Systemic Failure in the Provision of Safe Food

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Abstract

Many deficiencies in the capacity of a food system to deliver safe products are systemic in nature. We suggest a taxonomy of four general ways in which a systemic failure might occur. One relates to the connectedness, or topology, of the system. Another arises from mistrust on the part of downstream parties concerning signals on product attributes, production processes, and the performance of regulatory mechanisms. A third arises when asymmetric information leads to low incentives for preserving food quality. Finally, inflexibilities in adapting to different states of nature may leave the system vulnerable to failures. Innovations in information technology and institutional design may ameliorate many problems, while appropriate trade, industrial organization, science, and public infrastructure policies also may fortify the system.

Key words: incentives, information, mixing, process design, systems analysis, technology.

SYSTEMIC FAILURE IN THE PROVISION OF SAFE FOOD

Introduction

While food safety has had a long tradition as a significant political issue, the 1990s and the early years of this century has been a period of particularly intense legislative activity pertaining to food quality, including food safety. Over this period, product attributes addressed in the United States and in the European Union have included food and water pathogen and contaminant reduction. Legislation on process attributes has addressed animal welfare concerns, private and public certification of organic products, and restrictions on the types of genetic manipulation technologies that can be used. Legislation on information attributes has included guidelines on best practices as well as regulations on the content and format of product information that must be provided, can be provided, and cannot be provided.

Underlying many, if not most, of these market interventions is the existence of externalities, or costs not borne by those whose actions create them, that give rise to market failures in the provision of food. Externalities tend to arise when strong dependencies govern relationships between economic agents, and when the production environment is not sufficiently well understood to allow redress through viable market-based interventions. Strong dependencies between agent decisions do exist in food supply chains. Further, in comparison to non-biological products, the science of food products is both complex and poorly understood.

When food systems fail, the adverse consequences can be great. In developing countries, severe malnutrition or famine may result. In developed countries, where good health and longevity are a baseline expectation, markets may be severely disrupted and deaths may occur. Whatever the source of the problem, when food systems fail, or are perceived to fail, the political and economic consequences are notable.

The intent of this paper is to inquire into the nature of systemic risk in the provision of food and then use the findings to draw some policy conclusions concerning the security of food systems. The paper has three main sections. We first discuss a variety of types of systemic risks that have been studied in non-food sectors. Then we delineate a taxonomy of systemic risks that may arise in the food sector. The paper concludes with a discussion of policy implications.

Systemic Risk in Non-food Sectors

Systemic risk is a concept that is widely used and readily conveyed in a general context. It is the risk that a system fails to perform because of the ways in which its various components interact. Strong positive correlations among the risks of failure are a central feature of systemic risk. When people allude to systemic risk, they generally have a particular source of failure in mind. A solid understanding of the source of failure is clearly important if the likelihood of a breakdown and the magnitude of the losses arising from any given breakdown are to be better managed. To provide points of reference for further analysis, this section considers the nature and control of common sources of failure in insurance, banking, and electricity systems.

Insurance Industry

Insurers may hope for low positive, or even negative, dependencies among assumed risks so that pooling all but eliminates risk in the insurer's portfolio. Nature, however, is often not obliging in this regard. While house fires may occur quite uniformly across time in a neighborhood, a forest fire can burn down the whole neighborhood. Thus, although transaction costs and market power considerations may encourage an insurance company to focus its marketing efforts on a particular sector, systemic risk may temper these motives unless institutional structures for risk sharing, such as competitive, efficient re-insurance markets, are readily accessible.

In general, the origin of systemic risk in the insurance industry is the existence of a common external driver, such as the weather or dependence on a common source of an input. Secondary factors may include compounding problems with private incentives. For example, if risk is systemic and the incidence of a risk falls on politically influential groups, then government support to non-insured victims may be expected in the event of a failure. This leads to a moral hazard problem, whereby members of an influential group may not take due care to protect against losses. Public policy may also affect the extent of systemic risk in other ways. As an example, public forest management policies in the United States and in European countries often involve the systematic suppression of all wildfires. Yet, because fuel substrates are preserved, this practice is a major factor in catastrophic wildfire events (Mutch, Lee, and Perkins 1999; Goldammer 1999).

Banking Industry

As the banking system is integral to how vital capital markets function, the existence and nature of systemic risk in this industry are of much concern to policymakers. Perhaps the most obvious source of systemic risk in banking is the case where unfortunate or imprudent lending leads to bankruptcy. Genuine financial problems in the financial intermediary are at the root of these failures. However, the problems may be systemic in that a common shock, say, higher energy prices, could curtail the debt-servicing capacities of many borrowers across many banks. A depositor is not as well informed as the bank of deposit about the bank's risk exposure. As the bank's incentives for risk-taking are unlikely to be the same as lender preferences for risk-taking with deposited funds, government intervention may be required to prevent aggressive lending practices. Typical mechanisms employed include governmentally imposed capital liquidity requirements and limits on bank asset portfolio riskiness. The government may also legislate for deposit insurance, which retail banks may have to fund.

