new food safety technologies or methodologies. This information helps to reveal the incentives and constraints to food safety innovation and imitation in slaughter and processing plants. We then turn to two case studies of innovation in the beef industry. The first case study examines the development and marketing of a new food safety technology. The second examines the development of a microbial management system for hamburger patties.

Table A-5—Annual animal inputs per plant by plant size for cattle slaughter plants[1]

	Small plants[2]	Medium plants[2]	Large plants[2]
		Number of animals	
Cattle	161	3,448	191,781
Hogs	387	4,178	0
Other animals (mostly sheep and goats)	36	1,000	0
Number of plants	28	95	30

[1] Animal inputs based only on plants reporting one or more animal input.
[2] Plant size categories by percentile of output: plants in small category produced 19 percent of total industry output; plants in medium category 20-79 percent of total industry output; and plants in large category produced 80-100 percent of total industry output.

Source: Food Safety Inspection Service, Enhanced Facilities database and the Economic Research Service, Food Safety Technology and Practices and HACCP costs survey.

Table A-6—Product output share by plant size for cattle slaughter plants[1]

	Small plants[2]	Medium plants[2]	Large plants[2]
Raw meat products			
Carcasses	22.0	29.2	26.3
Ground beef	19.2	15.8	11.2
Trim or other boneless beef or pork	14.8	18.0	27.9
Sub-primal and fabricated cuts	10.2	14.9	15.2
Other raw-meat products	8.0	8.2	9.3
Cooked or otherwise further processed products	25.8	31.9	9.1
Mean pounds of output (1,000 pounds per year)	186	7,860	260,127
Number of plants	28	95	27

[1] Average output shares are based on all reporting plants.
[2] Plants in the small category are in the 0-19 percentile of plant sizes; plants in medium category are in the 20-79 percentile; and plants in large category are in the 80-99 percentile.

Source: Ollinger, Moore, and Chandran (forthcoming).

Food Safety Investments in the Meat and Poultry Industries
Survey Results

Michael Ollinger and Danna Moore

An empirical investigation into the level and type of food safety investments made by meat and poultry slaughter and processing plants reveals much about the diffusion of food safety innovation in the meat and poultry slaughter and processing industries.[1] The survey shows that larger plant size and stronger appropriation mechanisms, particularly those associated with buyer safety specifications, result in a higher number of safety investments. In this section, we examine the findings from this survey and their implications for the dissemination of food safety innovations.

ERS Survey Reveals Variation in Food Safety Investment

USDA's Economic Research Service (ERS) recently completed a survey on food safety technologies and practices in the 1,725 largest meat and poultry slaughter and processing plants inspected by USDA's Food Safety and Inspection Service (Ollinger and Moore, forthcoming). The overall survey response rate was about 57 percent or 987 plants.[2] Slaughter-plant respondents accounted for 44 percent of all slaughtered cattle, 77 percent of all slaughtered hogs, 48 percent of all slaughtered chickens, and 55 percent of all slaughtered turkeys. Respondents among processors with no slaughter operations accounted for 55 percent of all processed meat and poultry products.

Data from the survey include information on plant size, products, markets, type of food safety investments, and Pathogen Reduction Hazard Analysis and Critical Control Point (PR/HACCP) rule compliance costs (see box "Pathogen Reduction and Hazard Analysis and Critical Control Point Program (PR/HACCP"). The survey contains approximately 40 questions dealing with food safety technologies and practices covering five broad safety activities: equipment, testing, careful dehiding (for cattle slaughter plants), sanitation, and plant operations (see box "Sample questions from the ERS survey ...", p. 15).

To compare food safety investments across firms, Ollinger and Moore (forthcoming) created an index for each of the five types of food safety activities identified in the food safety questionnaire. In creating the index, they adhered to a number of principles. First, they maintained that the rating system should be monotonic because more intensive operations should yield greater food safety protection than less intensive ones. By monotonic, they meant that plants with more intensive cleaning or with a certain piece of food safety equipment have higher scores than plants with less intensive cleaning or without such equipment. Second, they compared plant food safety systems on the basis of similar technology types since some types of technology, such as plant operations, may have different purposes and long- and short-term effects than other technologies, such as equipment. Thus, they assert that the relevant comparisons are the equipment rating of one plant versus that of another and sanitation of one plant versus that of another, etc. Altogether, they considered five technology types: equipment, testing, dehiding, sanitation, and plant operations. Third, since food safety requires a systematic approach, it is necessary to consider a variety of technology components within each technology type. For example, they considered steam vacuum units, Frigoscandia carcass pasteurizers, and other food safety equipment as equipment technologies. Additionally, they categorized hand and knife cleaning and other cleaning practices as sanitation technologies. See Ollinger, Moore, and Chandran (forthcoming) for additional details on technology components in each technology type.

For the safety index, Ollinger and Moore assigned a value of 1 to safety activities that generated the most food safety process control, and a value of 0 to those that generated the least. They assigned values between

[1] It is worth noting that the Food Safety and Inspection Service examines all meat and poultry plants engaged in interstate commerce for the adequacy of plant food safety controls. Plants deemed to be using unsanitary production practices are prohibited from selling products. Thus, all plants must achieve a high level of food safety quality.

[2] This response rate is substantially higher than that achieved in recent surveys by Hooker et al. (1999) who had a less than 50 percent response rate (41 out of 98 questionnaires) and Boland et al. (2001) who reported a 36-percent response rate (18 of 50 questionnaires).

Pathogen Reduction and Hazard Analysis and Critical Control Point Program (PR/HACCP)

The Pathogen Reduction and Hazard Analysis and Critical Control Point (PR/HACCP) program is administered by the Food Safety and Inspection Service (FSIS) of the U.S. Department of Agriculture, which is responsible for ensuring the safety of raw meat and poultry products. The program covers all Federal- and State-inspected meat and poultry slaughter and processing plants in the United States, as well as foreign plants that export meat or poultry products to the United States. The PR/HACCP final rule was posted in July 1996 (USDA, FSIS, 1996).

The four major components of the HACCP program are:

(1) Implementation of a written HACCP plan by every slaughter and processing plant;

(2) Adoption of Sanitation Standard Operating Procedures (SSOPs) by every slaughter and processing plant;

(3) *Salmonella* performance standards for slaughter and ground product plants; and

(4) Generic *E. coli* performance standards for slaughter plants.

The HACCP plan component of the HACCP program requires each slaughter and processing plant to analyze its own production processes and identify Critical Control Points (CCPs) where potential hazards affect food safety. Plants must then develop a written HACCP plan and maintain records to ensure that the production process remains within predetermined critical limits at each control point, based on parameters such as temperature or chlorine level. The largest plants, 500 or more employees, had to implement HACCP plans by January 1998. Smaller plants had until 1999 or 2000 to implement plans, depending on plant size.

The SSOP component of the HACCP program requires all slaughter and processing plants to prepare a written plan describing the daily procedures used to ensure sanitation during production. Plants must also detect, document, and correct any sanitation deficiencies. All plants were required to have SSOPs in place by January 1997.

The *Salmonella* and generic *E. coli* performance standards included in the HACCP program allow FSIS to monitor whether plants are adequately preventing pathogen contamination of raw meat and poultry products. *Salmonella* was selected for monitoring because it is one of the most common foodborne pathogens and is present in a wide variety of raw food products. Generic *E. coli* was selected because it is naturally found in animal feces and serves as an indicator of fecal contamination during production. FSIS sets maximum acceptable limits for both pathogens, based on baseline surveys of each class of animal and food product. All slaughter plants were required to begin testing for generic *E. coli* in January 1997.

0 and 1 to activities that indicated an intermediate level of food safety process control. For example, for the equipment usage question listed above, Ollinger and Moore assigned a value of 1 to plants that responded yes, that they used a steam carcass pasteurizer. For the sanitation question, plants earned 0 points for this activity if they sanitized their drains once per week, 0.33 point if they sanitized more than once per week but less than once per day, 0.66 point if they sanitized more than once per day but less than once per shift, and 1 point if they sanitized more than once per shift. Ollinger and Moore then summed the points within each activity category and divided by the maximum points possible in that category, i.e., the number of questions in that category. This number is the firm's rating for the specific activity category. Each firm was given a rating for each of the five activity categories.

Ollinger and Moore also created an overall safety rating by summing the total number of points from all questions and then dividing that number by the total number of questions. For example, if the entire survey consisted of only the five questions listed above, then a plant would receive a total of 3.66 points if it responded that it 1) has a Frigoscandia pasteurizer, 2) tests for *E. coli* 0157:H7, 3) sanitizes drains once per day, 4) does not offer incentives, and 5) does have a vacuum at the dehiding area. Since there are five questions in this hypothetical survey, the plant's overall safety rating would therefore be 0.732 (3.66/5).

Other rating schemes are possible. For example, there is no reason why each technology component should have an identical maximum score of one. Ollinger and Moore used an equal rating of one as the maximum value because, for most technology components, they had no

Sample questions from the ERS survey of food safety in meat and poultry slaughter and processing plants

The ERS survey of meat and poultry slaughter and processing plants contained approximately 40 questions dealing with food safety technologies and practices covering five broad safety activities: equipment, testing, careful dehiding (for cattle slaughter plants), sanitation, and plant operations. Complete questionnaires and response rates are on the ERS website *http://www.ers.usda.gov/Data/HACCPSurvey/*. A sample question for each safety activity follows.

Equipment usage:
Does this plant use a steam carcass pasteurizer, such as a Frigoscandia, to pasteurize carcasses?

Testing:
Over and above that which is required under PR/ HACCP Rule, does this plant test raw or cooked product with tests for *E. coli* 0157:H7 or *Listeria*?

Sanitation:
Which one statement best describes how often drains are sanitized?

1. Drains sanitized once per week.
2. Drains sanitized one or more times per week, but less than once per day.
3. Drains sanitized one or more times per day, but less than once per shift.
4. Drains sanitized more than once per shift.
5. Don't know.

Plant operations:
Does this plant offer worker incentives, such as gifts or compensation, for detecting and reporting possible sources of contamination or unsanitary conditions?

Careful Dehiding:
Does this plant use an air exhaust system vacuum or other system that creates a negative air pressure around the carcass in the dehiding area?

information suggesting that one technology was superior to another for all the equipment and practices they considered. Additionally, instead of a proportional ranking scheme, they could have used a logarithmic or square root scale and still achieved monotonicity. Future research will refine the rating scale.

Plant Size Influences Amount and Type of Food Safety Activity

The ERS survey indicates that plant size influences both the amount and type of food safety investment, as reflected in the plant's food safety ratings. Table B-1 shows how food safety activity varied by cattle slaughter plant size. The table focuses on cattle slaughter plants, and not the other types of plants in the survey, because there is a larger variation in plant size and food safety activity in this industry. This variation provides a basis for comparing safety activity across plant size. Results are similar for other industries unless noted.

The largest cattle slaughter plants had the highest overall food safety rating of the size groups as well as consistently higher ratings across the five food safety activities than smaller plants. Differences were particularly dramatic in the more capital-intensive food safety technologies—equipment, testing, and careful dehiding—in which large-plant food safety technology index values were nearly twice as high as small plant levels. By contrast, ratings for large plants in the more labor-intensive technologies—sanitation and operations—were only about 20 percent higher.

Much of the difference in food safety rating between large and small plants is likely due to economies of scale, particularly with respect to capital-intensive activities. Large plants have much greater volume of production than small plants, lowering their average capital cost per unit of production. Some equipment that raises carcass temperature to 160 degrees or higher can cost more than $1 million, often requires technical skills that are available only in large plants with a variety of automated processes, and can be housed only in very large plants. Ignoring technical skills and plant size and assuming a 5-year life of the equipment, such equipment would cost a large plant (processing 100 animals per hour and running two 8-hour shifts per day, 240 days per year) about

Table B-1—Large cattle-slaughter plants have higher food safety ratings than small plants, mainly because of more capital-intensive activities

	Plant size category[1]			
	Small	Medium	Large	All plants
		Safety rating[2]		
Overall rating	0.43	0.49	0.62	0.50
Equipment	0.32	0.37	0.55	0.39
Testing	0.34	0.48	0.75	0.51
Careful dehiding	0.26	0.36	0.45	0.36
Sanitation	0.51	0.56	0.59	0.56
Operations	0.59	0.60	0.70	0.62
Number of plants	48	158	49	255

[1] Plants in the small category are in the 0-19 percentile of plant sizes; plants in medium category are in the 20-79 percentile; and plants in large category are in the 80-99 percentile.
[2] Higher numbers are better. See text for explanation.

