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Public Goods, Hysteresis, and Underinvestment in Food Safety

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Despite the economic damage inflicted by a foodborne disease outbreak, firms at all points in the supply chain appear to be reluctant to invest in the necessary food safety technologies and practices. We argue that these investments are subject to both hysteretic and public good effects, and construct a theoretical model of food safety investment, calibrated to describe the 2006 *E. coli* outbreak in California spinach. Both effects are found to induce delays in food safety investments, but the public good effect dominates. We suggest a number of policy options that improve incentives to contribute to the public good.

Key words: food safety, hysteresis, investment, public goods, real options, simulation

Introduction

Concerns regarding the safety and integrity of the fresh produce supply chain are becoming all too common in the media. From the *Hepatitis A* outbreak linked to green onions consumed at a restaurant in Pennsylvania in 2003, and the *E. coli* contamination of bagged spinach in 2006, to the spread of *salmonella* poisoning among jalapeno chili consumers in 2008, a seemingly endless stream of news stories links fresh produce and foodborne diseases. These incidents have led to a host of initiatives from industry officials, legislators, and fresh produce retailers to ensure the safety of fresh produce (Cline, 2007). The necessary technology and best practices knowledge exist, yet some suppliers have not made the investment required to ensure such outbreaks do not occur again in the future. The objective of this study is to explain why this is the case.

There are a number of reasons why suppliers appear to underinvest in food safety compared to what would be regarded as socially, or collectively, optimal. Investments in food safety can take the form of anything that reduces the probability of a foodborne disease: new production or packaging technology, developing and implementing a HACCP process, hiring a quality control consultant, or a similar commitment to industry best practices. Of all the possible explanations for underinvestment, we consider two that are plausible: (*a*) free riding on others' efforts to maintain a safe food supply, or the "public good" effect, and (*b*) a hysteretic effect that arises from the real option embedded in food safety investments.[1] Although

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[1] Hysteresis is the continuation of a phenomenon after its original cause has disappeared. In economic terms, hysteresis refers to a decision state that does not change despite a significant change in the costs or returns that may mean the decision is currently suboptimal. If suppliers begin without a food safety program, then if hysteresis is present, they will continue without one until conditions change significantly.

the two are related, the policy prescriptions differ substantially. Which of these two effects is likely to be more important is an empirical issue we seek to resolve.

Assuming suppliers follow net present value (NPV) criteria when evaluating investments in food safety, they will invest only when the expected present value of potential savings from avoiding a future outbreak exceed the initial capital cost. This decision criteria, however, ignores two critical features of the problem. First, some of the potential savings (or avoided losses) can accrue to the industry as a whole. Similarly, if produce from another shipper who does not invest is contaminated and leads to a disease outbreak, then everyone in the industry suffers. Food safety investments are, therefore, possibly "weakest link" and at least "weaker link" public goods (Hirshleifer, 1983; Cornes, 1993; Burnett, 2006). Weakest link public goods imply the total amount of the service provided is equal to the lowest amount contributed by any of the members.[2] Weaker link public goods imply each contributor still receives part of the total benefit from his or her own investment, and the degradation from free-riding is only partial. Insect control is a good example. If all growers in a community spray for insects, but one does not, the total population will likely be lower, but still able to migrate into all growers' fields. To the extent each grower cannot appropriate the full benefits from making an investment, that grower's incentives to make the investment will naturally be reduced.

Second, the potential returns to investments in food safety are inherently uncertain. With an uncertain savings stream, a large fixed (and irreversible) cost of food safety investment, and a firm-specific opportunity to benefit from any investments made, the decision to invest is likely to entail a significant real option value. If an investment in a business practice or technology includes a real option, then in order for investment to take place immediately the present value of expected savings must exceed not only the initial capital cost, but the value of the embedded option of waiting to make an investment. Consequently, the more valuable the option, the more expected potential savings must rise before an investment will be made. Expected savings, in turn, depend on three primary factors: (*a*) the underlying distribution of returns to growing the crop; (*b*) the probability of a discrete shock to returns, such as a foodborne disease outbreak; and (*c*) the effectiveness of a food safety program in reducing the probability of contamination. Waiting for a stochastic returns series to rise above an investment "trigger" level, therefore, gives rise to a phenomenon known as economic hysteresis (Dixit, 1989, 1992).