A more subtle form of banking system failure is the bank run, an occurrence that may be experienced even by a fundamentally sound lending institution. As private withdrawals do not normally bear strong positive correlations, the bank may invest some of the deposited funds and share some of the resultant dividends with depositors. However, as a result of this strategy, the banking system would not have sufficient funds readily available were all depositors to demand withdrawal at the same time. Withdrawals are met on a first-come, first-served basis. If withdrawals do occur at an unusually high rate, then the probability that withdrawal requests for the remaining funds can be met with available funds decreases. The remaining deposits have become, in a probabilistic sense, less liquid. As described by Diamond and Dybvig (1983), the remaining depositors have stronger incentives to seek immediate redemption. Panic can set in and, perhaps because depositors believe that banks borrow and lend among themselves, this panic may spill out to other banks.

Banks, seeking to establish orderly rates of withdrawal, typically offer rate inducements for time-committed deposits. The typical public policy mechanisms employed to reduce the probability of such bank runs are essentially the same as for a bankruptcy: deposit insurance schemes, governmentally imposed capital liquidity requirements, and limits on bank asset portfolio riskiness.

There are many theories about what might trigger the run in the first place, and most of these pertain to monetary phenomena.[1] System overload is a concept that is useful for understanding the relevance to food production systems. Overload, though of a slightly different nature, can also be a causal factor in food system failures. In the banking industry, a long-standing concern has been that a run-up in private sector debt would render borrowers vulnerable if an economic downturn should occur. Cash-strapped from servicing loans, borrowing firms may cut back on demand for inputs and so spread net cash shortfalls outside the set of highly leveraged firms (Fisher 1933). If a bank has allowed many of its borrowing clients to lever highly, then the bank may also be in trouble. How banks and borrowing firms are connected matters.

Electricity Industry

Ongoing electricity sector deregulation in the United States and elsewhere has led to increasing concerns that the electricity provision and distribution systems may fail in a systemic manner. At the extreme, deregulation would allow any customer to buy from any provider. The product has to be delivered through a system shared by many other providers and customers. This is good, in a sense, because pooling electricity demand reduces the effective variability of demand-supply differences and therefore likely reduces the cost of the infrastructure required to generate electricity at a given level of reliability.

However, and as we will argue is the case for food production too, interconnectedness lies at the root of significant incentive problems in the electricity industry. An implication of Kirchhoff's law of electricity is that power may flow over several available paths when traveling between points A and B in an electric grid. In a system, then, there exists the potential for significant inefficiencies because two players engaged in a trade may ignore the effects of the resulting electricity flows on others who are using the system. There is a failure to coordinate, and the complexity of the system makes it difficult to institute a pricing scheme that adequately internalizes the external costs arising in the normal course of business.

Systemic Risk in Food Sectors

The systemic risks, and the approaches to managing them, that arise in the insurance, banking, and electricity industries provide useful background for considering the inherent nature, and potential for control, of systemic risk in food sectors. In this section, we classify and discuss four sources of systemic risk in the provision of food. We do not claim that the list is exhaustive, and two or more sources of risk may compound in contributing to a food system breakdown. Table 1 provides a taxonomy of food system risks.

To preview the table, causes of types A through C are related in that all arise from dependencies in the production system. Causes of Type A are technological and are due solely to the ways that the system components interconnect. Technological interconnections are a facet of systemic risk in the provision of electricity. In food production, if all processes must be performed satisfactorily then interconnectedness makes a system vulnerable. In contrast to Type A, causes of Type B arise from incentives problems. We have already noted that incentive issues are part of the problem in each of the other three reference sectors. In this type of food system problem, there is mistrust because consumers or downstream processors are of the opinion that parties who may have pertinent information about food quality also may have the incentive to mislead. Consumers may mistrust a processor of allegedly high-quality food because the provision of quality food is costly. Also, consumers may mistrust the regulatory process if they

TABLE 1. Taxonomy of systemic risks in food production

Causes of Systemic Risk	Consequences	Potential Policy Implications
A. System topology *i*. Consequences are known but cause is not *ii*. Cause is known, but mixing occurs	* Losses spread through much of the system	*Reduce interconnectedness by* * improving traceability * closing of system * investing in efficient science, epidemiology, information management, and audit infrastructure
B. Mistrust in communication *i*. Mistrust of the sender *ii*. Mistrust of the process	* Uninformed consumers * Private branding * Crisis, consumer panic, and market disruption	* Improve communication paths and speed (HACCP, quality audits, etc.) * Facilitate a fair market in third party testing * Mandate labeling * Legislate for policies to prevent overprotection against risk * Implement truth in advertisement * Efficient procedures for redressing torts * Enforce laws on evasion of responsibility * Perceived impartiality and efficiency in government policy and oversight * Separate risk assessment, management, and communication functions
C. Asymmetric information leading to coordination failure	* Underprovision of care in protecting food quality * Underprovision of information	* Improve testing, traceability and verification methods (reduce coordination costs) * Rationalize production systems * Do not impede contract production * Encourage cooperation to establish longer-term supply relations * Promote trade in foods * Interpret policies on mergers and acquisitions more leniently for firms in food industry * Improve sanitation infrastructure * Promote leadership activities
D. Failure to develop state-conditioned technologies *i*. Narrow technology development platform *ii*. Overload	* System performance may deteriorate in the event of a state that the platform cannot readily adapt to * System performance varies as deterministic states change	* Encourage storage and seed banks * Develop emergency planning procedures * Provide subsidies for non-linear research * Adapt regulations to deterministic states of nature * Contemplate mechanisms to promote radical technical innovations

believe that it is not up to the challenge that it faces. Akerlof (1970) showed long ago that widespread mistrust may cause a market to fail.