$0.52 per head of cattle in equipment costs alone. By contrast, it would cost a smaller plant, processing only two animals per hour, but otherwise operating under the same conditions, about $26 per head. Note, this estimate varies with the assumed life of the equipment and considers only capital costs. We have ignored maintenance costs, housing costs, and the possibility of smaller scale equipment. Maintenance costs would rise over time and be more costly for smaller plants because they have fewer available skills to maintain complex equipment than do large plants. Housing costs would also be higher for smaller plants because their much smaller processing operations often run in batches rather than the continuous mode for which such equipment is designed. Of course, lower cost and lower volume equipment could also be designed, but there apparently has been little demand for it since, to our knowledge, no such units are for sale, much less installed.

Labor-intensive activities do not require such large fixed costs, and hence the smaller spread between large and small plants for more labor-dependent safety activities. Suppose workers in both the small and large plant are required to clean their knives after they finish cutting a carcass and that 10 cuts are made in each carcass. Additionally, assume workers are paid $12 per hour and that each cut takes 1 minute. For both the small and large plants, the cost per head of cattle for cleaning the knives is $2.40, so the practice favors neither large nor small plants.

Though economies of scale probably explain a large part of the safety variation between large and small plants, they do not explain it all—particularly for less capital—intensive activities. Another possible contributing factor is linked to the observation that large plants tend to supply large, homogeneous markets with relatively elastic demand, while smaller plants tend to serve smaller markets with less elastic demand. In homogeneous markets, in which a number of firms produce and market similar or identical products, any slip in safety could result in a sharp drop in demand for the offending plant. Buyers could replace sub-standard products with product from competing plants. The product from smaller plants may be less fungible. Small plants tend to compete with the larger firms by providing differentiated products for niche markets, such as fresher or more specialized cuts. Their products are less easily replaced, and their buyers may be more willing to overlook food safety slips or to work with a plant to overcome safety problems. To protect their markets, large plants may therefore have more incentive than small plants to adopt food safety innovations.

In fact, slaughter plants that can consistently supply high levels of product safety, as required by a number of major food retailers, gain access to almost guaranteed markets for large volumes of product. Plants that can produce the desired level of safety at the lowest cost will reap the largest benefits, and those that can supply the desired amount of safety only at higher prices will face greatly reduced demand. Plants in markets with relatively elastic demand have incentive to adopt the most efficient approaches for achieving product safety. Large slaughter plants operating in elastic markets may therefore have more incentive to adopt the safety activities included in the ERS survey than plants operating in less elastic markets.

An additional incentive for large firms to innovate is tied to the observation that large and small firms tend to face different size markets. As discussed in the

theory section, even if innovative activity is scale neutral, the benefits of innovation are proportional to the size of the market. Holding constant the cost of innovation, more innovative activity would be expected in the larger market or in the market expected to grow more rapidly. This fact may have spurred large plants, which tend to operate in large markets, to innovate more than small plants, which tend to operate in smaller markets.

Another reason large firms may invest more in food safety than small firms is that food safety lapses have the potential to be very costly for large firms because they may involve large amounts of product. Large amounts of contaminated product increase both the probability of detection and the cost of recall. Larger plants have more potential for larger amounts of contamination than smaller plants because mistakes that expose product to contamination spread more quickly the faster the line speed and the greater the volume of production.

For example, suppose both large and small plants clean their dehiding areas once per hour. Assume also that workers in each plant rupture the intestines of an animal at the beginning of the hour. A plant running 100 head of cattle per hour will contaminate the carcasses of those 100 animals before cleaning the contaminants while a plant running two head of cattle per hour will contaminate the carcasses of only those two animals. The problems do not stop there, however. If each one of the contaminated cattle has trim that goes into separate bins, then those 100 cattle contaminate 100 bins. Further, if each one of those 100 bins is then mixed with 20 other bins to achieve a desired ground meat quality (a common practice), then the 100 head of cattle would have contaminated 2,000 bins of meat while the small plant would have contaminated only 40 bins. The greater volume of contaminated product produced by the larger plant increases the likelihood of a detectable foodborne illness outbreak and the likelihood that the plant will be identified and held liable. As a result, larger plants may have greater incentive to invest in food safety activities.

Appropriability Influences Food Safety Investment

The survey data also reveal that meat and poultry processors that had mechanisms for appropriating the benefits of food safety innovation used more types of safety investment and had better safety ratings. Among the processors in the survey, the appropriability mechanism most strongly linked with more safety investment was *buyer specification*. When buyers specify higher safety or quality requirements from their suppliers—and pay a premium or guarantee sales—they provide processors with a way to benefit from safety investments. Processors who invest to supply safer products appropriate the benefits of their investments through the price premiums or guaranteed sales.

In the meat industry, a growing number of large buyers, such as Burger King, Jack in the Box, McDonald's, and Wendy's, require their suppliers to meet safety and quality standards. These buyers spend millions of dollars advertising their brand names and building reputations for safety and quality. To protect their brand-name investments, these buyers set input safety and quality standards and require their suppliers to meet them. These standards cover a wide variety of safety activities ranging from pathogen tolerance levels to accounting procedures. Buyers enforce the standards through testing and process audits.

Table B-2 shows a marked difference between cattle slaughter plants facing buyer specifications and others. Again, cattle slaughter plants are an interesting case because of the large variation in safety activity in these plants. Results are similar for the other industries unless noted. The largest differences appear for safety activities requiring the most sophisticated technologies, equipment, testing, and careful dehiding. However, even for the other two activities, sanitation and plant operations,

Table B-2—Food safety ratings for cattle slaughter plants with buyer specifications are considerably higher than for other plants

Process control method	Does customer impose standards[1]	
	No	Yes
Overall rating	0.43	0.63
Equipment	0.30	0.56
Testing	0.35	0.77
Careful dehiding	0.28	0.48
Sanitation	0.51	0.61
Operations	0.58	0.68
Number of plants[2]	128	98

[1] Question in survey asks, "Do some major customers of plant test product for pathogens or harmful bacteria or require sanitation and product handling practices that are more stringent than those demanded by FSIS?"
[2] 29 plants did not indicate whether customers impose standards.

there is a large difference. The pervasiveness of the difference in safety activities between firms with and without buyer specifications suggests that buyers establish standards along a wide spectrum of activities.

Export markets may also entail higher quality specifications. These markets can provide a lucrative outlet for meat suppliers if plants meet the importing country's food safety standards. Table B-3 provides ratings for food safety technology for cattle slaughter plants that serve export markets. The pattern of the ratings, as in table B-2, shows a distinct difference in plant food safety technology between cattle slaughter plants that export and those that do not. The magnitude of the differences and their pervasiveness across all five categories is striking. The greatest differences are for equipment, testing, and careful dehiding technologies. The differences are smaller for sanitation and plant operations, yet a substantial gap remains.

Branding should have the same effect on food safety activity as buyer specifications and export markets. Meat processors, such as Oscar Meyer, that sell branded products through retail outlets are held directly responsible for food safety quality by consumers. These processors, and others who are easily linked to their product, should have stronger incentives to invest in safety than processors that sell unbranded products to large grocery stores and restaurant chains or to a host of smaller buyers that serve as intermediaries between the slaughter plants and the consumer. Having no brand name means that consumers can make no connection between the producer and food safety.

Table B-3—Food safety ratings for cattle slaughter plants that serve export markets are higher than for non-exporters

Process control method	Does plant export products[1]	
	No	Yes
Overall rating	0.43	0.64
Equipment	0.28	0.62
Testing	0.36	0.79
Careful dehiding	0.28	0.51
Sanitation	0.54	0.60
Operations	0.59	0.68
Number of plants[2]	169	84

[1] Question on survey asks, "Does this plant export products outside the United States?"
[2] 2 plants did not indicate whether they export.

Surprisingly, selling branded product appeared to have less impact on safety investment than buyer specification. Table B-4 shows plant food safety technology differences between hog slaughter plants selling products under their own brand and other plants. The survey data show only a modest difference in safety activity between the two types of plants. Dehiding and sanitation are higher for plants not selling products under their own brand and the other categories are higher for plants that do sell products under their own brand.

One explanation for this result could be that surveyed firms may have misunderstood the branding question. This question asked whether the plant produced products under its own name. The intent of the question was to see if the plant sold branded products to consumers. However, the overwhelming majority of all plants responded affirmatively. Yet, most plants, particularly cattle slaughter plants, do not sell directly to consumers. Thus, it appears that respondents understood the question to be whether the product was shipped to a customer with the producer's name on the box, regardless of whether it was going to final consumers or vendors to be repackaged or further processed.

The confusion over the branding question resulted in a watered-down definition of branded for the analysis: "branded" denotes plants that either sell a branded product to consumers or put their name on a box of products that are shipped elsewhere for processing. The very modest differential illustrated in table B-4 shows that selling under a brand, as defined here, failed to generate much of a difference in the use of food safety technologies.

Table B-4—Food safety rating of hog slaughter plants that sell products under their own brand are about the same as other plants

Process control method	Is product sold under plant's own brand?[1]	
	No	Yes
Overall rating	0.44	0.50
Equipment	0.34	0.39
Testing	0.40	0.50
Careful dehiding	0.32	0.30
Sanitation	0.59	0.55
Operations	0.52	0.61
Number of plants[2]	25	180

[1] Question on survey asks, "Does this plant produce products under its own brand?"
[2] 5 plants did not indicate whether they sell products under their own brand.

The effects of the appropriability mechanisms were similar for cattle, poultry, and pork slaughter plants; however, the effect of one of the appropriability mechanisms was slightly different for processors. Table B-5 summarizes responses for cooked-meat processors without slaughter operations (results were similar for raw-meat processors). The table shows that plants with buyer specifications had distinctly higher equipment and testing activity ratings than plants without, but nearly identical ratings for sanitation and plant activities.

Why did buyer specifications not have the same positive effect on sanitation and plant activities? One possible explanation for the higher testing rating for plants with customer requirements is that the buyer may demand proof that the products it buys are safe. The almost equal scores for plants with or without customer requirements for sanitation and plant operations could be due to the nature of the meat processing industry compared to animal slaughtering. Processing plants tend to sell unique products that can be readily linked to the producer. This linkage forces producers to adhere to as strict a standard as a buyer would require explicitly in a contract since buyers, regardless of whether they have specifications, can readily punish a plant that practices poor food safety quality control. Slaughter plants, on the other hand, produce generic products that cannot be distinguished from products from other plants with which they may be commingled. Thus, without buyer specifications, slaughter plants may feel they can adhere to weaker sanitation and food safety operating activities.

Appropriability Mechanisms Encouraged Early Adoption of HACCP-Like Programs

The influence of appropriability is also evident in rates of adoption of HACCP-like programs prior to implementation of PR/HACCP (see box "Pathogen Reduction and Hazard Analysis and Critical Control Point Program (PR/HACCP"). HACCP programs are designed to enhance safety and quality control management in food processing operations. Producers who are able to reap the benefits of improved quality or safety should have stronger incentives to adopt these programs than producers who cannot.

The ERS survey queried plants about their use before 1996 of the three core elements of HACCP programs: schematics, review of operations, and product or environmental testing. If plants had the three core elements, they were considered to have a HACCP-like program. Table B-6 shows the relationship between plants with HACCP-like programs and the three appropriability mechanisms (branding, buyer specifications, and export markets). The data indicate that plants subject to buyer specifications were much more likely than other plants to have implemented a HACCP-like process control program before 1996.

ERS Survey Indicates that Buyer Specifications Are Key to Spurring Safety Innovation

The ERS survey shows that plant size and appropriability mechanisms seem to encourage the use of more

Table B-5—Food safety ratings for three appropriability mechanisms for cooked-meat processing plants without slaughter operations

Process control method	Market mechanisms					
	Product sold under own brand		Customer food safety requirements		Plant exports	
	No	Yes	No	Yes	No	Yes
Overall rating	0.55	0.57	0.51	0.64	0.53	0.63
Equipment	0.51	0.55	0.46	0.65	0.49	0.65
Testing	0.67	0.61	0.47	0.78	0.51	0.78
Careful dehiding	--	--	--	--	--	--
Sanitation	0.53	0.56	0.55	0.57	0.56	0.56
Operations	0.61	0.63	0.60	0.66	0.61	0.65
Number of plants	12	356	202	166	230	138

Table B-6—Percent of plants with HACCP-like programs prior to promulgation of the PR/HACCP rule by various appropriability mechanisms

Industry category	Appropriability mechanisms					
	Product sold under own brand		Customer food safety requirements		Plant exports	
	No	Yes	No	Yes	No	Yes
	Percent					
Cattle slaughter	16	24	23	49	14	38
Hog slaughter	20	18	15	24	15	22
Poultry slaughter	22	26	12	33	7	29
Processing—cooked-meat	22	25	17	36	18	36
Processing—raw meat	20	24	16	32	17	32
	Total number of plants by market mechanism					
Cattle slaughter	43	210	128	98	169	84
Hog slaughter	25	180	106	66	138	68
Poultry slaughter	11	99	65	28	16	93
Processing—cooked-meat	23	575	354	244	378	220
Processing—raw meat	109	690	439	360	458	341

sophisticated food safety technologies. Investments by large plants could be a response to economies of scale, greater product demand, and demand elasticity, but production technologies that make large plants more likely to be exposed for a food safety failure may also drive these investments. Appropriability mechanisms, such as product branding, buyer specifications, and export markets, enable suppliers to benefit from food safety and encourage the adoption of a spectrum of food safety practices and equipment.