Real options can arise in a number of agricultural applications, including capacity choice in the anhydrous ammonia industry (Stiegert and Hertel, 1997) and technology adoption by Texas dairy farmers (Purvis et al., 1995). In fresh produce, Price and Wetzstein (1999) show that uncertainty and sunk investment costs can combine to cause the hurdle returns to establishing or removing a peach orchard to diverge significantly from what traditional net present value analysis would suggest. Because the probability that a random returns process will exceed an "investment trigger" level increases with time, we do not directly observe the gap between full-cost and neoclassical hurdle rates in aggregate data. Rather, we observe periods during which neither investment nor disinvestment occurs despite considerable variability in returns (Abel and Eberly, 1994; Oude Lansink and Stefanou, 1997). This is economic hysteresis.

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[2] At the other extreme, a "best shot" public good is one in which the effective contribution is the highest amount provided by one member. In terms of the pest analogy, the best shot public good may be termed the "Pied Piper" effect in which one member attracts all of the pests and takes it upon himself to eradicate them. A similar opportunity in the food safety example is not plausible.

In this study we estimate the impact of hysteresis and free-riding on the timing of investments in food safety. Although the effects we describe are likely to exist throughout the supply chain, we frame our empirical analysis in terms of the costs and benefits specific to growers. The impact of each is demonstrated using an ex ante analysis of investments in food safety technology by members of the California spinach industry. We incorporate many realistic features into the investment-decision simulation model: (*a*) stochastic returns to growing spinach, (*b*) the probability of a discrete shock to returns caused by a future foodborne disease outbreak, and (*c*) the likelihood that a firm-specific investment will contribute to reducing the probability of a commodity-specific disease outbreak. With this simulation model, we estimate the contribution of both hysteresis and public good effects on food safety investments and whether either phenomenon constitutes a likely explanation for the apparent unwillingness to invest.

The remainder of the paper proceeds as follows. First, a theoretical model of food safety investment is described that admits the potential for hysteresis and free-riding. Hypotheses are developed for both effects relative to a competitive, certain benchmark. In the next section, we develop an empirical application in which investment under the benchmark case is compared to scenarios under which either uncertainty or free-riding may occur. This is followed by a section devoted to a description of the spinach case study, including the scenario we seek to explain, the data used to parameterize the returns process and the investment decision, as well as an explanation of the simulation techniques employed. The simulation results are then presented and discussed. The final section provides some conclusions and policy implications for how food safety measures can be crafted to ameliorate the impacts of hysteresis and free-riding.

Economic Model of Food Safety Investment

The returns to an investment in food safety (R_t) are equal to the avoided damages that would otherwise result from a contamination: the cost of returned or destroyed product, the value of any legal settlements, and a long-run loss in demand. Returns thus include both ongoing savings from preventing the lost goodwill or reputation that tends to permanently impair demand following a foodborne disease outbreak and one-time loss associated with the event itself. Because the timing, severity, and locus of the outbreak are inherently uncertain, the returns to an investment in loss prevention follow a stochastic process. Under traditional investment rules, growers ignore the uncertainty in future returns and make decisions based on net present value (NPV) criteria. However, if they take the random nature of returns into account, the investment opportunity likely contains a real option value and the investment decision will differ accordingly.

We also assume there exists an aggregate level of investment, whether by an individual firm or industry organization, which provides a privately optimal level of protection such that the marginal benefit of avoiding industry-wide losses is equal to the marginal cost of investment.[3] Individual firms decide whether or not to invest a fixed amount, equal to their proportionate share of the "complete protection" investment, on the assumption that all other firms' decisions are given. Industry equilibrium, therefore, is Cournot-Nash. Importantly, the *amount* of investment is not a decision variable, because it is determined by the nature of the food safety technology, but the *timing* of the investment decision is. More formally, assume

[3] This amount of investment, although privately optimal, still may be socially suboptimal from a broader perspective.

K_0 represents an amount of industry-wide investment that is sufficient to ensure the marginal benefit of avoiding an outbreak is equal to its marginal cost whereby:

$$K_0 = \sum_{i=1}^{N} k_{i0}\,, \tag{1}$$

where the N firms in the industry are indexed by i. The incentives to contribute to an industry-wide food safety effort are discussed below.