Causes of Type C introduce more subtlety into the information/incentives problem because actions other than the decision to buy are involved. Actors in the food processing chain are imperfectly informed about the actions of others in the chain. All will take privately optimal actions given the profit functions they face. The result may be that each firm takes insufficient care of food when the food passes through its gates. This problem is, in a sense, a failure to coordinate because if an enforceable means of contracting upon actions could be implemented then all firms might benefit. Knowing for sure that all other firms were taking care in their respective operations, each firm may then have the incentive to take good care. That is, a better equilibrium may then be sustainable.

The final type of cause, Type D, has little to do with system structure or with static incentives. It arises because the number of states of nature that can occur may exceed the number of states that the available technologies can cope with. First, suppose that states of nature are random. Then a trade-off may exist between (*a*) locking into a narrow technology development trajectory that may not work for all states of nature, and (*b*) proceeding with the more costly development of a wider set of technologies that is more likely to be able to cope with all states of nature. Second, if states of nature are deterministic but non-constant, then a single decision variable affecting food safety may not adapt well to all states of nature. Given the available technical opportunities, it may require prohibitive costs to adapt the system to perform well under all circumstances.

System Topology

Consequences Are Known, But Cause Is Not. One type of systemic risk occurs when mortality, illness, financial loss, or evidence of possible future adverse consequences is ascertained but the origin of the problem is not known. A graphical depiction emphasizes the systemic nature of such a failure. Suppose that three restaurants source from two providers. Figure 1 is a node diagram of the system, with the three restaurant nodes to the right. Arrows indicate the direction of product flow.

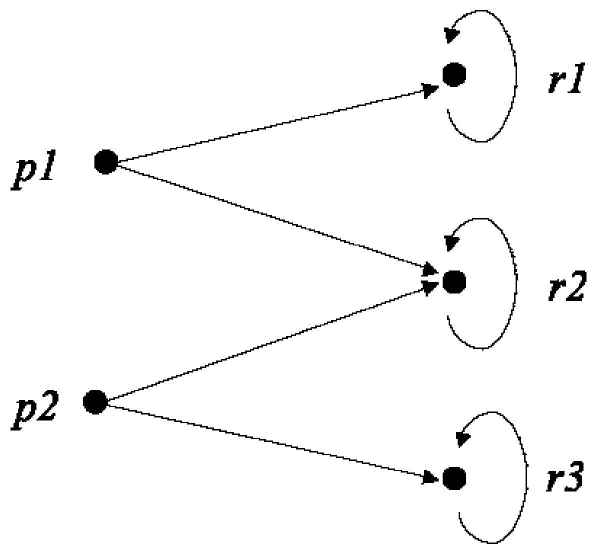

FIGURE 1. Node diagram of restaurants and providers

Restaurant *r1* sources from provider *p1* only, restaurant *r3* sources from provider *p2* only, while restaurant *r2* sources from both *p1* and *p2*. The circular arrows at the restaurant nodes indicate that the restaurants also provide some of their own inputs.

Suppose that problems, such as illness, arise at *r1*. Then to be safe, and in the absence of information to preclude problems emanating from *p1*, nodes *r1*, *r2*, and *p1* may have to close for quality audits. Were problems to be evident at node *r2*, then the whole system would have to close for an audit. Node *r2* is the most strongly connected among all the nodes, and the systemic risk associated with a problem that becomes evident there is most severe. We might enumerate the systemic risk relations in the manner of Table 2, which maps node failures to product losses. Notice that failure at one among a set of nodes leads to losses through a set of nodes that is possibly much larger.

An example of this type of risk is the bovine spongiform encephalopathy (BSE) epidemic that emerged in the United Kingdom in 1986. Among the problems arising in managing BSE was the lack of knowledge concerning its epidemiology. It was not until the middle 1990s that prions became widely accepted as the cause of the disease. Even in 2001, much remains unknown about preventing and diagnosing BSE (U.S. Department of Agriculture 2001). Given this very uncertain environment, and seeking to move toward putting the outbreak behind it, in April 1996 the British government condemned all

TABLE 2. Failures and consequences when causes are unknown

Failure at Nodes	Losses at Retail Nodes	
	When cause is unknown	*When cause is known*
r1	*r1* and *r2*	*r1*
r2	*r1* and *r2* and *r3*	*r2*
r3	*r2* and *r3*	*r3*
p1	*r1* and *r2*	*r1* and *r2*
p2	*r2* and *r3*	*r2* and *r3*

bovine animals aged 30 months or older to slaughter. These carcasses were not to enter human or farm animal feed paths. There are many other instances of systemic risk owing to uncertainty about the science of BSE. Having strong evidence implicating animal tissue in feed, commencing in July 1988 the British government banned animal-derived feed in ruminant diets. But in 1993, some 6,000 cattle born after the ban succumbed to the disease. Believing contaminated feed to be the sole cause, the British Ministry of Agriculture attributed these cases to illegal transgressions of the feed ban. By April 1994, however, it was certain that BSE could be transmitted from cow to calf.