A Case Study of the Equipment Market and the Invention of the Beef Carcass Steam Pasteurization System

Tanya Roberts and Elisabete Salay

In 1995, Frigoscandia Equipment began marketing a Beef Steam Pasteurization System (BSPS), a new technology designed to kill pathogens on the exterior of beef carcasses. This case study examines the economics of the BSPS invention, using published literature and open-ended interviews of the parties involved in the invention. The survey questions follow the object approach in the Oslo Manual (OECD, 1997). (For the survey questionnaires, see Salay, Caswell, and Roberts, 2003).

The BSPS case study highlights the importance of collaboration between technology developers and users in successful food safety innovation. It also highlights the difficulty of designing and successfully marketing technologies for the control of pathogen contamination in meat. Pathogen control requires systematic control throughout the farm-to-table supply chain (Ahl, Roberts, and McDowell, 1995; Gill, 1999). While some steps in pathogen control can substitute for each other, often the controls are complementary in producing an increased probability of safe food. Even the best technology, however, can be undermined by deficiencies in control along the supply chain. The interlinked nature of the steps required to control pathogens (and prevent them from growing) means that the technological success of one particular piece of equipment may be difficult to accurately determine and market.

The BSPS equipment is the invention of Frigoscandia Equipment, though its successful adaptation to beef slaughter plants was also due to contributions from Excel, the second largest U.S. beefpacking company (a division of Cargill, Inc.) and microbiological data from collaborators at Kansas State University (KSU). The BSPS technology uses steam to kill pathogens on beef carcasses. The BSPS unit itself is contained in a stainless steel cabinet that is installed at the end of the slaughter line, just before the sides of beef (hanging from an overhead rail) enter the chiller. Within the BSPS cabinet, three procedures are performed:

- Air is blown onto the carcass to remove the film of water covering the side of beef. This permits the steam to reach and kill the surface bacterial pathogens that otherwise would be protected by the water film.
- Steam is applied to the side of the beef at a sufficient temperature and over a sufficient time period to kill the target pathogens, generally *E. coli* O157:H7, *Salmonella*, and generic *E. coli*. The industry commonly uses steam heated to 190° Fahrenheit (F) applied for 10-15 seconds to the sides of beef (Brodziak, 2002), though individual plants may vary temperature and time depending on the stringency of their safety requirements.
- Icy water is briefly poured over the carcass to help bring back the "bloom" (red color) to the carcass and to stop the depth of "cooking."

The 1993 *E. coli* O157:H7 outbreak from hamburgers from Jack in the Box was the key initiating event in the development of the BSPS. First, it increased consumer awareness of and demand for food safety. After this outbreak, consumers, retailers, government officials, and processors themselves began to reassess the beef industry's food safety standards. The outbreak forced companies to respond to growing customer and consumer concerns, if for no other reason than to avoid legal liability suits. Second, the outbreak accelerated efforts to modernize Federal requirements for food safety using the Pathogen Reduction and Hazard Analysis and Critical Control Point (PR/HACCP) system (see box "Pathogen Reduction and Hazard Analysis and Critical Control Point Program). PR/HACCP provided food processors with more flexibility to innovate and adopt new safety technologies, such as the BSPS. In addition, the increased testing for pathogens included in PR/HACCP increased the probability that a foodborne disease outbreak would be discovered. The testing also potentially increased demand for food safety innovations such as the BSPS.

The initial assessment of the steam pasteurization technology for reducing pathogen contamination of beef was encouraging. Engineers at Frigoscandia Equipment considered the BSPS's technological

risks to be low (Wilson, 2001 and 2002). Steam, the technology behind the BSPS, was well-known for its ability to kill pathogens, and early experiments in the meat and poultry industry, though mixed, were promising enough to interest Frigoscandia in the technology (table C-1). Discussions with key people in the U.S. beef industry were positive, indicating potential market demand.

Discussions with consumer activists indicated that they considered steam a safe and acceptable method for killing pathogens. Surveys of consumers have indicated that steam pasteurization is more acceptable than some other new food safety technologies such as irradiation (Fingerhut et al., 2001). However, the extent of pathogen reduction is also important to consumer evaluations of competing food safety technologies (Lusk and Hudson, forthcoming).

Given the positive initial assessment of the innovation, Frigoscandia Equipment funded an exploration of the technical feasibility of the project. Frigoscandia Equipment realized a substantial investment would be required to develop the equipment. Building the machinery and testing the efficacy of the procedure would require time and financial commitment. Whether the BSPS innovation would prove financially profitable would depend on how well the BSPS equipment reduced pathogens, the cost of the equipment, and the cost and benefits of alternative pathogen-control systems available to beefpacking plants. Would the domestic beef industry consider the pathogen-reduction benefits worth the purchase price of the equipment? Would the innovation succeed in global markets?

History of BSPS Invention: Collaboration and Risk Sharing

The Swedish company, Frigoscandia Equipment, had extensive experience with inventing and marketing equipment in cold storage and food transportation (see Timeline in appendix A). By keeping foods at a very low temperature, food product quality was improved, shelf-life was extended, and food safety concerns were met. Frigoscandia's ultra-cold storage unit was being used for long-distance meat shipment by 1950. Its FLoFREEZE, a belt-type freezer tunnel, was named one of the 10 most important Swedish inventions ever by the Chalmers University of Technology in Gothenburg, Sweden. Steam pasteurization was a new food safety technology, a complementary addition to the company's product line, and a new marketing opportunity for Frigoscandia Equipment.

To reduce the technological risks and share the costs of creating the new BSPS technology, Frigoscandia Equipment contacted a business client, Excel, the second largest U.S. beefpacking company, which agreed to collaborate on the BSPS invention. Excel had the day-to-day knowledge of operating beefpacking plants where the equipment was to be used. Though the two companies jointly developed the technology and applied for the patent, Frigoscandia Equipment holds the rights to the patent on this technology because the global beef industry was the target sales market. If Excel co-held the rights to the patent, other beef companies may have been reluctant to purchase equipment, thinking they would be supporting a competitor.

As a first test of the technology's efficacy, Frigoscandia Equipment built a prototype BSPS unit.

Table C-1—History of U.S. steam pasteurization experiments on meat and poultry

Year of publication	Product	Results and effectiveness against bacteria	Researcher(s)
1972	Hog carcass	Steam effective, significant distortion of pigskin	Carpenter
1972	Meat surfaces	Steam applied in jacketed chamber; effective	Vogel and Silliker
1979	Frozen and thawed beef	Steam applied with a nozzle 10 cm away, not effective	Anderson, Marshall, Stringer, & Naumann
1985	Chicken carcass	Steam chamber with continuous flow, mixed results, cooked appearance of skin	Davidson, D'aoust, and Awell
1994	Beef frankfurters	Steam chamber to "surface pasteurize," effective against *Listeria*—4 log reduction	Cygnarowicz-Provost, Whiting, and Craig
1996	Sheep, beef	Steam treatment is effective if meat is first air-dried	Dorsa, Cutter, Siragusa, and Koohmaraie

Source: Data from Phebus et al., 1997.

Preliminary tests at Frigoscandia Equipment found that the BSPS prototype successfully killed the pathogen on small pieces of beef inoculated with *E. coli* O157:H7.

Next Frigoscandia Equipment and Excel decided to add academic microbiologists to the team as outside, nonbiased evaluators of the performance of the BSPS prototype. Dr. Randall Phebus at Kansas State University (KSU) was chosen to head the academic team. Frigoscandia Equipment shipped the prototype steam pasteurization system to KSU. Excel supplied six live market-weight steers. Both Frigoscandia Equipment and Excel contributed the kits and other materials required for pathogen tests of beef samples.

After slaughter at KSU, meat samples were inoculated with 5 logs of a pathogen (100,000 organisms/cm^2) and then treated in the BSPS prototype. All three pathogens tested, *E. coli* O157:H7, *Salmonella typhimurium*, and *Listeria monocytogenes*, were reduced by 4.65 to 5 logs at 15 seconds of steam treatment at 196-99° F (table C-2 and fig. C-1). Dr. Phebus and his team concluded that "Steam pasteurization is an effective method for reducing pathogenic bacterial populations on surfaces of freshly slaughtered beef…" (Phebus et al., 1997, p. 476).

The researchers found steam pasteurization provided numerically greater pathogen reductions than any other single treatment studied. One reason for this result is that steam vapor uniformly blankets irregularly shaped surfaces, in contrast to hot water coming from a nozzle aimed at carcasses. If there is any irregularity on the surface of the carcass, the back side of the irregularity will not receive the hot water treatment and pathogens lurking there will not be killed. Properly applied steam can reach these problem areas. BSPS is superior to chemical rinses for carcasses because it does not entail treatment of potentially toxic wastewater.

Table C-2—Reduction in pathogens as a function of steam application time in SPS

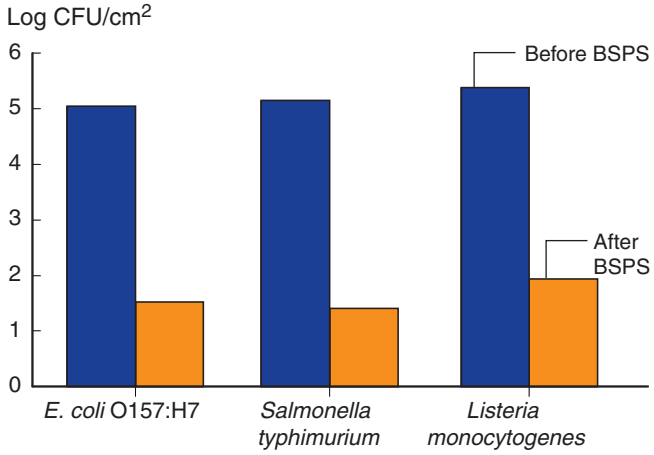
Seconds of steam used in SPS unit	Pathogen reductions in $\log_{10}$ CFU[1] (5 logs inoculated on carcass)		
	E. coli O157:H7	*Salmonella typhimurium*	*Listeria monocytogenes*
5 seconds	3.37	4.54	4.51
10 seconds	3.57	3.95	4.23
15 seconds	4.65	5.08	5.01

[1]CFU (colony forming units) is the unit microbiologists use to count pathogens.

Source: Data from Phebus et al., 1997.

Figure C-1

Steam pasteurization reduces mean pathogen population on beef carcasses



Source: Data from Phebus et al., 1997.

In 1995, after the success of the prototype at KSU, Frigoscandia Equipment engineers designed, built, and installed a commercial sized BSPS unit at an Excel plant in Sterling, Colorado. This stainless steel clamshell could hold four sides of beef at a time and moved along the slaughter line (fig. C-2). It also used monitoring techniques for temperature and lot identification that Frigoscandia Equipment had developed for its food chilling and freezing equipment. After solving a number of technical issues related to the pressure, temperature, and application of the steam in the moving clamshell BSPS, Wilson (Frigoscandia Equipment), Leising (Cargill/Excel), and other Frigoscandia Equipment inventors filed a patent application on Nov. 6, 1995 (U.S. Patent, 1998).

Testing the Commercial-Scale Prototype

To test the efficacy of the commercial scale-up of the BSPS prototype, Frigoscandia Equipment and Excel again invited the KSU team into the plant to conduct tests. The objective was to determine the effectiveness of the BSPS unit in reducing naturally occurring populations of indicator organisms on the surfaces of commercially slaughtered beef carcasses. Indicator microorganisms, not pathogens, were used because of the danger of introducing pathogens into a commercial facility. Over a 10-day testing period, 140 carcasses (70 cows and 70 fed cattle-steers/heifers) were tested with steam applied for 8 seconds at 195-201° F. Twenty carcasses (9 cows and 11 fed cattle) were tested with steam applied for 6 seconds. An additional 20 control carcasses (10 cows and 10 fed cattle) received no steam treatment.

Figure C-2

Beef sides exiting the SPS clamshell unit in Sterling, Colorado

Source: Tanya Roberts.

The KSU team found that steam treatment for 8 seconds was "very effective" in a commercial setting for reducing overall bacterial populations on beef carcass surfaces after 24 hours in the chiller (Nutsch et al., 1997, p. 491). In most cases, the enteric bacteria (some of which can be pathogens) were undetectable after pasteurization. Reductions in bacterial populations after a 6-second steam exposure time were very similar to those obtained with an 8-second exposure time. The equipment worked equally well with cows and steers/heifers, despite considerable variations in carcass size and shape.