Investments in food safety technology reduce the probability of a foodborne disease outbreak. In a static model, or dynamic model without option values, such preventative investments directly reduce the probability of a negative shock to earnings (Kim et al., 2006). In our case, however, the returns process is regarded as inherently stochastic, so investments influence the probability of an outbreak through the mean and volatility of both the continuous and discrete parts of a stochastic returns process. More specifically, assume any shock to demand, or erosion of goodwill due to a foodborne disease outbreak, is manifest in a backward shift in demand. The extent to which the shock is reflected in market returns depends upon an impact parameter, θ, which in turn depends upon the amount of industry investment in food safety measures, $\theta(K_0)$. With this assumption, annual returns are written as:

$$R_t = \theta(K_0)(p_t - c_t)q_t\,, \tag{2}$$

where p_t is the output price, c_t is marginal production cost, and q_t is the amount shipped by a representative firm in year t.

Typically, the concepts of risk and public goods are used to explain underinvestment, which is assumed to mean the amount of investment relative to a perfectly competitive norm. Our interest, however, lies less in the amount of investment than in its timing. Clearly, these are dual problems. Consequently, we compare the timing of an investment in food safety under three scenarios in order to determine the relative importance of each potentially confounding factor: (*a*) no option value, no free ridership; (*b*) option values, no free ridership; and (*c*) no option values, and free ridership. Because combining both the real option and free ridership effects does not reveal anything about the independent effect of each, our experiment does not involve simulating both together.

The Benchmark Case

Under benchmark assumptions (no option value, no free riding) the decision maker invests when expected net revenue rises above the opportunity cost of invested capital, or:

$$R_t > rk_0\,. \tag{3}$$

If current returns are at R_t or above, then the firm will invest immediately. However, under the assumption that returns are stochastic, if $R_t < rk_0$, then investment will only occur at some point in the future when returns rise above the trigger level. To estimate when investment is likely to occur, we define a stochastic process for the returns to an investment in food safety that embodies both the ongoing uncertainty and discrete shock as described above.

Market returns are assumed to evolve according to a Brownian motion process of the form:

(4) $$dR_t = \mu(K_0)dt + \sigma(K_0)dz,$$

where μ is the mean drift rate per unit of time dt, σ is the standard deviation of the process, dz is an increment of a standard Weiner process with zero mean and variance equal to dt, and both the mean and volatility of the process depend upon investments in food safety subject to standard regularity conditions: $\mu_K > 0$, $\mu_{KK} < 0$, $\sigma_K < 0$, and $\sigma_{KK} > 0$. For the benchmark case, assume each grower has sufficient incentive to provide his or her share of the necessary industry-wide investment level as defined in (1) above.

Returns are assumed to follow a Brownian motion because per period changes in returns are normally distributed, independent from one another, and short-run dynamics are dominated by the volatility component whereas long-term dynamics are dominated by trend. It is not likely, however, that any trend away from the mean in (4) is likely to be sustained over the long run as returns in competition cannot grow without bound, nor will they fall below zero for a sustained period of time. Therefore, the process in (4) is modified to include a mean-reversion term so that:

(5) $$dR_t = \kappa\left(R_t^m(K_0) - R_t(K_0)\right)dt + \sigma(K_0)dz,$$

where κ is the rate of reversion to the mean, and R_t^m is the mean return. Further, returns are also subject to periodic "spikes" that capture periods of instantaneous change, which we assume to represent the announcement that a foodborne disease outbreak has been traced to the commodity in question.

Industry-wide commitments to outbreak prevention are assumed to reduce the probability of an outbreak, but not necessarily affect the magnitude of the shock to demand should one occur. We model shocks to demand as Poisson-distributed jumps in the stochastic process and allow aggregate food safety investments to reduce the value of the Poisson parameter, or the average number of occurrences per unit of time (Merton, 1976; Ball and Torous, 1983, 1985; Jarrow and Rosenfeld, 1984; Jorion, 1989; Naik and Lee, 1990; Bates, 1996; Hilliard and Reis, 1999). Therefore, the most general form of the returns equation becomes:

(6) $$dR_t = \left(\kappa\left(R_t^m(K_0) - R_t(K_0)\right) - \lambda(K_0)\phi\right)dt + \sigma(K_0)dz + \phi dq,$$

where jumps occur according to a Poisson process (q) with average arrival rate (λ) and a random percentage shock (ϕ). The random shock, in turn, is assumed to be lognormally distributed with mean $\phi - 0.5\delta^2$ and variance δ^2. The Poisson process q describes a random variable that assumes a value of 0 with probability $1 - \lambda$, and a value of 1 with probability λ, and with the assumption that $\lambda_K < 0$ and $\lambda_{KK} > 0$, or food safety investments reduce the probability of occurrence at a declining rate. With this definition of the stochastic process for returns, the "time to investment" is calculated as the expected number of periods before the NPV condition in (3) is met—or when the trigger value of returns is met whereupon immediate investment is value-maximizing. Because the stochastic process is highly nonlinear, we use numerical simulation (Monte Carlo) to calculate the average number of weeks before the investment condition in (3) is reached.[4]

[4] We define the time to delay in weeks (as opposed to months or years) based on the results of our simulation model. Using weekly data, the optimal time to delay was always less than 52 weeks.