Cause Is Known, but Mixing Occurs. A variant on *i* above occurs when we isolate the role of interconnectivity from that of ignorance in contributing to a systemic risk. Suppose that the sale of products containing genetically engineered soybeans is prohibited in a country. In the node diagram in Figure 2, soybeans and input *a1* are ingredients in retail product *b1*, while soybeans and input *a2* are ingredients in retail product *b2*. If the soybean ingredient materializes as partially genetically engineered, then products *b1* and *b2* must be removed from the market because of the mixing that occurs during processing.

Clearly, the loss that occurs when the problem source is known can be no larger than when the problem source is unknown. If, in Figure 1, *r1* fails and the problem is known to be internal (i.e., attributed to internally provided inputs at *r1*), then the output from *r2* is not lost. However, mixing ensures that if *p1* is known to fail, then both *r1* and *r2* will fail. The loss would then be just as severe as when the consequences of a failure emerge at *r1* but the cause of failure is not known. Two examples illustrate the role of mixing and the importance of controlling its extent.

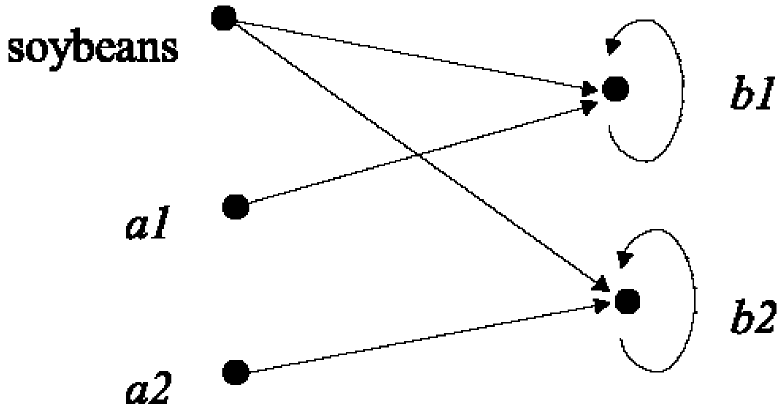

FIGURE 2. Node diagram of ingredient mixing

An outbreak of *E. coli* O157:H7 caused about 20 deaths in Scotland during late 1996. An official inquiry, summarized in Pennington (1998), pointed to a butcher's shop as the point of failure. Concerning mixing, the report strongly recommended that raw meat and unwrapped cooked meat should be stored in separate facilities and processed with different equipment. Where at all possible, handling staff should be separated also.

In Belgium in 1999, recycled animal fat was directly contaminated with dioxins and polychlorinated biphenyls (PCB) when stored before melting. The truck that delivered contaminated fat to a feed mill was not properly rinsed before being used for a delivery of animal fat to another feed ingredients company. As a result, several feed mills processed contaminated fat and sold the contaminated feed to poultry, pig, and cattle farms. After the problem was identified, all animals from these farms were destroyed.[2]

In both the sub-cases (where cause is unknown, and where it is known but mixing occurs), the consequences of the system failure can be spread throughout the entire food system. The risk cannot be contained in the sectors (product) at immediate risk. The case where the consequences of failure are known but the cause is not bears many similarities with systemic bank failures. The nature of interconnectivity, for example, a common feed source, matters, and losses may occur mainly because of poor information flows. As with banking, efforts to alter the pattern of connectivity (e.g., food identity preservation versus prohibitions on interstate banking) will affect system vulnerability, as will improvements in information flows. Unlike monetary risks, however, food quality attributes are not readily reversed. *Ex post* remediations analogous to deposit insurance can only be of limited effectiveness.

Mistrust in Communications

Mistrust of the Sender. Depositors may interpret signals issued by banks, such as size, reputation, and declared risk management strategies, when deciding where to deposit funds. They are, however, unlikely to be fully apprised of bank activities because banks may be unable, or unwilling, to communicate some information. If feasible, it will be optimal for a bank to lend at high rates to entrepreneurs engaged in risky projects but to borrow at low rates. The bank has an incentive to dissimulate about its lending portfolio. In food markets, too, customers use informative signals, such as food nomenclature and brands, in an attempt to reduce risk exposure. The branding, labeling, and, to a limited extent, categorization of food are strategic variables available to firms, and so a consideration of firm strategies in determining the level and communication of risks is warranted.[3]

In developing brand recognition, a firm may seek to insulate itself from possible systemic risk spillovers arising in other brands of similar products. The firm should, however, realize that if problems arise within the brand then the adverse consequences will be more severe. For example, publicity following the 1993 *E. coli* contamination at the Jack-in-the-Box chain of fast food outlets led to a 25 percent decline in sales. As discussed in Swinbank (1993) and in Henson and Traill (1993), firms may seek to vigorously protect brand reputation because a whole line of products, whether or not of suspect quality in the eyes of experts, may be tarred in the marketplace. Hence, there may be a socially excessive provision of food safety embedded in some marketed foods. If a brander does face a problem, it may rue its market presence because it has provided a clear target for retribution in the marketplace. Rosenbaum, as reported in Buzby and Frenzen (1999), believes that large franchises are more likely than are most defendants to settle food safety liability claims out of court.

A related issue arises when laws require a country-of-origin label on foods. This provides the consumer with more information, and consumers may wish to exercise preferences for domestic product. If, however, a problem arises in domestic production, this label may act to reduce demand for domestic product.