For the third set of tests in 1996, Frigoscandia Equipment installed a moving clamshell BSPS in a larger commercial facility, Excel's plant in Fort Morgan, Colorado. Again, KSU conducted the testing (Nutsch et al., 1998). This time, the testing team made several changes to the testing protocol to more closely approximate an actual plant operation. Samples were randomly selected from 200 carcasses from two production shifts, rather than the known carcasses in the earlier test at the Sterling plant. Steam temperature was lowered to 180° F. for either 8 or 6.5 seconds. Instead of excising a small piece of meat to test, sponges were swabbed over the carcass and the liquid was tested to see if microbes were detected. Twenty carcasses were sampled at five carcass locations to see if the steam treatment effectiveness differed at the five sites. The KSU team concluded that the BSPS moving clamshell unit was effective in reducing natural bacterial populations on freshly slaughtered beef carcasses.

Frigoscandia Equipment submitted the KSU's laboratory results on pathogen reduction to USDA. USDA regulatory approval of the BSPS process was a necessary step for commercial acceptance. The KSU data was shared with regulators, industry members, and consumer groups. In December 1995, USDA certified that Frigoscandia Equipment's BSPS moving clamshell can significantly reduce pathogens (Cargill, 1995). The BSPS is equipped with recordkeeping capabilities: carcass identification, carcass surface temperature in the steam chamber, exposure time, and deviations are automatically logged into a computer for plant monitoring and regulatory review. The monitoring features make it feasible to use the BSPS as a critical control point under FSIS PR/HACCP regulations.

In 1996, another food processing equipment innovator, Chicago-based FMC FoodTech (FMC) purchased Frigoscandia Equipment (table C-3). FMC has 100 years of experience designing and selling food-processing equipment. FMC manufactures a wide variety of "in-container" sterilization systems, such as canning and retort systems. FMC was particularly interested in Frigoscandia Equipment for its GyroCompact freezer. The purchase of Frigoscandia Equipment's freezing and chilling equipment complemented FMC's sterilization equipment. In 2001, FMC's sales were $2 billion annually, of which $150 million were Frigoscandia Equipment sales (Brodziak, 2001 and 2002). Though the BSPS technology was not an important factor in the Frigoscandia Equipment purchase, it did add another piece of food safety equipment to the FMC product line.

Table C-3—General characteristics of Frigoscandia Equipment, 2001

Main activity	Designing, installing, and maintaining equipment and their monitoring mechanisms for the food processing industry.
Main products	Freezing and chilling equipment (half of world's frozen food is frozen in Frigoscandia Equipment units); steam pasteurization systems
Number of employees	Around 300 employees all over the world, primarily involved in sales, service, or engineering
Sales	Around $150 million annually, primarily in the chilling and freezing business
Exports	Half of sales are in USA, almost half in Europe. Sales growth areas are Latin America and East Asia
Parent Company: FMC FoodTech	Sales of about $2 billion annually. Headquarters in Chicago. Emphasis on solutions (R&D centers around world), food safety (innovative technologies), and service (technical support, HACCP certification)
Ownership	Privately owned corporation

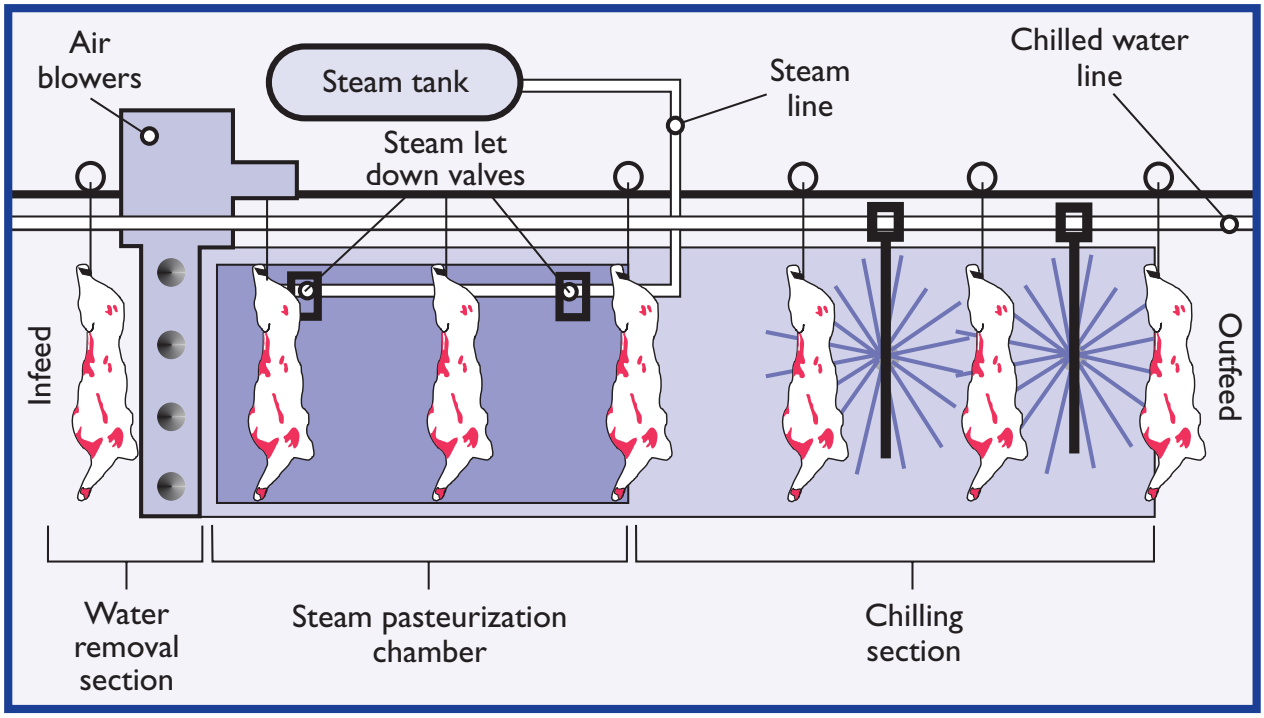
Development of the Static-Chamber BSPS

The KSU researchers had noted two problems with operating the moving clamshell BSPS unit at the Fort Morgan plant: 1) The steam pasteurization treatment was somewhat less effective at the neck area, perhaps because the steam inlet valves were only at the top of the moving BSPS clamshell. 2) A small percentage of carcasses were not steam treated during the two sampling days because of occasional cycle failure (Nutsch et al., 1998, p. 576). This last problem was caused by problems synchronizing the timing of the moving clamshell unit on fast line speeds—a problem that could not be readily fixed.

To address these problems, Frigoscandia Equipment decided to redesign the BSPS as a static chamber. The BSPS-Static Chamber unit (BSPS-SC) envelopes the sides of beef as they move along the overhead rail from the slaughter floor to the chiller. The static chamber performs the same three processes as the moving unit, except that with the static unit, the sides of beef travel through the enclosed chamber and sequentially receive 1) dewatering treatment, 2) steam treatment, 3) cold water shower (fig. C-3). With the BSPS-SC design, carcasses can travel through the chamber at

Figure C-3

Beef Steam Pasteurization System — Static Chamber Unit



Source: Frigoscandia Equipment

any chosen line speed. The doors and the overhead rail (on which the carcasses hang) have seals to maintain the positive air pressure in the chamber. In January 1998, Wilson (Frigoscandia Equipment), Leising (Excel), and other Frigoscandia Equipment inventors filed a patent application for a static chamber system that uses steam to destroy surface pathogens on meat (U.S. Patent, 1999).

The BSPS-SC has several advantages over the moving clamshell BSPS. The unit does not break down as often or require as much maintenance as the moving unit, reducing the warranty costs to Frigoscandia Equipment (Brodziak, 2002). This additional reliability is a benefit to customers as well: it facilitates use of the BSPS-SC system as a control measure in a plant's PR/HACCP system. Control measures must be reliable because the whole slaughter line must stop production if any of the critical control points in the PR/HACCP system are not functioning correctly. The BSPS-SC unit is reliable enough to use as a critical control measure.

Another benefit to beefpacking plants with the BSPS-SC was a reduction in operating costs because the steam part of the tunnel can be kept at a constant high temperature (Leising, 2002). In the moving unit, all three processes were conducted in the same chamber with the temperature fluctuating between the hot steam and the cold water wash, resulting in greater costs to bring the steam chamber up to its desired temperature.

The fourth and final invention was a change in the entrance and exit doors. Instead of two large doors, the doors were subdivided on each side into two-foot long segments, or eight doors on each end of the BSPS-SC. With this modification, the uneven-sized sides of beef enter the chamber with only the relevant doors being opened. As a result, the doors remain open less time with the static version. As a result, the vacuum seal is more easily maintained, the amount of steam needed was reduced, and the reliability of the equipment was further improved. In February 1999, Wilson (Frigoscandia Equipment), Leising (Excel), and other Frigoscandia Equipment inventors applied for a patent on the improved doors (U.S. Patent, 2000).

The Innovating Collaborators Appropriated a Variety of Benefits

The three collaborators for the BSPS-SC invention, Frigoscandia Equipment, Excel, and KSU, contributed in different ways to the development of the technology—and benefited differently. Frigoscandia Equipment, through Craig Wilson, initiated the innovation and contributed technical and administrative expertise. The costs to Frigoscandia Equipment of designing, building, and testing the BSPS prototype and the moving clamshell BSPS unit was $1.2 million spread over 3 years, mid-1994 to mid-1997 (Brodziak, 2001 and 2002). These costs were in-house labor and other variable costs, including contracting costs to the machine shop that produced the parts for the prototypes. The BSPS-SC modification took Frigoscandia Equipment 9 months and $100,000 to design and build. Frigoscandia Equipment's total investment was $1.3 million for the BSPS-SC innovation.

The two largest U.S. beefpacking companies, Excel and IBP, bought the equipment for all of their slaughterplants. Frigoscandia Equipment earned a small profit on the BSPS-SC equipment sales and the installation (Brodziak, 2001 and 2002). From 1996-2001, Frigoscandia Equipment sold 28 BSPS-SC units: 20 large and 8 smaller units. Smaller units were sold at approximately $250,000 each, depending on site-specific requirements.

Excel's contribution included paying for the beef used in the testing and all plant operation costs during the testing at the Excel's Sterling and Fort Morgan plants. Excel also invested a considerable amount of resources in adjustments and adaptations to the unit, including engineering maintenance. Excel recouped some of these expenses because it was not charged for the first moving clamshell BSPS unit and adjustments were made in the purchase price of other BSPS units to compensate for Excel's investment. Excel also benefited by taking advantage of its "first right of refusal" and being the first U.S. company to install the BSPS and BSPS-SC in all its packing plants (Cargill, 1997). This gave them a "first mover" advantage (Porter, 1998), namely, an enhanced reputation as a leader in food safety research and development that led to an increase in beef sales and contracts.

KSU was brought into the development team to conduct a wide variety of microbiologial tests on pathogens and indicator organisms using four different pieces of equipment, using different testing procedures, and using different combinations of steam temperature/time in the BSPS units. KSU contributed the time of two Ph.D. students and one professor to the project. Most of the testing equipment was purchased by Frigoscandia

Equipment and Excel, including about $40,000 to $50,000 worth of testing kits and other supplies.

All three collaborators boosted their food safety reputation through their involvement in the innovation. Frigoscandia Equipment strengthened its position in the food safety equipment industry. Excel became known as a food safety leader and gained market share in the beefpacking business (Leising, 2002). KSU became known for its expertise in microbial food safety (Leising, 2002). Two KSU students earned doctorates doing microbiological research on the BSPS technology. KSU now grants distance-learning degrees in Food Science and this program has been recognized for its quality by the Institute of Food Technologists (Phebus, 2002).

The BSPS-SC: Three Years to Technological Innovation and Market Acceptance

A review of the history of the BSPS-SC technology reveals that numerous factors led to the successful development and commercialization of the technology, including outbreaks and recalls, patent protection, technical expertise, industry contacts, and government regulations. The 1993 *E. coli* O157:H7 outbreak supplied the initial push for the innovation, driving Frigoscandia Equipment and Excel to pursue the technology (Cargill, 1997). In August 1997, another outbreak of *E. coli* O157:H7 in hamburger occurred, and the Hudson Foods Company recalled 25 million pounds of contaminated beef, closed the plant for cleaning, and finally sold the plant because sales contracts were canceled. This outbreak convinced IBP, the largest U.S. beefpacking company, to purchase the BSPS equipment for all its slaughterhouses.

Patents played a critical role in protecting the appropriability of the innovation. To keep competitors from copying the design of the BSPS-SC, four patents were issued to Frigoscandia Equipment. The first patent, on the prototype tested at KSU, was a concept patent and was filed early in the innovation process, 1994, to act as a place-holder for patent protection for more developed designs (Wilson and Leising, 1994). The BSPS-SC invention was protected by three more patents on the more complex and complete designs: moving clamshell unit, static chamber model, and static chamber with improved entrance and exit doors (U.S. Patent, 1998, 1999, 2000).