Hysteresis in Food Safety Investments: Option Values, No Free Ridership

The investment rule described by equation (3), however, ignores the existence of a real option in food safety investments. If returns are uncertain, if the investment involves an irreversible commitment of capital, and if the firm has a unique opportunity to make the investment, a real option will exist (Dixit and Pindyck, 1994). By a "unique opportunity" we mean the investor has monopoly control over the benefits expected to flow from the investment. In the case of an industry-specific food safety investment, such monopoly power is clear. Because the option value explanation for hysteresis is well understood, we present an outline of the structure of such a model and focus our attention instead on its implications for estimating and testing an empirical model of hysteresis in food safety investments.

The option to postpone making an investment in food safety technology is analogous to a financial call option. We estimate the value of the real option using a risk-neutral valuation method where the "strike price" is the amount of the initial investment and weekly returns provide periodic dividends. Risk-neutral methods are appropriate because returns to spinach farming are not likely to be correlated with the market portfolio (Cox, Ingersoll, and Ross, 1985).

Risk-neutral valuation uses a three-stage algorithm. First, we "risk neutralize" the returns process by estimating (6) and removing all dynamics that are explainable by changes in the mean, by mean reversion or by jump processes. The remaining random variation is then a martingale, $\boldsymbol{Q}$, and dz becomes dv, where v_t is a $\boldsymbol{Q}$-Weiner process (Alaton, Djehiche, and Stillberger, 2002). Second, we form an expectation of the intrinsic value of the derivative under the $\boldsymbol{Q}$-measure defined by our risk-neutralized process. Third, we discount the expected payoff value back to the current date at the risk-free rate. This discounted expected payoff is the market equilibrium price of the real option (Harrison and Kreps, 1979; Turvey and Komar, 2007). More formally, given a constant market price of risk (ψ), a constant rate of interest (r), and assuming each contract pays one dollar per unit of returns, the martingale that defines the returns to the underlying index becomes:

$$(7) \qquad dR_t = \left(dR_t^m / dt + \tau(R_t^m - R^m) - \lambda\phi - (\delta + \psi)\sigma\right)dt + \sigma dv + \phi dq,$$

where dv is now a $\boldsymbol{Q}$-Wiener process (Alaton, Djehiche, and Stillberger) and the K_0 argument is suppressed for the sake of clarity. Hull (2005), however, argues that if the returns process is indeed statistically independent of the market portfolio, then the market price of risk is zero. Because this is likely to be the case for returns to a specific commodity, we set $\psi = 0$ in (7) and proceed to price the derivative using the risk-free discount rate.

Among all possible types of options, the ability to postpone an investment in food safety is akin to a call option on the returns to making the investment. A call option is the right, but not the obligation, to acquire an interest in the underlying process, which here is the stream of returns generated by investing in better monitoring technology. The expected payoff to a call option is given by $C_T = \max[R_T - rk_0, 0]$, where rk_0 is the annualized cost of the investment made by an individual grower. This expectation must be found under the $\boldsymbol{Q}$-measure. Taking the expectation and discounting to the present from T at the rate r gives a call-option value of:

$$(8) \qquad V_c = \exp\left(-r(T-t)\right)\left[(\mu_n - rk_0)\Phi(R_t) + \left(\sigma_n / \sqrt{2\pi}\right)\exp\left(-\sigma^2 / n\right)\right],$$

where μ_n and σ_n are the mean and variance, respectively, of the returns process, and Φ is the standard normal distribution function.[5] The expectation in (8) is found numerically using a Monte Carlo simulation with 1,000 random draws of the continuous diffusion process and 100 independent draws of the discrete Poisson jump process (for a total of 100,000 random combinations).