Mistrust of the Process. In this case, consumers no longer trust the competence and/or integrity of parties involved in ensuring the quality of particular food products. This was likely a major factor in consumer response to the admission by the United Kingdom's Minister for Health in March 1996 that there may be a link between the agent that causes BSE and cases of *new variant* Creutzfeldt-Jacob disease in humans. Authorities had delayed the official revelation until long past when most consumers had heard reports to that effect from other sources. Rampton and Stauber (1997) document newspaper articles on a possible connection in early 1993. Tardy action was likely also a factor in contributing to consumer concerns in the Belgian dioxins case in the spring of 1999.

At first blush, an analogy might seem to exist between this type of food system failure and the banking crisis model of Diamond and Dybvig (1983). But one critical element is missing—the multiple equilibria in the bank run model are self-fulfilling because of feedback. It is reasonable to become increasingly concerned about the security and future liquidity of one's own funds when others withdraw large amounts. There is no such reinforcing feedback when customers begin to lose confidence in those responsible for delivering quality food. Where there is feedback as a crisis evolves is in the level of consumer exposure to information about the risk in question and about a production system that may leave something to be desired. Media incentive structures in the dissemination of information are unlikely to be well aligned with public welfare, even if libel laws pertain.[4] Consumers who have lost confidence in the system will be more prone to panic when faced with new scares.[5]

In each particular case where consumers lose confidence, there probably are technical solutions to the problem at hand. But immediate recourse to technical fixes may miss one of consumers' main concerns: that the institutions charged with safeguarding food do not work well. It is likely that more lasting solutions will come by way of altered institutional mechanisms.

A failure in the process design may distinguish a crisis from a simple "accident." A crisis may be thought of as an accident that can no longer be addressed with existing institutions and routines. It generally adheres to the following characteristics (Zwetkoff 2000): (1) the accident threatens the achievement of one or more of the primary societal objectives, (2) agents involved in the crisis are subject to an abnormal degree of uncertainty, and (3) the return to "normality" requires resources that go beyond the actors directly involved in the accident. The crisis develops as it becomes clear that established institutions and routines no longer suffice to address the problem. Institutional innovation that involves new procedures and new resources may be required to establish an acceptable equilibrium (Hodgson 1988; Zwetkoff 2000).

Asymmetric Information Leading to Coordination Failures

Middle nineteenth century food provision systems to urban areas tended to be fragmented, with food changing ownership many times. The food science discipline at that time was nascent, and so it was often difficult to verify the quality of products for sale. Given ample opportunities, it should be of little surprise that deception and fraud pervaded food systems. Collins (1993), looking at food systems in the United Kingdom in the latter half of the nineteenth century, documents the extent of food adulteration. Liquid foods were watered down by up to 50 percent, while condemned meat regularly re-entered human food systems. Poisons, such as lead and arsenic derivatives, were common additives. These problems were also pandemic in the United States (Scheuplein 1999).

Clearly, this was an unsatisfactory situation for consumers. Neither was it likely to be satisfactory from the perspective of many producers, because the system was prone to waste. Quality producers might have been particularly unhappy because potential investors in the food system might not have had sufficient confidence in the quality of the product to make further investments in preserving quality along the supply chain.

Game theory provides a means of interpreting the production problem. One participant, say, X, in the production system may not know for a fact that another participant, say, Y, is not engaging in activities that preserve food quality. However, if X deduces that there is no private incentive for Y to take good care of the food, then X will correctly infer that Y does not take good care of the food. X may conclude that there is then little point in taking good care of a food that will likely not reach the consumer as prime product. Y, too, may be in the same situation with regard to imputing the behavior of X. It may be logical for both to save on costs by behaving with less care toward the product that they handle. Owing partly to a failure to coordinate, the firms have beggared themselves.

Several factors contributed to a large-scale cleanup of UK and U.S. food systems by World War I. In 1860, the British parliament passed into law the Adulteration of Food Act. It was not seen as a success, however, in part because the law required proof that the vendor knew of the adulteration and of its potential to harm consumers. In addition, few local authorities employed sufficient staff to enforce the act. Later acts redressed these problems, while scientific advances permitted more informed judgments about what was actually hazardous to human health. In 1906, in response to strong public concerns, the Pure Food and Drugs Act was passed into U.S. federal law. Infrastructural innovations, such as the widespread availability of potable water and city garbage collection, likely also contributed to the cleanup. Food companies that best took advantage of these modernities would gain custom and expand.

As developed in Collins (1993), perhaps the main reasons for the cleanup were economic. For the United Kingdom, freer trade with her colonies and with the New World put downward pressure on food prices, thus removing the profit incentives from fraud. Increasing wealth also allowed consumers to be more discriminating about the quality attributes of consumed food. Branded products, competing on quality dimensions, proliferated. Freer trade also had significant structural impacts. By centralizing and recapitalizing an undercoordinated and undercapitalized distribution system, incentives were stronger for the few importers to source good quality raw materials and then protect that quality thereafter.