Technical expertise and personal contacts also played critical roles in the development of the innovation. Frigoscandia Equipment had a 50-year history in making chilling and freezing equipment for the beef industry. The BSPS-SC used pieces of the monitoring equipment from these chillers and freezers in building the monitoring equipment for the BSPS. Craig Wilson, director of special projects for the U.S. office of Frigoscandia Equipment, played the pivotal role in conceptualizing the invention, building the prototype, and designing the commercial scale-up. His professional and personal relationship with Dr. Leising helped forge the links in the agreement between Frigoscandia Equipment and Excel that led to the risk-sharing and knowledge-sharing and culminated in the successful BSPS innovation. KSU played a critical role in testing different BSPS models at a variety of time/temperature combinations. These data from an academic and independent source were critical for USDA approval and important for the beef industry to understand the relationships among pathogen reduction levels, steam temperature, and the duration of steam application.

U.S. government certification in 1995 that BSPS significantly reduces pathogens lessened the uncertainty facing industry purchasers regarding the efficacy of the technology and opened the door for use of the BSPS as a critical control point in PR/HACCP (Cargill, 1995; USDA, 2002). In addition, a number of government guidelines have explicitly endorsed the use of the technology. For example, in 2000, USDA's Agricultural Marketing Service specified that suppliers of beef trim and ground bison to Agency-administered purchasing programs, such as the school lunch program, must include an anti-microbial intervention as a critical control point (CCP) in the establishment's HACCP plan. "The CCP must be one of the following processes: steam pasteurization; an organic acid rinse; or 180º F hot water wash" (USDA, 2000).

The BSPS-SC innovation has enjoyed great market success in the United States. Excel, the second-largest U.S. beefpacking company, installed the technology in all seven of its beefpacking plants by June 1997. IBP, Inc., the largest beefpacking company, installed BSPS-SC equipment in all its beef slaughterhouses. (In 2001, IBP was purchased by Tyson Foods, Inc., and Tyson became the world's largest marketer of beef, pork, and chicken.) Costco requires all of its beef suppliers to use the Frigoscandia Equipment BSPS-SC in the slaughterhouse.

The positive market response is also reflected in a beef-product recall insurance policy available through the American Meat Institute, the meat industry's largest trade association. This recall insurance, which is sold by MacDougall Risk Management, offers the possibility of reduced rates and higher likelihood of coverage for plants that have installed the BSPS-SC (MacDougall, 2002). Other insurance programs covering product quality or safety are also sensitive to baseline plant risks and safety investments.

Despite the major marketing accomplishments in the United States, the BSPS-SC technology has yet to become standard practice in the beef industry outside of North America. One explanation for this result could lie in the difficulty of successfully integrating even the most reliable technology into a plant's pathogen control system (Bisaillon et al., 1997; Powell et al., 2001). Part of the skill in using any new pathogen-reduction technology is integrating it in the whole production system. For example, the effectiveness of the BSPS-SC, may be compromised if the carcasses are not chilled fast enough or are improperly spaced. Improper spacing of carcasses allows touching in the chiller and results in compromising both the temperature reduction and the rate of drying, creating conditions where pathogens can multiply (Phebus, 2002).

Pathogen control is difficult, and the food industry has a history of using multiple-hurdles to control foodborne pathogens, especially since pathogens can recover from a "kill-step" and grow back (unlike chemical or material contaminates) (Morris, 1999). Key factors in pathogen control in a beef slaughter plant include whether pathogens enter the plant on the hides and in the gastrointestinal tract of incoming cattle, whether hide removal or evisceration contaminate the carcass after killing, whether steam pasteurization and other kill steps are effectively administered, and proper spacing and temperature reduction in the chiller. The combination of all these events determines the probability of pathogen-free status for carcasses as they enter the fabrication room (Roberts, Malcolm, and Narrod, 1999; USDA, 2001; Sofos et al., 1999; Roberts, Narrod, Malcolm, and Modarres, 2001).

The benefits of any pathogen-reduction system are also difficult to measure on an ongoing basis, since constant monitoring and microbial testing are required. There is great variability in the pathogen load that the individual cattle bring into the plant, there is variability among workers and their practices, and different firms may use different steam times and temperatures. Pathogen testing is required to assure the BSPS-SC is as effective "as planned." The benefits of the BSPS-SC technology can also be reduced if the appropriate level of control is not maintained at all subsequent key processing stages in the plant. Because the efficacy of the technology is judged within the context of a plant's whole safety system, the dependability of the technology could vary greatly from plant to plant, depending on the characteristics of each plant's safety system. This fact complicates the task of developing and marketing food safety technologies—and the task of proving and maintaining their efficacy on a daily basis.

The series of tests that Frigoscandia Equipment and Excel funded prior to marketing the BSPS was necessary to gain U.S. regulatory acceptance and market acceptance by the two largest U.S. beefpacking companies. Nevertheless, even this level of testing has so far been unable to convince European companies to purchase the BSPS-SC. In addition, the technology has not been adopted by other slaughter industries: to date no U.S. hog slaughter companies have purchased the BSPS-SC system for pork carcasses. Future market penetration of the BSPS-SC technology, both domestically and internationally, hinges on the proven dependability of the technology and its role in the process control systems of the future.

Appendix A: Time Line for Beef Steam Pasteurization System Innovation

1979: Frigoscandia Equipment, now established in the United States, begins working with the U.S. meat industry on freezing.

Jan. 1993: A foodborne disease outbreak in the Western States is associated with *E. coli* O157:H7 in hamburgers from Jack in the Box.

Late 1993/early 1994: Craig Wilson, in charge of special projects at Frigoscandia Equipment (Bellevue, WA) discusses with other Frigoscandia engineers how to prevent such outbreaks. Steam pasteurization of beef carcasses is suggested as a technically viable option. Wilson calls his professional friend Jerry Leising, Excel Vice President and Director of Research and Development, who offers to collaborate in inventing and testing equipment to use steam to pasteurize the surface of beef carcasses.

Early 1994: Frigoscandia designs and builds a small prototype to assure that *E. coli* O157:H7 on beef can be killed with steam. Informal talks with meat and poultry companies reveal that beef companies are the most interested in steam pasteurization equipment.

Nov. 7, 1994: Wilson (Frigoscandia Equipment) and Leising (Excel) apply for a patent, "Method and apparatus for steam pasteurization of meats," U.S. Pat. Appl. 08/335,437. Frigoscandia Equipment is the assignee on the patent.

1994: Kansas State University (KSU) is included as part of the development team. Frigoscandia's prototype moves to KSU and tests begin on beef carcasses.

1995: Larger moving clamshell BSPS unit pieces are manufactured by subcontractors and assembled/installed by Frigoscandia engineers in an Excel plant in Sterling, Colorado.

Nov. 6, 1995: Patent application is filed by Wilson (Frigoscandia Equipment) Leising (Excel) and other Frigoscandia inventors for a larger moving clamshell BSPS unit. Frigoscandia Equipment is the assignee on the patent.

Dec. 1995: USDA approves the BSPS process for killing pathogens on the surface of beef carcasses.

1996: FMC FoodTech, a Chicago-based firm with 100 years of experience in food technology, buys Frigoscandia Equipment.

June 1, 1997: Excel announces that Frigoscandia's BSPS has been installed in all its North American beef plants.

Aug. 1997: FSIS requests the recall of ground beef for contamination with *E. coli* O157:H7 at Hudson Foods. The recall is very large, because contaminated meat from one day is mixed in with the next day's production.

Aug. 1997: IBP, Inc. executive asks Wilson to meet with IBP executives. IBP decides to purchase the BSPS-SC for all its beef slaughter plants.

Sep. 1997: USDA turns over approval of meat and poultry equipment to NSF International, a private certification body.

Jan. 23, 1998: Patent application is filed by Wilson (Frigoscandia Equipment), Leising (Excel) and other Frigoscandia inventors for a static chamber system that uses steam to destroy surface pathogens on meat. Frigoscandia Equipment is the assignee on the patent.

Oct. 1998: Wilson leaves Frigoscandia Equipment and becomes Costco's assistant Vice President for food safety and technology in Issaquah, Washington.

Feb. 26, 1999: Patent application is filed by Wilson (Frigoscandia Equipment), Leising (Excel) and other Frigoscandia inventors for apparatus for steam pasteurization of food. The unique element is the improved entrance and exit door structures to the static chamber. Eight doors, each 2 feet tall on each side, move when touched by the side of beef, and the vacuum seal is better maintained in the system. Frigoscandia Equipment is the assignee on the patent.

2002: Costco and other buyers stipulate that beef supplies must come from a plant using the Frigoscandia Equipment's BSPS-SC system at an appropriate time and temperature (Wilson, 11/4/02).

Innovation for Microbial Pathogen Control in the Supply Chain for Hamburger Patties

Elisabete Salay, Julie A. Caswell, and Tanya Roberts

Microbial pathogen control in hamburger patty production poses several challenges. Grinding operations typically take raw beef trimmings from multiple sources and mix these inputs together to make patties. Meat trimmings may carry high pathogen loads because of how they have been handled and because they have multiple exposed surfaces. The grinding operation itself disperses any pathogens present on the trimmings throughout the ground product, and there is opportunity for those pathogens to multiply in the subsequent supply chain. Designing testing protocols for detecting sporadic pathogen loads in high volumes of product is a challenge, as is getting quick results on which to base management decisions.

This case study focuses on the development of the Bacterial Pathogen Sampling and Testing Program by the Texas American Foodservice Corporation (Texas American) in collaboration with four other entities: the Jack in the Box restaurant chain, one of Texas American's major customers; Qualicon, a unit of DuPont Company; the Public Health and Science Office of the U.S. Department of Agriculture's Food Safety and Inspection Service; and the National Cattlemen's Beef Association.[1] The story of the Bacterial Pathogen Sampling and Testing Program is one of a series of factors coming together at one time. These included a demand for increased pathogen control by a major buyer of hamburger patties, the competitive interest of the supplier in building a reputation for quality control, and the technological opportunity afforded by the interest of an input supplier in adapting its improved testing technologies to the food industry. The outcome was a significant food safety innovation.

The Bacterial Pathogen Sampling and Testing Program is a process innovation combining a new sampling protocol/management system for *E. coli* O157:H7, *Listeria monocytogenes*, and *Salmonella* sp. and a new application of a patented testing technology to hamburger patty processing lines. The process innovation has resulted in a product innovation: hamburger patties with consistently low levels of pathogen contamination. This case study sheds particular light on the nature of appropriability for process innovations aimed at improving the safety of food products. It also sheds light on the set of incentives generated in the supply chain when operational change is necessary to assure a higher and more reliable level of food safety.

The 1993 *E. coli* O157:H7 Outbreak Catalyzed Changes at Texas American Foodservice

Texas American is a unit of the American Foodservice Corporation, a privately owned company that operates three plants in the United States (table D-1 presents background on the general characteristics of Texas American). American Foodservice Corporation is one of the largest independent ground beef producers in the United States. The main product of Texas American is frozen hamburger patties, supplied mostly to national and regional fast food companies, such as Jack in the Box. At the time of the 2001 interview, Texas American had 430 employees and processed 150 million pounds of ground beef annually, all of which was sold within the United States.

When Texas American began producing hamburger patties in the mid-1980s, there was no significant publicity or regulatory policy around ground beef and microbial food safety risk. Nevertheless, in the early 1990s, it began to focus on the effects of improving quality control and food safety. These effects included improving external failures (product rejections, product returns, liability, threatened loss of supply contracts, and a threatened increase in USDA inspection oversight), as well as internal process failures that resulted in product losses.

In 1992, Texas American hired a leading expert on quality control, Timothy Biela, to assist it in the redesign of its pathogen control system. Shortly thereafter it began investigating clinical microbiological testing technologies, such as Polymerase Chain Reaction (PCR) testing,

[1] Information on this innovation was obtained in interviews with Timothy Biela (Texas American Foodservice) in 2001 and 2002 and with Dr. David Theno (Jack in the Box) in 2001 and 2002. (For survey format see Salay et al., 2003.)

Table D-1—General characteristics of Texas American Foodservice Corporation, 2001

Main activity	Ground meat producer, two facilities in Fort Worth, Texas
Main products	Ground beef, 150 million pounds annually
Number of employees	430 employees (under USDA FSIS classifications, this is a small (< 500 employees) operation)
Main market segment	85% of production is frozen patties for commercial fast food, other markets include casual dining, retail, and wholesale
Exports	No exports
Parent Company: American Foodservice Corporation	5 plants in the United States with total production of 280 million pounds of ground beef annually
Ownership	Privately owned corporation

that could be adapted for use in monitoring pathogens in the hamburger supply chain.