Once the real option is priced, estimating the implied hysteresis effect is relatively straightforward. When the embedded option is taken into account, the decision criteria must change to reflect the fact that net revenues must also cover the opportunity cost of exercising the option: $R_t > rk_0 + V_c$.[6] Because V_c is always positive, this decision rule implies that the full-cost R_t trigger is higher under a real option relative to traditional rules. Hysteresis arises because the process for net revenues is the same in either case—the decision maker will "wait longer" for the random returns process to exceed the higher full-cost trigger than in the benchmark case. We solve for the hysteretic effect by simulating the investment rule using Monte Carlo methods and comparing the optimal time to invest between traditional NPV and real option criteria.

Free-Riding and Food Safety Investments as a Public Good

The preceding investment rules assume a symmetric Nash equilibrium in the amount of food safety investment where the level of food safety control achieved is optimal in the sense that the marginal benefit attained is equal to its marginal cost, from a social perspective. Yet, this ignores the possibility that the absence of contamination represents a public good, or that producers may have an incentive to free ride on the investments made by others. In other words, if the aggregation technology characterizing the relationship between individual investments and the effective amount of the public good (K_0) is as described in (1), but firms are free to decide on their own contributions without institutional constraint, then we can expect free-riding to occur. Specifically, if the level of protection is the sum of all individual investments as in (1), then it is well understood that, in equilibrium, each firm lacks sufficient incentive to invest the socially optimal amount (Cornes, 1993; Cornes and Sandler, 1996).

The "summation" model of public good provision is not plausible in the food safety context, however, because the magnitude of the problem is such that no grower can completely ignore his or her potential to do seemingly irreparable harm to the industry. Nor is the weakest link scenario likely to arise because each firm can gain a measure of protection by developing its own food safety program and ensuring that any contaminated produce is not traced back to its own packing shed. Therefore, we model aggregate investment as a "weaker link" technology in which the marginal product of smaller contributors is higher than that of larger contributors, but the marginal benefit is not zero for anyone. In intuitive terms, investments in foodborne disease prevention are weaker link public goods—i.e., more investment by an individual firm can indeed lower the probability that it is the source of any outbreak, but can never completely eliminate the chance that the industry as a whole experiences an outbreak.

The most general aggregation technology represents the aggregate investment as a generalized mean of all individual investments, or a constant elasticity of substitution (CES) production technology which is written as:

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[5] The mean and variance found under the ***Q***-measure include the market price of risk and jump terms, but their specific form is not material here. They have been derived, however, and are available from the authors upon request.

[6] Dixit and Pindyck (1994) provide an exact solution in terms of the parameters of the stochastic process governing net revenues.

(9) $$K_0 = \theta\left(\frac{1}{n}\sum_{i=1}^{n} k_{i0}^{v}\right)^{1/v},$$

where θ and v are the CES parameters and there are n firms in the industry (Cornes, 1993). This general specification nests: (*a*) the weakest link model given above if $\theta = 1$ and $v \to -\infty$, (*b*) the best-shot model where $\theta = 1$ and $v \to +\infty$, (*c*) the average contribution model if $\theta = 1$ and $v = 1$, (*d*) the summation model (pure public good) if $\theta = 1$ and $v = n$, or (*e*) the weaker link assumption if $v > 0$ and $v \to 0$.[7] In the weaker link case, the CES specification in (9) reduces to:

(10) $$K_0 = \left(\prod_{i=1}^{n} k_{i0}\right)^{1/n},$$

where the critical attribute driving underinvestment, but not zero investment, is that the marginal product of those who contribute little is positive, but is higher than those who contribute more.

In the complete model of food safety investment, we include the possibility of free-riding by modeling aggregate investment in food safety according to the weaker link technology given by (10). In order to solve for the effect of free-riding on the timing of investment, it is first necessary to solve the dual problem—how much each firm can be expected to contribute in equilibrium. Assuming periodic variable returns are given by (2), and that industry equilibrium can be described by a symmetric Nash equilibrium with quadratic costs of investment, the amount each firm can be expected to contribute is found by maximizing current-period profit:

(11) $$\pi_i = \theta(K_0)(p_i - c_i)q_i - 1/2\gamma k_i^2,$$

with respect to the individual firm's contribution level, subject to the weaker link aggregation technology described in (10). The necessary condition for a solution to (11) is given by:

(12) $$\frac{\partial \pi_i}{\partial k_i} = \frac{\partial \theta}{\partial K_0}\frac{\partial K_0}{\partial k_i}(p_i - c_i)q_i - \gamma k_i = 0,$$

which is easily solved for the equilibrium contribution of each firm:

(13) $$k_i = \frac{(\partial \theta / \partial K_0)(p_i - c_i)q_i}{\gamma n},$$

where n is the number of firms in the industry.