Even today in developed countries, unfocused supply chains are believed to be a major reason for chronic quality problems. During the 1980s, U.S. poultry processors started providing pre-packed products to supermarkets, thereby reducing the potential for point-of-retail contamination. By the late 1990s, pork, beef, and lamb processors had followed suit. Consolidation among retailers has propelled that trend. Smithfield Foods, Inc., a vertically integrated pork producer and processor, has suggested that the move by Wal-Mart into food retail was a major factor in the trend toward pre-packing (*Des Moines*

Register 2000a). In the case of Japan, following a sequence of food quality failures during the hot summer months of 2000, many express the belief that the ultimate cause of such problems is the inefficiency in food processing made possible by protectionism (*Economist* 2000).[6]

Failure to Develop State-Conditioned Technologies

States of nature may arise randomly or in a deterministic manner. In the first part of this section, we will discuss how randomness in the evolution of nature may lead to a level of technical diversity that is socially insufficient in protecting against adverse future possible states of nature. The reasons may be failures in the political process or failures in intergenerational incentive structures. But, even when states of nature are deterministic, systemic "risk" may arise because of the costliness of providing production and processing infrastructure adequate for all such states. Economic incentives may favor overloading the production infrastructure in some states of nature. In the second part of this section, we will discuss possible reasons for food safety concerns, even in a deterministic, but mutable, environment.

Narrow Development Platform. Diversity in a species gene pool likely carries with it the real option value of enhanced sustainability for the population.[7] Diversity increases the probability that some sub-population will be able to adapt to a stressed environment such as the introduction of an exotic pathogen. In the case of a food product affected by a quality problem, high variability in the gene pool likely increases the probability of a timely solution when genetics is an important determining factor. With reference to the common external-driver type of systemic risk typically encountered in insurance markets, a heterogeneous species gene pool is better for society because the least and most affected genetic lines offer breeders a lead in finding a genetic solution to a food system breakdown.

Technologic homogeneity also limits flexibility in meeting the challenges of a food crisis. Wolf and Zilberman (1999) argue that a critical role of public research is to engage in fundamental research on differentiating technologies because time lags and incentive structures likely bias private research toward linear technology extensions and because heterogeneous technologies limit the extent of market power. Biotechnology, in increasing the capacity to differentiate food attributes and in reducing the time taken to do so (Mazur, Krebbers, and Tingey 1999), should enhance a society's ability to cope with crises even if these same attributes may also contribute to the development of such crises. More generally, *ex ante* research on combating such contingencies at the advent of an alien hazard that is common in other production regions of the world will provide real options when managing a crisis.

The nature of homogeneity in the approach to veterinary and medical problems is also a food safety issue. We have previously documented that the suppression of small fires can exacerbate catastrophic risk for insurers. In these cases, it may be better to allow small losses in order to reduce the probability of larger losses. Similar trade-offs arise in managing food systems. Having proven to be a success in human medicine, the same or related antibiotics were introduced into animal feeds because healthy animals convert feed more efficiently. Over time, however, evidence has mounted that resistance developed in the course of agricultural applications could be transferred to bacteria that pose significant risks to humans (Gorbach 2001). Of much lesser concern is the possibility that human and other uses of antibiotics might promote resistance in bacteria harmful to agriculture. Either way, regulators must decide whether to ban some uses of a technology in order to increase its prospects for durability in the remaining uses.

In managing such trade-offs, the political economy of pressure groups may become important. There may be strong opposition to a regulation that increases a narrow loss because the losers (producers) might be severely impacted and may form a cohesive lobbying group. The potential benefactors (the population at large) from a reduction in systemic risk may not be significantly impacted at the individual level, and may not have enough in common to lobby effectively (Olson 1965). A related political problem may narrow the feasible choices for institutional innovation in managing food quality failures. Rent-protecting public servants may be able to block innovations that are less reliant on public involvement.

A tendency toward a state of homogeneity that is costly to reverse, be it in bio-variety, the menu of technologies available, or the portfolio of tools applied to a set of problems, could result from intertemporal market failures. Von Amsberg (1995) has pointed out that an early generation may logically opt for homogeneity, with the consequence that later generations are exposed to increased risk. In such a situation, insurance markets and political solutions cannot be supported in the absence of altruism because consumers at risk in later generations are inadequately represented.[8]

Overload. While the findings are somewhat mixed, the weight of evidence suggests that increased line speed in meat slaughtering operations causes an increase in carcass bacterial contamination (Bell 1997; Sheridan 1998). Line speed is a critical determinant of capital requirements in meat processing. Seasonality is one of the distinguishing features of agricultural processing operations. In the United Kingdom and Ireland, for example, most milk is produced during the spring and summer from grazing cows while most cattle and sheep are slaughtered after being fed on cheap summer grazing. For each of these products, processing facilities are fully utilized only a few months of the year. Given the limited seasonal interval available to recoup capital costs, there may be strong incentives for processors of seasonal products to push in-season product flow beyond the point where product reliability is acceptable.

Another form of overload involves the presence of external environmental conditions that give rise to increased risks. Systemic insurance risk might present the best analogy. Infrastructure failures, such as power outages, create vulnerabilities by disrupting food storage and distribution logistics. Problems may be more severe if the source of disruption is a disaster, for example, floods or earthquakes, when humans also are dislocated and vectors for pathogen contamination pervade the environment. Even under less extreme circumstances, in a heat wave for instance, increased biological activity may expose vulnerabilities in a food system. In this case, the risks across food sectors are likely to be correlated.