The need for better pathogen control in the hamburger patty supply chain was brought to widespread attention in the United States by the 1993 Jack in the Box foodborne illness outbreak associated with inadequate cooking of hamburger patties that were contaminated with *E. coli* O157:H7 (see box "Pathogen Reduction and Hazard Analysis and Critical Control Point Program," p. 15). In the wake of the 1993 outbreak, Jack in the Box instituted quality control programs reaching over all aspects of company operations from procurement through in-store cooking and handling to the consumer. First, the company hired a new manager with food safety experience in the poultry industry, Dr. David Theno, to head its safety program. Next, the company suspended all existing contracts with hamburger patty suppliers and designed new contract specifications. Only two companies, one of them Texas American, met the demands of the new contracts.

Texas American was in a good position to respond to the call from Jack in the Box for producers who could supply hamburger patties that met strict quality standards. It was able to move quickly after the 1993 outbreak because it had already begun developing a new systematic approach to pathogen control and had begun investigation of testing methodologies.

Development of New Sampling and Testing Protocols: Innovation Through Collaboration

The Bacterial Pathogen Sampling and Testing Program is a process innovation combining two parts: a new sampling protocol/management system and the new application of a patented testing technology to hamburger patty processing lines. Safety in the Texas American program is controlled through strict testing to assure that standards are met in raw materials, in bulk product coming out of the grinder, and in finished patty products. Though Texas American maintains strict temperature control and cleaning regimes within the plant, it does not include a kill step, such as steam pasteurization or irradiation, in its production lines. The key critical control point in its safety system is the quality and temperature of raw materials coming into the grinding plant (most of the actual activities necessary to reduce pathogen loads occur in the plants of the raw material suppliers).

The successful development of the Bacterial Pathogen Sampling and Testing Program hinged on the development of a well-targeted sampling protocol and a good testing technology (see box, "Texas American Foodservice Corporation Bacterial Pathogen Sampling and Testing Program" for the major elements of the innovation and the appendix to this chapter for an overall timeline for the development of the innovation). Sampling protocols are of great importance to the management of pathogen risk because testing every product is not economically feasible, particularly since the pathogens of interest tend to be sporadic and at a low level (Pruett et al., 2002).

The Texas American sampling protocol is designed to manage risk to an acceptably low level. Trimmings entering the plant are sampled based on type, supplier, and supplier performance but not less than every 100,000 pounds, which for most raw material suppliers is daily. If lots test higher than standards, the supplier is notified immediately and testing is intensified. All raw materials are routinely screened for Aerobic Plate Counts (APC), generic coliforms, generic *E. coli*, Staphylococcus aureus, *Salmonella*, and *Listeria monocytogenes*. These routine test results are reported to suppliers and reviewed with them monthly.

Samples are next taken at the final grind head, where each batch of 3,000 pounds of hamburger is tested for *E. coli* O157:H7. Finally, samples of the finished prod-

Texas American Foodservice Corporation Bacterial Pathogen Sampling and Testing Program (and description of additional quality control procedures)

Element of Protocol

Temperature monitoring of incoming combo bins (2,000 lbs.) of beef trim; reject if temperature is above 40ºF

Combo bins sampled based on type, supplier, and supplier performance record; sampled not less than every 100,000 lbs.; most raw material lots sampled daily

Test results given to supplier monthly for all lots tested; if lots test higher than standards, supplier is notified immediately and testing is intensified, monthly review of supplier performance on microbiological criteria and in-plant audits to assess compliance with Texas American standards with performance compared to that of other suppliers

Temperature control (40ºF) and inventory management system for combo bins, first-in-first-out, use by 5th day after boning

Samples are taken at the final grind head for each 3,000-lb batch of hamburger tested for *E. coli* O157:H7

Samples of finished products are taken from each process line every half-hour; half-hour samples are combined into "half shift" composites representing every 4 hours of production, tested for complete microbial profile (APC, coliform, *E. coli, Staphylococcus aureus, Salmonella* sp., and *Listeria monocytogenes*), individual backup samples for each half hour are tested only if composites show spikes or high counts

Rework procedures in place, internal failures (e.g., the patty does not meet specifications) are continuously reworked during the day with quantity of rework recorded for each batch, end of day rework is only used during the last hour of production on the next day (segregated by product), at end of week all remaining rework is destroyed

In-plant cleaning regime in continuous operation, monthly random pre-operational swab tests to verify the efficacy of cleaning procedures and monitor the environment for pathogens

Temperature control (less than 10ºF) for frozen patties

Continuous review of procedures and results; adjustment of operating procedures to address problems and opportunities for improvement

uct are taken from each process line every 15 minutes. Every hour, composites of the four samples are tested to detect *E. coli* O157:H7. These samples are also combined to make a "half-shift" composite, which is tested for an entire microbial profile (APC, coliform, *E. coli*, *Staphylococcus aureus*, *Salmonella* sp., and *Listeria monocytogenes*). If the half-shift composites show spikes or high counts, more tests are run on the backup samples, also collected every 15 minutes. At all testing points, action levels and actions to be taken if deviations occur are clearly defined.

The development of a good testing technology was as important as the sampling protocol to the success of the Bacterial Pathogen Sampling and Testing Program. Texas American believed that no one truly understood the incidence of contamination of beef with pathogens and that traditional microbiological testing methods were inadequate because they relied on culturing samples of meat, were not very sensitive, took time to run, and were not well defined for these organisms. Texas American started its quest for a new testing methodology by upgrading its own microbiology lab and investigating the availability of human clinical microbiological testing technologies that could be adapted for use in monitoring pathogens in the hamburger supply chain. It eventually settled on Qualicon's BAX™ detection system, which uses Polymerase Chain Reaction (PCR) technology to test for *E. coli* O157:H7 and other pathogens. The PCR technology allows users to target known DNA strands from specific organisms and is capable of detecting the target organisms at levels much lower than standard serological (cultural) methods.

The BAX™ technology was being used to detect human illness, but had not been used to detect pathogens in a food production setting. The application of the BAX™ test to food processing required Texas American to conduct experiments to assure that the tests performed as expected in the new setting. This need was an important motivation for Texas

American to engage in cooperative and collaborative arrangements in developing the program. For its part, Qualicon needed a partner to help validate the use of the PCR/DNA Bacterial Testing equipment and methods for meat products.

To properly validate and sell the efficacy of the technology, Texas American also solicited the involvement of several other groups. Until this time, there was significant speculation about the sensitivity of the PCR/DNA method and resistance to its use. It was also not well understood how organisms contained in food products (meat) reacted in typical grinding operations, for example, how they moved and the level of transfer from contaminated to non-contaminated meat. The validation collaboration involved parallel testing, using different methods, of a number of samples by Texas American by Silliker Laboratories (the largest independent commercial testing lab in the United States) and by USDA's Food Safety and Inspection Service (FSIS), through its Office of Public Health & Science (Pruett et al., 2002). Texas American funded its technicians, the microbiological assays, and data analysis. The National Cattlemen's Beef Association funded the testing by Silliker Laboratories. FSIS funded testing at FSIS labs.

Jack in the Box played an active role throughout the development of the Bacterial Pathogen Sampling and Testing innovation. Since Texas American sells unbranded product in intermediate markets, it must tailor its product to the specifications of its major potential customers such as Jack in the Box. When Texas American became a supplier, Jack in the Box was looking for partners who could work with it to overcome the limits of microbial pathogen control. Jack in the Box established standards and was involved in monitoring the quality of raw material suppliers and specifying plants approved to supply to grinding operations producing hamburger patties for sale to Jack in the Box (Jack in the Box signs essentially cost-plus contracts with its patty producers that cover the costs of quality control). The result was a close collaboration that evolved over time as both parties learned more about the systems required to assure food safety.

Interestingly, government regulation was not an obvious driver in the development of the innovation. In fact, though some USDA regulation was a stimulant to better management of risks, Texas American often found itself in the position of sharing its superior information with regulators or driving collaboration with FSIS. Regulatory and consumer developments in other countries were also not drivers for innovation by Texas American because the company sells only within the United States.

The successful collaboration of Texas American, Jack in the Box, Qualicon (DuPont), FSIS, and the National Cattlemen's Beef Association ultimately resulted in the Texas American Bacterial Pathogen Sampling and Testing Program. Texas American believes that this innovation has reduced by 80 percent the risk associated with distributing a raw product that can potentially contain organisms that can cause illness or death if consumed prior to proper cooking and preparation. The company has never had a recall of its products and believes that its program significantly lowers the risk of recall or negative publicity associated with foodborne illness outbreaks.

Texas American Leads the Way… and Appropriates the Benefits

Texas American appropriated the benefits of its process innovation through establishing a substantial lead over its competitors. Texas American did not believe that pursuing patents or secrecy was important to maintaining or increasing the competitive advantage it would gain from the innovation. Indeed, the collaborative nature of the innovation process, with strong involvement from Qualicon and Jack in the Box, which in turn would be working with other suppliers, probably made secrecy unworkable. In fact, Texas American and Jack in the Box have been very active in sharing the new approach with other members of the hamburger patty supply chain. They believe that the reputation of the entire industry, including their own, is on the line anytime poor quality control results in illnesses and outbreaks associated with hamburger products. Texas American's stance is to share its knowledge about the implications of organisms like *E. coli* O157:H7 with potential customers as well as with competitors.

The Texas American experience supports the idea that transparency of an innovation does not necessarily imply that it will be widely imitated. The complexity of the management systems and the discipline they require, along with continued innovative activity, have helped Texas American build and maintain a competitive advantage. In addition, given current market conditions, the costs of adoption are high relative to opportunities to market improved pathogen control.

Texas American's first-mover advantage is also maintained through the fact that it captured a significant share of the market for hamburger patties produced to a higher pathogen control standard. Its dominant position may discourage other firms. However, this could change if demand for higher quality control standards becomes more widespread among buyers.

Texas American has been able to reap numerous benefits from its food safety innovation—and its first-mover advantage. One of the major benefits is that Texas American has been able to shift from being a commodity producer selling on a week-to-week basis to being a contract supplier. This shift has allowed Texas American to improve its operational efficiency through better planning for capacity utilization, capital investment, spending plans, and other business activities.

Another benefit of the innovation is Texas American's ability to use its superior knowledge and expertise in the area of pathogen control to attract new customers. Texas American has enhanced its reputation with quality control, superior knowledge, and risk management skills it has built over a period of almost a decade. The company's sales increased approximately 5 percent annually after it implemented the innovation. Over the 3 years up to 2001, Texas American estimates that about 25-30 percent of its new sales opportunities occurred because of the innovation. The increase in sales has had the added important benefit of allowing Texas American to increase its utilization of fixed capital by 20 percent over the last 5 years.

Texas American also attributes significant savings and other financial benefits to adoption of the program. The superior knowledge about incidence rates and potential for product contamination that Texas American has gained through the program has enabled it to make better risk-management decisions regarding suppliers of raw materials. Texas American's understanding of which raw material suppliers have higher incidence levels and at what times of the year to expect positive test readings in different types of raw materials allows it to make better purchasing decisions. Avoiding high-risk raw materials leads to fewer product rejections and helps save money. Thanks to the Bacterial Pathogen Sampling and Testing Program, Texas American has been experiencing very few contamination incidents per year for *E. coli* O157:H7; in some years it has had none or one.

The benefits of the Bacterial Pathogen Sampling and Testing Program to Texas American have outweighed the costs of the innovation even though the costs of instituting the program involved significant initial expenditures. Texas American characterized the startup expenses as very high. In addition, there were high costs related to destruction of product in the early stages of the implementation. To contain some of these costs, Texas American worked with USDA to get approval of a system to identify sub-lots for purposes of testing and recall. Over time, costs have not increased, even though testing technology has become increasingly sensitive.

Texas American reports that costs are being controlled due to several factors. First, the development of the sub-lot system has reduced the amount of product that needs to be removed by pinpointing product that is contaminated. Second, the raw materials industry has reduced microbial contamination rates for incoming product under the Texas American program, since Texas American works with its suppliers to reduce contamination and the performance of the industry has generally been improving. Finally, Texas American has set a reasonable threshold level for the BAX™ tests of its finished, frozen hamburger patties. Texas American set the threshold level for product rejection to eliminate the possibility of outbreak and massive recall. The most sensitive BAX™ test for ground meat is extremely sensitive; it is able to detect 1 cell/125 grams of product. Using the lower bound of such a sensitive test could result in rejection of as much as 30-65 percent of product depending on the geographical source and time of year.

Current costs of the program are minimal now that the innovation has been in place for a period of years. Texas American estimates that the cost per pound of the system runs between $0.001 and $0.01, without significant increases in labor, raw material consumption, or energy consumption. To maintain a competitive edge, and its name as a food safety leader, Texas American continues to expend capital on research and development, with the bulk of these expenditures going to food safety improvements.