In the empirical application below, based on the market effects of the spinach outbreak in 2006, we assume that the incremental level of protection provided by an industry-wide food safety effort ($\partial\theta/\partial K_0$) is 10%. We then solve for the minimum time to investment by numerically simulating the returns process in (6) and calculating the first period in which the NPV investment trigger in (3) is met. The traditional NPV criteria are used for this purpose,

[7] Hirshleifer (1983) shows that there is, technically, no unique Nash equilibrium in the strict weakest link case, but rather a continuum in which ". . . it pays no one to do more than match the prevailing contribution level of others if the marginal product of any further contribution is literally zero" (cited by Cornes, 1993, p. 262). Therefore, we assume, as does Cornes, that the CES scale parameter is instead finite so that a unique equilibrium does exist.

and not the real option trigger, because we want to isolate the hysteretic effect due to the existence of a real option from the public good effect, or the incentive individual growers have to wait until someone else makes the investment. Because the Nash solution depends critically on the structure of the industry (n), we simulate the optimal investment rule under a base case ($n = 120$) that approximates the current state of the industry, and provide comparative static results showing how the optimal time to investment varies with the number of firms. We also provide numerical comparative statics for another important determinant of investment under uncertainty: the volatility of the returns process. As the results below demonstrate, the comparative statics with respect to volatility have important, and somewhat counterintuitive, policy implications.

Case Study: Investment in Food Safety by California Spinach Growers

To make the empirical simulations comparing the hysteretic and public good effects more concrete, we use data from a real-world foodborne disease outbreak as a case study. Moreover, by parameterizing the model with values taken from actual experience, we provide results that are more general to the extent they are not based on arbitrary empirical assumptions. Specifically, the *E. coli* outbreak in bagged spinach is chosen to demonstrate the relative importance of what we regard as the two primary causes of underinvestment in food safety. In September 2006, the Centers for Disease Control and Prevention (CDC) notified other federal and state health agencies that they had evidence of a large-scale outbreak of *E. coli* O157:H7 contamination which was likely linked to bagged spinach sourced from farms in Central California. The outbreak eventually sickened over 200 people and led to the deaths of three. Estimated costs to the industry ranged from $100 million per month to $200 million over the entire episode in lost spinach sales. By some accounts, the spinach industry has yet to recover and may not do so for years to come.[8] In order to determine the cost and returns to an investment in food safety that would have prevented this outbreak, we require estimates of the nature of the returns process to growing spinach and the initial investment in food safety technology and practices.

The primary components of the investment model are the distribution of future cash flows and the initial investment. The initial investment required to establish a rigorous food safety program is estimated at $4.5 million for the entire industry. This was the amount required to establish the California Leafy Green Products Handler Marketing Agreement (CLGMA), which was the industry response to the spinach *E. coli* outbreak (Cline, 2007). This investment is assumed to be perfectly divisible, so the initial capital commitment is either $4.5 million at $t = 0$ by a monopoly entity, or as the sum of individual investments for a "summation" public good (Hirshleifer, 1983).[9] The investment includes such things as technology required for detection, hiring of a testing staff, or establishing industry-wide certification standards and a monitoring body. This investment is assumed to be shared by

[8] These estimates are thought to be reasonable, because an outbreak of *salmonella* poisoning in April 2008, initially linked to tomatoes, is estimated to have cost the industry at least $100 million before the blame was redirected to jalapeno chilies (Zhang, Jargon, and Miranda, 2008).

[9] This figure is an estimate of the cost of an industry-wide food safety effort. Cline (2007) reports an additional "25-cents to comply with the regulations and recordkeeping," but these costs are more accurately described as variable and not fixed investments. Because the amount of the initial investment is important in determining the timing of when an individual firm will invest, and this estimate is somewhat speculative, we provide a thorough sensitivity analysis regarding the impact of this value on the simulation results.

120 firms, which is the current membership of the CLGMA (California Department of Food and Agriculture, 2009).

Cash flows to the investment, however, are more difficult to ascertain. We assume that establishing improved food safety detection and prevention technology and procedures has two effects: (*a*) reducing the probability and severity of a one-time event occurring, such as the *E. coli* outbreak in the fall of 2006, and (*b*) preventing the erosion of goodwill (demand) over time, resulting from a permanent loss of some consumers or foodservice buyers. This latter effect means the preservation of both shipments and prices which would otherwise be significantly lower following a disease outbreak.