Overload often increases risk correlation, to the detriment of system performance. Pseudorabies is a significant problem in U.S. hog production. While not a hazard to humans, animals infected by the virus display low fertility as well as other ailments. Spatial correlation in incidence is high because the disease is spread primarily by direct or indirect contact. Eradication efforts emphasize movement controls on infected herds. The problem is most severe where hog population density is very high, as in the state of

Iowa. Laws that control hog movement in the state led to the slaughter of 900 pregnant sows by Iowa Select Farms in the mid-summer of 2000 (*Des Moines Register* 2000c).

Policy Implications

While information problems arise in each of the four outlined classes of problems, they do so in a variety of forms. In Type A, the roles of additional information are to facilitate design and to diagnose the cause of a breakdown in a more timely manner. Perhaps the easiest way to increase the level of information is to re-organize the system so that production occurs through closed, or disconnected, sub-systems. Alternatively, identity preservation could reduce the mixing problem by distinguishing between products that flow through different paths. Concerning prompt determination of failed nodes, it will always be helpful to have a strong science base to draw upon. Helpful, too, would be a rigorous, timely, flexible, and objective approach to auditing, and a reliable, readily accessible data base on product flows.

Strong inter- and intra-firm communication infrastructures are also important. Quality assurance schemes, such as ISO 9000 (Holleran, Bredahl, and Zaibet 1999), the Pome fruit production systems in many European countries (Cross and Berrie 1995), and livestock integrated quality control systems in the Netherlands (Bekman 1998), provide a common language for rapid communications. Effective data flows facilitate *ex post* epidemiology in the event of a realized quality problem. In promoting learning, they may also lead to innovations in protection technologies. In addition, they may enhance incentives to take precautionary actions even within a given set of available technologies.

In Type B, strategic aspects to the provision of information then arise. This is particularly true when a seller is not trusted by the buyer. The private sector may overcome many of these problems without the involvement of government. Strategic communication through branding may redress the problem if the buyer believes that the sender has a reputation to protect. However, it is conceivable that private sector activities to overcome this problem will cause additional social waste through excesses in protective behavior. There are several ways the government could improve system performance. The absence of standards in food labeling may make it difficult for consumers to understand the messages the sender seeks to convey. Labeling standards likely would improve the consumer's information environment and could reduce the incentives for excessive protection.

A private sector approach to alleviating mistrust could involve a third party that tests for food quality. To work satisfactorily, consumers must understand and trust the role of the third party. The government might affirm the independence and competence of the testing firm. This would involve regulations on the behavior of both the food seller and the testing firm, but it should not involve so much regulation that a market in independent testing becomes unviable. Related concerns arise if the government uses the law of torts when seeking to strengthen the seller's incentives to be truthful. If private citizens are to take civil actions, then the legal system must be accessible, efficient, and effective.

The government could also act directly by subjecting firms to quality audits, as is often the case in HACCP (Hazard Analysis Critical Control Point) programs, and then punishing firms that do not meet prescribed standards. Punishment might take the form of a fine or a public announcement that the firm failed the audit. While not improving the buyer's trust in the seller's word, punishment should reduce the need for communication on quality and may enhance the buyer's trust in the quality audit itself. An approach that would directly reduce mistrust on the part of the buyer is a set of enforced truth-in-advertisement laws.

When the issue is mistrust in the process, it would be preferable to have had in place an adaptable, preventative infrastructure before a crisis makes weaknesses obvious. As an effort to promote prevention, a National Research Council (1983) report recommended that food safety risk mitigation procedures be comprised of three distinct, but integrated, functions: risk assessment, risk management, and risk communication. In this way, there is clarity as to what a team is responsible for, be it identifying and measuring risk exposure, reducing the risk, or communicating with interested parties.

Also, and again with emphasis on mechanism design, separation of food safety regulators from organizations perceived to be advocates of one party or another is advisable if consumers are to trust regulators. Many would claim that, perhaps as fallout from conflicting policy goals, public authorities sometimes do not merit that trust.

Lobstein (1999) argues that while governments promote at a verbal level the substitution of fruits and vegetables for fatty foods, their actions often contradict this message. For example, funded EU policies would seem to promote a less healthy diet. In the United States, some have expressed concerns, through the judicial process, that industry self-monitoring aspects of HACCP programs in the meat industry constitute an abrogation of government responsibility (*Des Moines Register* 2000b).[9] In other words, many citizens worry that self-monitoring does not work.

Most governments in developed countries now have moved toward separation of the food safety regulation responsibility from other charges such as agricultural production policy. Some have sought a separation of responsibility within the food safety remit. The new European Union Food Authority is designed to comply with the National Research Council recommendations that the assessment, management, and communication functions be separate but integrated. The body, which will be independent of other community institutions, will focus on risk assessment.

While many issues other than information problems arise in cases of Type C, much of what has already been stated about information policy also applies here. More coordination will likely occur when system participants are better informed about behavior elsewhere in the chain. The information asymmetries may often arise from the costs associated with conveying information, and any approach to reducing these costs will likely facilitate coordination. Contracts to source food may help in this regard, especially if contract duration is long and each party has access to the other’s production facilities. Producer cooperatives that seek to establish longer-term supply relations may also help to reduce the costs of acquiring information.