An Emerging Market for Food Safety Opens the Door to Food Safety Innovation

The Texas American case study illustrates the impact that the emergence of a market for food safety can have on the appropriability of food safety

innovation—and hence on innovation itself. In the Texas American case study, Jack in the Box, a highly knowledgeable buyer with the ability to test for and verify safety attributes helped spur the development of the market for food safety attributes. Jack in the Box, and a number of other fast food and restaurant companies, have a great deal staked on the continued good reputation of their brand names. Particularly since the 1993 *E. coli* O157:H7 outbreak, these companies have had strong incentives to expend the resources necessary to control for food safety. They also typically deal with a very small number of suppliers and maintain traceability systems that allow them to track the source of any problems. Thus the failures usually thought to exist in markets for food safety are mitigated to a significant extent by the nature of the supply chain for hamburger patties used in chain restaurants.

The development of demand for food safety in this market, in response to the need to manage risk, in turn increased the probability that a company that invested in innovation for food safety control would be able to appropriate benefits from that investment. For Texas American, the push by Jack in the Box to find high-quality hamburger patty suppliers offered the opportunity to intensify the company's new commitment to quality assurance with substantial certainty that its efforts would be rewarded with sales at prices that would recognize the company's quality achievements.

Texas American and Jack in the Box worked collaboratively over time to attain higher standards. Both companies were first motivated by the need for risk management to limit or eliminate the damage in reputation, sales, and liability stemming from inadequate quality control. Both companies have found that a reputation for quality has served as a foundation for growth. These companies have helped develop a market for food safety—and through their reputations as safety leaders, both have reaped benefits from supplying this market.

Appendix B: Time Line for the Texas American Foodservice Corporation Innovation

1985: Texas American plant starts hamburger patty production.

Early 1990s: Texas American becomes concerned about quality control and begins exploring new methods to improve quality assurance.

Mar. 1992: Timothy Biela, Director of Quality Assurance, conducts hazard analysis for bacterial, physical, and chemical hazards for Texas American hamburger patties.

Early 1993: Jack in the Box *E. coli* O157:H7 outbreak.

Mar. 1993: Biela and Texas American General Manager schedule meeting with Jack in the Box to discuss a strategy and program for supplying frozen hamburger patties to Jack in the Box.

Mar.-Apr. 1993: Contract negotiated with testing details and responsibilities for affected products specified in the contract.

May 1993: Texas American starts supplying Jack in the Box.

May 1993-1994: Texas American upgrades microbiology lab, writes specific operation procedures, develops new sampling and testing protocols, acquires equipment from Qualicon and other suppliers.

1993-1994: Validation of Qualicon testing protocols.

1994-Present: Continued refinement of sampling and testing program.

2000: Begins joint venture into retailing Modified Atmosphere Packing of ground beef products.

2001: Texas American opens a second plant in Texas.

Part III. Market and Regulatory Incentives for Food Safety Innovation

Market Incentives for Food Safety Innovation: Lessons from the Meat Industry

The ERS survey and the two case studies illustrate how the meat processing industry has developed mechanisms for partially overcoming the incentive problems caused by asymmetric information in food safety markets. In this section, we identify and discuss eight primary drivers of food safety innovation in the meat industry, as revealed by the survey and case studies.

Emerging Markets for Food Safety Overcome Market Failure

By far, the dominant drivers of food safety innovation in the meat industry are the stringent requirements on product safety and quality demanded by large fast food restaurants, such as Burger King, Jack in the Box, McDonald's, and Wendy's. By demanding safer products from their suppliers, these restaurants have successfully created markets for food safety. The success of these markets rests on the ability of these large buyers to enforce standards through testing and process audits—and to reward suppliers who meet safety standards and punish those who do not. Through contracts with these large buyers, meat processors are able to appropriate the benefits of their investments in food safety.

The emergence of savvy buyers who demand quality alleviates two market failure problems that typically occur in markets for food safety. The first problem characterizing most food markets is that demand for product differentiation on the basis of safety is typically episodic because consumers are largely uninformed about food safety. The large fast food restaurants reverse this trend; they are anything but uninformed. To protect their investments in brand equity, these restaurants have become educated about food safety processes and testing. They are pushing food suppliers to provide safer products—something that typical food consumers rarely do.

The second market failure problem, that of asymmetric information, is also alleviated by the emergence of demanding large buyers. In typical food markets, producers who use the safest processes and produce the safest products have a difficult time differentiating themselves from their less safe competitors, since most buyers cannot tell the difference between safe and unsafe product. Because large retailers have the capability to test or otherwise verify safety, food processors that use safe processes can differentiate themselves from their competitors and seek compensation for higher quality products. Thanks to the emergence of these technically proficient buyers, safer meat processors can appropriate some of the benefits of their investments in safety through price premiums or guaranteed sales.

In the market for hamburger, fast food restaurants have adopted the role of channel captains, monitoring the safety of products up and down the supply chain. They have created markets for food safety that have stimulated demand for safety and provided processors with mechanisms for appropriating the benefits of food safety innovation. Slaughter plants subject to buyer specifications invest in more food safety activities than those without buyer specifications.

The experiences of Texas American/Jack in the Box and Frigoscandia Equipment/Excel illustrate the advantages of a market for food safety. These companies gained reputations for safety and benefited from increased demand and market stability. As pointed out in the Texas American case study, the fact that there are so many advantages to creating markets for food safety raises the question of why markets for food safety have not developed as quickly in other parts of the food industry. In particular, though some grocery stores are beginning to monitor the safety practices of their suppliers, why have food retailers generally not adopted the same channel captain role as restaurant chains in overseeing the quality of hamburger sold through their outlets? Why have food retailers not been as aggressive in demanding safer inputs? Maybe the real question is: What prompted the large fast food restaurants to break ranks with other retailers and begin to demand safer inputs?

Branding to Appropriate Benefits from Food Safety Innovation

Branding also plays an important role in helping firms appropriate the benefits of safety investments. Though

the ERS survey did not reveal more safety investment by branded slaughter plants, this result is probably explained by the fact that many respondents misunderstood the branding question. A better indicator of the importance of branding for food safety innovation is the key role that the major name brand fast food restaurants have had in driving safety innovation. As discussed above, these companies have emerged as savvy food safety consumers and have succeeded in stimulating food safety innovation.

The major, name-brand fast food restaurants are able to appropriate some of the benefits of their investments in food safety because of their reputations for safe food. Even more important, perhaps, these firms benefit from their investments through a reduced risk of being associated with a foodborne illness outbreak. A firm that is identified as being responsible for a foodborne illness outbreak faces the potential for bad publicity, liability, and recalls. A food safety outbreak could cost the firm in terms of market share, equity value, and legal liability. As previously mentioned, in the 18 months after the 1993 outbreak of *E. coli* O157:H7, Jack in the Box and its parent company, Foodmaker, Inc., lost about $160 million (Roberts et al., 1997).

Not only do branded firms have more equity investment at risk than unbranded firms if they are associated with an outbreak, they also have a higher probability of being identified and held liable in the case of food safety problems. Name brand recognition is a double-edged sword: it allows consumers (and regulators) to identify and reward firms that produce high-quality, safe products, but it also increases their chances of identifying firms that are guilty of safety lapses. Branding reduces the chances of remaining anonymous in case of a foodborne disease outbreak.

The fact that the advantages of anonymity are forfeited with branding may explain why fast food restaurant chains, and not foodstores, have been the first to become channel captains in the meat industry. The ability of these restaurants to remain anonymous may have been very limited in the first place, meaning that they had little to lose by aggressively branding their products. For slaughter plants, meat processors, and foodstores, product mixing reduces the chance that the source of a foodborne illness will be identified and that the guilty party will be held accountable. For these firms, the value of remaining anonymous may be larger than the value of branding and channel captaining.

In addition, since restaurants have final responsibility for meat preparation, they bear final responsibility for proper meat handling and cooking. They are clearly liable if food is improperly prepared, while such liability is less clear cut in the case of slaughter plants or processors. The added risk of liability is likely another factor driving more and more restaurants to shoulder the role of channel captains.

In fact, only a limited number of input providers or retailers have chosen to brand and to become channel captains. For example, few if any U.S. food retailers engage in premium or luxury house branding of meats. With this approach, retailers attempt to build a name for quality and safety that umbrellas all of the store-branded products—including their branded meat products. Surprisingly, European retailers have been using this strategy for some time with great success. For example, as early as 1992, supermarket chains' brands accounted for about 50 percent of sales in the United Kingdom (Selame and Kolligian, 1992). In the United Kingdom and European Union generally, grocery stores have taken on the role of channel captain and many developments in food safety management on that side of the Atlantic can be traced to the major grocery stores. The question remains as to why European retailers find it advantageous to relinquish their anonymity and become channel captains, while U.S. retailers do not.

International Trade Stimulates Demand for Safety and Provides Technological Spillovers

International trade has played an important role in stimulating the demand for food safety, with many foreign buyers playing a channel captain role in much the same way as the large fast food restaurants. Foreign buyers who demand high safety standards tend to test product for safety and to pay premiums or to guarantee sales for safe producers; these are the buyers who fuel the growth of markets for food safety and stimulate safety innovation. The ERS survey data reveal that slaughter plants with foreign buyers invested in more safety activities than those serving exclusively domestic markets.

The Frigoscandia Equipment case study illustrates another potential benefit of trade in food safety: technology spillovers between countries. The development of the Steam Pasteurization System benefited from the technological expertise that the Swedish company had built up over 50 years in the cold storage business.

Swedish technological expertise provided spillovers that benefited U.S. food safety innovation.

First Movers Appropriate the Benefits of Innovation and Encourage Diffusion

The Texas American case study illustrates the importance of first-mover advantage in establishing a means to appropriate the benefits of innovation. Texas American did not patent the Bacterial Pathogen Sampling and Testing Program or seek any other sort of protection for the innovation. It was confident that its first-mover advantage would forestall pressure from the competition and provide it with space for appropriating the benefits of the innovation. In fact, the complexities of the Bacterial Pathogen Sampling and Testing Program, along with continued innovative activity, have helped Texas American build and maintain a competitive advantage. In addition, as a first mover, it was able to capture a significant share of the market for safety-controlled hamburger patties, making entry less attractive to other firms.

Not only did Texas American choose not to seek protection for the innovation, it actually sought to disseminate the Bacterial Pathogen Sampling and Testing Program throughout the industry. Jack in the Box and Texas American have both been very active in sharing the innovation with other members of the hamburger patty supply chain. Both companies argue that hamburger-borne outbreaks hurt everyone in the industry and that anything that helps reduce the possibility of outbreaks associated with hamburgers is good for business.

Another reason that firms may have an interest in sharing new technologies with their competitors and with government regulators is to influence the "standard of care" for the industry. For innovators such as Frigoscandia Equipment, the advantage of setting the standard of care is simple: more sales of its patented Steam Pasteurization System. For a firm like Texas American, which is not selling its innovation, the advantages are subtler, though potentially as large. Setting a standard of care that is difficult to meet can help set a barrier to entry that benefits the innovating firm. First adopters gain larger market shares (and maybe market power) if the expense or complexity of the innovation forces some producers out of business. Even if all firms eventually adopt the innovation, first movers will benefit from limited competition during the period when their competitors are installing and adapting the new technologies or processing protocols.

Collaboration Facilitates Innovation and Dissemination

The observation that the performance of the industry as a whole affects the reputation and profitability of all firms in the industry provides incentives for firms to collaborate to improve overall industry performance. In both case studies, the innovative process was dependent on collaboration. The successful collaboration of Frigoscandia Equipment, Excel, and Kansas State University led to the development of the Steam Pasteurization System. In the case of the Bacterial Pathogen Sampling and Testing Program, Texas American, Jack in the Box, Qualicon, USDA-FSIS, and the National Cattlemen's Beef Association worked collaboratively to develop the innovation and improve industry performance.

In each case, the technical and managerial expertise of the collaborators combined to facilitate the development of the innovation and ensure that it would be effective in a commercial setting. Teamwork is essential to move an industry:

> …innovation…requires careful, dedicated, and enthusiastic attention to detail—to the specifics of product and services and markets and materials—by all kinds of people in the organization. These people are not merely implementers; they are strategists too, because any really good idea can change a company—and an industry." (Mintzberg, 2002, p. 143)

In addition to technical and managerial benefits, collaboration also provides important risk-sharing benefits. In both case studies, collaboration between buyers like Excel and Jack in the Box and sellers like Frigoscandia Equipment and Texas American reduced marketing risks and provided feedback that improved the quality and success of the innovation. In both case studies, collaboration was essential to the willingness of the innovators to commit time and resources to the endeavor. Collaboration between buyers and sellers also helps speed diffusion of the innovation.

Market Conditions Push Large Firms to Innovate

The ERS survey indicates that large slaughter plants had much higher food safety technology ratings than smaller ones, particularly with respect to more capital-intensive activities. For the capital-intensive activities of equipment, testing, and careful dehiding, large

plants had ratings about twice that of smaller plants whereas for the more labor-intensive activities of sanitation and operations, they had only about a 20-percent higher rating. These differences in technology ratings suggest that economies of scale, i.e., much lower unit costs for large plants versus small ones, play a major role in whether plants adopt capital-intensive food safety technologies. However, economies of scale do not sufficiently explain all differences. Two characteristics peculiar to the beef industry and food safety also explain some of the differences in food safety investment between large and small plants.