In 2006, shipments in the five weeks prior to the outbreak averaged 1.216 mil. lbs., falling to 0.626 mil. lbs. per week for the five weeks during the scare. Similarly, prices were \$0.486 per lb. prior to the food scare, while they averaged \$0.197 per lb. during the incident. In the five weeks following, prices rebounded to \$0.289/lb., which is a level similar to the same five-week period in prior years. This suggests the *E. coli* scare resulted in a dramatic, yet temporary reduction in total industry revenue of 79.1%. Over the longer run, however, it is more difficult to estimate the total, ongoing impact on consumers' perception of spinach. Therefore, we assume a permanent 10% downward shift in demand at each price level. While arbitrary, this assumption is supported by interviews with industry officials.

The stochastic process in (6) is estimated using a sample of weekly shipments and prices for spinach grown in California over the 288-week shipping period from April 2002 through October 2007 (see table 1 for pre- and post-outbreak quantities and prices). These data are derived from USDA National Agricultural Statistics Service sources. Because this sample period includes the *E. coli* outbreak that occurred in the fall of 2006, the data reflect at least one instance of a "spike" in demand. This fact helps to identify the jump component of the theoretical process described above.

Production costs are taken from University of California cost of production estimates for a representative spinach grower in Ventura County, CA, in 1999. All cost estimates are inflated to reflect 2007 currency values. Using an average variable cost estimate of \$0.30 per pound, the average weekly net revenue over the entire sample period for the industry as a whole is \$129,500.

Estimates of (6) are obtained by maximum-likelihood estimation over the entire sample data set, using the likelihood function:

$$(14) \qquad L(R) = -T\lambda - \frac{T}{2}\ln(2\pi) + \sum_{t=1}^{T} \ln\left[\sum_{m=0}^{M} \frac{\lambda^m}{m!} \frac{1}{\sqrt{\sigma + \delta^2 m}} \exp\left(\frac{-\left(dR_t - \left(\kappa(R_t^m - R_t) - \sigma/2 - m\delta^2/2 - m\phi\right)\right)^2}{2(\sigma + \delta^2 m)}\right)\right],$$

where T is the total number of time-series observations, M is defined as a number of jumps sufficiently large to include all potential jumps in the observed data (six proved sufficient in this application), and R_t is defined as weekly returns (percentage change in the gross margin from growing and selling spinach). Further, we approximate the change of R_t (dR_t) with a discrete change: ($R_t - R_{t-1}$). Richards, Manfredo, and Sanders (2004) demonstrate how this method can be used to estimate a similar type of process in an application to derivatives based on temperature indices (weather derivatives).

Table 1. Summary of California Spinach Price and Movement Data: April 2002–October 2007, per Week

Description	Units	N	Mean	Std. Dev.	Minimum	Maximum
Entire sample period:						
Quantity	mil. lbs./week	288	1.772	0.773	0.090	4.820
Price	$/lb.	288	$0.366	$0.128	$0.120	$0.959
Pre- *E. coli* outbreak (September 13, 2006):						
Quantity	mil. lbs./week	233	1.732	0.649	0.810	3.760
Price	$/lb.	233	$0.367	$0.124	$0.153	$0.959
Post- *E. coli* outbreak:						
Quantity	mil. lbs./week	55	1.946	1.151	0.090	4.820
Price	$/lb.	55	$0.360	$0.147	$0.120	$0.743

Source: Derived from USDA National Agricultural Statistics Service data.
Note: The data in this table refer to the entire sample period prior to the *E. coli* outbreak (September 13, 2006) and the entire period after. In the text, we refine these periods to include only the five weeks immediately preceding, and the five weeks following the incident.

Results and Discussion

To explain why growers appear to delay investments in food safety, we need to understand the nature of the stochastic process governing the investment decision, whether the estimated process is likely to generate a significant option value, and finally, whether the public good nature of food safety investments dominates any real-option effect that may exist. To that end, in the empirical application to the *E. coli* outbreak in spinach in the fall of 2006, three sets of results are of interest: (*a*) the structure of the stochastic process governing returns to an investment in food safety measures, (*b*) the real option value inherent in this investment, and (*c*) the extent to which the existence of a real option leads to hysteresis relative to the tendency of growers to free ride on the food safety investments of others.