There are other, perhaps more effective, ways of promoting coordination. Impediments to the rationalization of production systems may arise because of a lack of domestic or external competition. In addition, the measures involved in obtaining permission to install such novel equipment as an electronic pasteurizer or in building new plants may be too prohibitive. Infrastructure policy also has a role to play. It is unlikely that incentives to take precautions will be strong when other risks pervade the environment. Even today, infrastructural deficiencies are considered a serious impediment in street food sectors, especially in developing countries (FAO 1995). Transportation, water quality, power reliability, and access to education/training may be among the main infrastructural constraints.

Many of the organizational problems in the processing sector would disappear if parties could enforce actions through contractual agreements. Best hygiene practices could be verifiably mandated, with penalties for measured non-compliance. Best practices, though, are often innately non-contractible. While worker personal hygiene might easily be imputed, and observed with some effort, it would be difficult to use this evidence when disciplining a worker or firm. Quite a large literature now exists on the issue of how non-contractibility affects the optimal organization of economic activities, especially the make-or-buy decision.[10] This literature might reveal much about systemic failures in incentive structures and how specific system designs can alleviate these failures. For example, a Hennessy, Roosen, and Miranowski (2001) study of food production systems applies the notion of non-contractibility to identify situations in which communicated leadership on the part of one firm may improve the profits of all firms while also increasing food safety. Private attempts to initiate communicated leadership in developing systems that have a commitment to quality might be encouraged by government product quality branding schemes, by recognizing firms that emphasize food quality, or by promoting integrated quality control programs. Alternatively, a stick might be applied by making some firm in the chain liable for a failure if the true culprit cannot be identified. This approach is in effect in the United Kingdom, where the Food Safety Act of 1990 would appear to place residual liability on food retailers.

Some systemic risks that arise through overload may be ameliorated by integrating production over time or space. With regard to time, effective storage can permit off-season processing of crops. With regard to space, animal production might occur at dispersed locations so as to reduce the probability of contagion. Other technical and logistical fixes may also be possible. The use of vegetable varieties that ripen at different times of the season can spread processing times for tomatoes. Formal international networks for disease identification may assist countries in coping with identifying the nature and extent of a problem in a timely manner. In animal agriculture, on-farm segregation and all-in, all-out production systems in hog production with tight biosecurity procedures will limit disease outbreaks. Some businesses will benefit from complementarities when planning to avoid hazards. A closer look at production flows through a system may identify sources of efficiency that previously had been overlooked.

Regarding contingent planning, seed banks have long been used to preserve options for the future. Well-designed emergency planning procedures will certainly help in addressing failures attributable to disasters. In many cases, however, incentive structures for innovation will need to be strengthened. The patent system is not particularly well suited to encouraging a broadening of the technology base because the patent likely will have expired before the real option on a novel technology is availed of. The fuel cell, now a competitor to replace the polluting diesel engine, was invented over a century ago. University incentive structures in the form of professional acclaim for scholarship and innovation and the opportunity to engage in remunerated consultation seem to be more suitable for encouraging these sorts of innovations.

When a disaster occurs, it may become very clear that the food system is being subjected to stress. However, this deduction may not be as obvious. It would seem wise for regulators to formalize the notion of state-conditioned stress when eliciting information from firms, when approving HACCP programs, when inspecting production facilities, and when otherwise engaging in oversight activities.

In conclusion, because many food safety problems are systemic, analysis and policy prescriptions should also have a systemic orientation. Many do, but there is less integration than there should be. Food safety analysts, and particularly economists interested in the issue, may have much to learn from the systems analysis approaches of such professions as industrial engineering and computer science. These professions have developed tools to formally model the main aspects of systemic interactions as they occur in their disciplines. The application of such tools would strengthen the scientific foundations of designing reliable production systems.

Endnotes

1. See, e.g., chapters 5 and 7 of Davis (1992).
2. There is also an element of the risk form described under point *i*. Animals and produce that were safe may have been destroyed because it took a long time to identify the failure and because products were difficult to trace in the Belgian system.
3. A related issue, developed in Loader and Hobbs (1999), is that of firm strategy adjustment when accommodating innovations in food safety legislation.
4. Several states in the United States have in place food product disparagement, or veggie libel, laws. The intent is to deter the distribution of negative opinions about food products when the opinions are not grounded in valid science. See Hayenga (1998) for a discussion of issues.
5. An example is the reaction to the outbreak of foot and mouth disease (FMD) in the United Kingdom and elsewhere during early 2001. FMD is not known to be a danger to public health. At the time it also became known to the public that BSE had made further inroads into continental European cow herds. Food safety issues, pertinent to BSE, were confounded in the eyes of the public with the FMD problem.
6. The Snow Brand Dairy event received the most media attention. Some 180 consumers were hospitalized as a result of dirty dairy pipes at the processing level.
7. Broadly, a real option value is the value associated with maintaining a comparatively large set of opportunities when making decisions in an uncertain environment. See Trigeorgis (1998).
8. See Swanson (1995) for a series of papers on possible causes of increasing bio-uniformity.
9. On June 30, 2000, the U.S. Circuit Court of Appeals reversed an earlier decision. The Court of Appeals declared that a federal inspector should inspect each carcass at all slaughter facilities.
10. See Hart and Moore (1990), and Maskin and Tirole (1999).

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