First, large and small slaughter plants face different markets. Large plants tend to supply large, homogeneous markets with relatively elastic demand, while smaller plants tend to serve smaller markets with less elastic demand. In homogeneous markets, in which a number of firms produce and market similar or identical products, any slip in safety could reduce demand for products from the offending plant. In less elastic markets, products are less fungible, and buyers may be more willing to overlook food safety slips or to work with a plant to overcome safety problems. To protect their markets, large plants may therefore have more incentive than small firms to adopt food safety innovations. In fact, slaughter plants that can consistently supply high levels of product safety, as required by a number of major food retailers, gain access to almost guaranteed markets for large volumes of product. Large firms may therefore have more incentive than small firms to pursue food safety innovation.

Another reason large firms may invest more in food safety than small firms is that food safety lapses have the potential to be more costly for large firms because they may involve larger amounts of product. Large amounts of contaminated product increase both the probability of detection and the cost of wasted product or recall as illustrated in the Frigoscandia case study, though smaller lot sizing can help control the extent and cost of contamination. For large firms, the cost of not adopting the safety innovation may be greater than the cost of adopting the innovation. For small firms, the cost of not innovating may be much less and therefore not provide the same motivation.

Outbreaks Spur the Demand for Safety and Accelerate Innovation

The 1993 outbreak of *E. coli* O157:H7 was a seminal food safety event in the United States. This outbreak led to increased consumer awareness of food safety issues and triggered a spike in demand for food safety that is still being felt in the industry. It is directly responsible for the decision by fast food restaurants to assume channel captain roles—a decision that has had repercussions for the safety of the whole industry.

The outbreak also pushed the Federal Government to reassess the beef industry's food safety standards and to make a number of key policy changes, including declaring *E. coli* O157:H7 an adulterant in raw ground beef. The effects of this change have yet to be fully appreciated. The outbreak also accelerated efforts to update the Federal inspection system with PR/HACCP.

Technological Validation is as Important as Technological Opportunity in Driving Innovation

The Steam Pasteurization System case study highlights an important observation about technological innovation for food safety: the design and fabrication of the technology may be secondary to technological validation in determining the ultimate success of an innovation. Not only is it difficult to measure pathogen control and technological efficacy, but even the best technology can be undermined by deficiencies in the overall safety system. The actual efficacy of the technology may vary greatly from plant to plant, depending on the characteristics of each plant's safety system. As a result, innovators may have a difficult time certifying or otherwise guaranteeing the efficacy of the technology for controlling pathogen contamination.

One of the largest stumbling blocks Frigoscandia Equipment faced in the development of the Steam Pasteurization innovation was the validation of the technology. The long and arduous series of testing that Frigoscandia Equipment required prior to marketing the technology was necessary to gain market acceptance. Nevertheless, even this level of testing was unable to convince all U.S. or foreign beef companies of the dependability of the equipment in different production environments.

Designing Regulatory Incentives for Food Safety Innovation

Asymmetric information in food safety markets may result in a level of food safety investment that is less than socially optimal. If policymakers determine that intervention is necessary to stimulate innovation, they then face the task of determining which policy tools to

use. As discussed in the previous section, the ERS survey and the two case studies reveal a number of mechanisms developed by the beef industry to overcome asymmetric information problems and stimulate innovation. What can policymakers learn from industry experience? Has the market evolved in such as way as to make some policy choices more efficient than others? This section examines those policy options suggested by the theoretical and empirical evidence.

Strengthen Appropriability Through Safety Information

The success of the fast food restaurants and other channel captains in stimulating innovation reveals the importance of the ability to verify safety and quality claims. Channel captains require their suppliers to provide testing and/or other evidence that food safety standards have been met. As a result, asymmetric information problems are reduced—and food safety innovators can more easily appropriate the benefits of their investments.

Likewise, reducing asymmetric information is probably an important step in any government policy designed to stimulate food safety innovation. Government programs that provide consumers (both final consumers and input consumers) with food safety information, particularly information on safe and unsafe producers, will help the market to operate more efficiently. With more safety information, consumers will be able to choose the level of food safety (and price) that best matches their preferences. As a result, the market supply of food safety and food safety innovation will better reflect consumer preferences. For example the introduction of irradiated meat patties in some markets has expanded the welfare of consumers who place a high value on safety. These consumers are able to pay a premium to purchase meat virtually guaranteed free of pathogens.

With better informed consumers, it is more likely that unsafe firms will bear some of the costs of unsafe production, such as recall, liability, and bad publicity. Information therefore strengthens market incentives for firms to produce safe foods—and to invest in food safety innovation. Information helps firms appropriate the benefits of safety investments and helps ensure that unsafe firms "appropriate" at least some of the costs of safety failures. Jin and Leslie (2003) found that consumer demand was sensitive to hygiene quality grades required by Los Angeles County and posted in restaurant windows. Information about hygiene helped clean restaurants benefit from their investments while restaurants that did not meet county standards paid the price of their negligence in the form of fewer customers. In addition, foodborne hospitalizations decreased after the 1998 Los Angeles County requirement.

The government has a number of tools at its disposal to reduce asymmetric information and transform credence attributes, such as food safety, into attributes more closely resembling search attributes that consumers can evaluate by reading labels or investigating other information sources prior to purchasing products (Caswell and Mojduszka, 1996). Labeling programs could provide general food safety information like the safe-handling labels on retail meat and poultry packages in the United States, or more specific information like the "*Salmonella* Free" labels available to Danish poultry producers. Government safety labeling programs could be mandatory, like nutrition labeling, or voluntary, like some allergen labeling.

Labeling is not the only government program targeted at increasing food safety information and the transparency of the safety system. For example, both FSIS and the FDA post a list of recalls for contaminated, adulterated, or misbranded products. In another program, FSIS requires that the results of the HACCP *Salmonella* testing program for meat and poultry be published annually and made available to the public (though, unfortunately, results are not reported for individual firms, as was originally proposed by FSIS).

Other government programs that could be used to provide consumers with more information about food safety include time/temperature indicators for each package of refrigerated food; harvest/lay/slaughter dates on each package of an animal protein product; pathogen performance information on each company and its products; and a government-certified label for low-risk foods, so companies can compete on providing safety from pathogens.

As a prerequisite to providing consumers with information on safe and unsafe producers, the government must generate data on safety records. In the United States, the Federal Government and other public health officials have taken strides in building the infrastructure for tracking the incidence and sources of foodborne illness. The Foodborne Diseases Active Surveillance Network (FoodNet) combines active surveillance for foodborne diseases with related epidemiologic studies to help public health officials better respond to new and emerging foodborne diseases.

FoodNet is a collaborative project of the Centers for Disease Control and Prevention (CDC), nine States, the United States Department of Agriculture, and the Food and Drug Administration.

Another network, PulseNet, based at CDC, connects public health laboratories in 26 States, Los Angeles County, New York City, the FDA, and USDA to a system of standardized testing and information sharing. PulseNet helps reduce the time it takes disease investigators to find and respond to foodborne outbreaks. Both FoodNet and PulseNet differ from passive surveillance systems that rely on reporting of foodborne diseases by clinical laboratories to State health departments, which in turn report to CDC. Under passive information gathering, only a fraction of foodborne illnesses are routinely reported to CDC.

In addition to improving market results, information on safe and unsafe producers is also important for targeting government enforcement activities. Unless regulators can distinguish between safe and unsafe processors, they cannot ensure that those with poor records pay the cost of their safety lapses. Information is vital to government efforts to ensure that food safety innovators appropriate the benefits of their investments and the shirkers appropriate the costs of any failures.

Strengthen Appropriability Through Increasing the Costs of Failure and the Benefits of Success

Not only do restaurants and other entities acting as channel captains distinguish between safe and unsafe producers, they provide real benefits to those who consistently produce safe products. Suppliers that meet standards benefit in terms of sales contracts and/or price premiums, while those that fail standards lose access to these important markets. The ERS survey results indicate that plants with buyer specifications had higher levels of safety activities than those without. Government policies targeted at strengthening the costs of food safety lapses and the benefits of food safety compliance and investment may likewise stimulate innovation.

Policies specifically targeted to rewarding producers of safe products include government safety certification and preference in government procurement programs. Policies specifically targeted to increasing the cost of food failures include recalls, testing schedules linked to performance, and higher fines or longer plant closures in cases of noncompliance. Any policy that increases the probability of getting caught selling unsafe food also increases the probable cost of producing unsafe food.

A potential drawback to any policy targeted to strengthening appropriability is the possibility that imitation and the diffusion of new technologies will be slowed. When innovating firms have strong appropriability mechanisms, the costs of imitation rise, reducing the rate of diffusion. In the case of food safety, the stimulating effect of strengthened appropriability on social welfare may outweigh the dampening effect of lowered diffusion.

Provide Flexibility in Choice of Food Safety Technology

Regulation that does not dictate any particular technology is likely to encourage efficiency and innovation. When government safety standards focus on performance, not process, individual firms can choose the most efficient approach to achieve a particular standard. For some firms, capital-intensive activities will be more efficient than labor-intensive activities; for other firms, the opposite will be true. Performance standards encourage efficiency by letting firms use whatever approach is best for their particular production process.

Performance standards encourage innovation by giving firms the freedom to develop new approaches to achieve outcome targets. Past regulations have often prescribed particular remediation technologies. For example, in pollution control, the government has specified "best available technology" and "best available control technology," while food safety regulation has focused on the prescription of Good Manufacturing Practices. The specification of process is deeply rooted in U.S. practice and implies that one technology is best, which discourages innovation. As Porter and Linde (1995) note, the government should maximize the opportunity for innovation by letting industries discover how to solve their own problems.

The Steam Pasteurization System case study directly illustrates the power of a flexible regulatory approach for stimulating innovation. PR/HACCP provides food processors with flexibility to innovate and adopt new safety technologies as critical control point measures in a plant's PR/HACCP system. If PR/HACCP had specified particular technologies for each critical control point, the drive for more efficient control point measures would have been severely dampened and

Frigoscandia Equipment would have had little incentive to develop the Steam Pasteurization System.

The variety of food safety activities listed in the ERS survey results provides more evidence of the role of regulator flexibility in stimulating innovation and efficiency. If PR/HACCP had specified particular technologies for each critical control point, then the variety of safety activities would likely have been restricted and large and small firms would have had more difficulty finding an efficient mix of capital- and labor-intensive activities.

Invest in the Scientific Infrastructure and Support Research on Safety Testing

The ERS survey and the two case studies did not highlight any food safety innovations that directly depended on government research and development or on government expertise. This does not mean that government-supported institutional infrastructure, such as intellectual property rights protection, was not important to the development of the innovations highlighted in the empirical investigation (patent rights were critical in enabling the invention of the Steam Pasteurization System technology). Nor does it mean that basic government-funded research did not contribute indirectly to the development of these innovations. By expanding the general pool of knowledge about pathogen testing and food processing, government researchers helped build the infrastructure for both the Steam Pasteurization System technology and the Bacterial Pathogen Sampling and Testing Program.

Fuglie et al. (1996) contend that government research and development plays an important role in food safety innovation: They note:

> The private sector often underinvests in agricultural research because only a share of the total economic benefits can be captured. This is most true of fundamental (pre-technology) research and is also true for applied research that generates important non-market benefits, such as environmental, social science, food safety, and nutrition research. (p. 33)

Government can also play a role in building collaborations—something that the case studies showed to be important to successful innovation. Governments encourage collaborations through a number of vehicles, including cooperative funding agreements, outreach programs, and tax-free research areas. In the United States, the Federal Technology Transfer Act of 1986 and the National Cooperative Research and Production Act of 1993 (National Science Board, 2002) bolster collaborative research efforts.

The Frigoscandia Equipment case study suggests a more direct sort of technical research support that could be provided by government research: validated testing methodologies or certification for pathogen control technologies. To successfully commercialize the Steam Pasteurization System technology, Frigoscandia Equipment needed to establish the efficacy of the technology. However, as with many pathogen reduction technologies, success was not easy to prove, particularly given the wide range of production technologies in different slaughter plants. When standards are technically difficult to verify, government services may be instrumental in helping to establish testing norms. For example, the Grain Inspection, Packers, and Stockyards Administration has established a reference laboratory to evaluate and verify the validity of analytical techniques applied to the detection of genetically enhanced traits in grains and grain products (for more information, see *http://www.usda.gov/gipsa/newsroom/backgrounders/b-reference-lab.htm*).

Another important function for government research and development may be to improve food safety monitoring capabilities. Advances in technology are key to supporting, and in many cases, stimulating information provision. For example, "DNA fingerprinting" technology makes it easier to link illness to specific firms. Such information may be key in health investigations of outbreaks and in food safety litigation (Buzby et al., 2001).

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