Table 2 provides the parameter estimates for the most general form of the net return process. Although the results are not presented in this table, a specification testing procedure was conducted to test among successively more comprehensive forms of the stochastic returns process (detailed results are available from the authors upon request). Likelihood-ratio tests compared a simple Brownian motion (BM) process, to a mean-reverting Brownian motion (MR-BM) process, to a Brownian motion process with jump diffusion (JD-BM), and finally, to the mean-reverting, jump-diffusion BM (MR-JD-BM) process described above. This testing procedure favored the MR-JD-BM process, so the results presented here are taken from the preferred model.

As is evident from the parameter estimates presented in table 2, each of the structural parameters is significantly different from zero, and of the expected sign. Specifically, the estimate of λ, the Poisson arrival parameter, suggests a shock to demand can be expected to occur 0.59 times during every 288-week period, or approximately once every 10 years. This finding is consistent with industry experience. When a shock does occur, returns are expected to fall by 10.7%, on average. The *E. coli* scare of 2006 reduced demand by far more than 10%. Thus, the 10% estimate likely understates the most extreme cases because it represents an average over many smaller instances. Spinach returns increased by approximately 6.1% over the sample period, which reflects both higher prices and shipment levels prior to

Table 2. Weekly Stochastic Returns Process for California Spinach: Mean-Reverting Brownian Motion with Poisson Jump Process, April 2002–October 2007

Variable	Definition	Estimate	*t*-Ratio
λ	Poisson arrival rate	0.590*	9.372
σ	Standard deviation of continuous part	0.003*	6.736
δ	Standard deviation of jump process	0.023*	4.137
μ	Mean growth rate	0.061*	5.362
κ	Rate of mean reversion	0.342*	13.026
ϕ	Magnitude of jump	−0.107*	−5.439
Year 1	2002 binary variable	−0.001	−0.732
Year 2	2003 binary variable	0.002	0.189
Year 3	2004 binary variable	−0.024	−1.728
Year 4	2005 binary variable	0.011	0.749
Year 5	2006 binary variable	−0.012	−0.654
Log-likelihood function = 222.607			

Notes: An asterisk (*) denotes statistical significance at a 5% level. The MR-JD-BM process is estimated with maximum likelihood. Estimates of other processes are available from the authors upon request. Comparing the estimated LLF value to the null model LLF gives a χ^2 test statistic value of 145.321.

Table 3. Real Option Values for an Investment in Food Safety Technology, California Spinach ($000s)

	Standard Deviation of Stochastic Process, σ				
Investment, *X*	0.001	0.002	0.003	0.004	0.005
$1.5 mil.	$11.518	$11.778	$12.725	$13.969	$15.454
$3.0 mil.	$10.687	$11.042	$12.059	$13.382	$14.915
$4.5 mil.	$9.855	$10.343	$11.408	$12.818	$14.385
$6.0 mil.	$9.045	$9.646	$10.786	$12.263	$13.857
$7.5 mil.	$8.247	$8.958	$10.197	$11.730	$13.336

Notes: The values in this table represent the real option value of an investment (*X*) in food safety technology or processes in California spinach. Investment values are in millions of 2007 dollars. Real option values are calculated using Monte Carlo simulation of the mean-reverting, jump diffusion, Brownian motion process from April 2002–October 2007.

the *E. coli* outbreak. Finally, spinach returns revert to the long-term mean at a rate of 34.2% per week, which implies that any deviation is fully removed within three weeks. Again, this is broadly consistent with industry experience, although the most recent shock to demand lasted considerably longer than this average estimate.

The parameter estimates in table 2 were then used to simulate real option prices embedded in food safety investments. Table 3 shows the option values obtained under a number of alternative assumptions regarding key model parameters. Assuming base uncertainty (σ) and investment size (*X*) values of 0.003 and $4.5 million, respectively, the baseline real option estimate is approximately $11.4 million. Specifically, any proposed investment in food safety of $4.5 million must generate returns with an NPV of $11.4 million over and above the initial investment amount before it will rationally be undertaken, which is fully 253.3% greater than under traditional NPV rules. As the level of uncertainty rises, the real option value grows, reaching nearly $15.5 million under the base shock scenario at a standard deviation of 0.005.

As expected, the value of the real option is very sensitive to changes in the value of the initial investment. Indeed, the value of the real option embedded in a food safety initiative costing \$7.5 million is only 80% of the real option embedded in one costing \$1.5 million. The intuition behind this result is straightforward. The size of the investment is akin to the strike price for a financial option, so the further "in-the-money" the option may be, or the lower the investment amount relative to the present value of the expected returns, the higher the value of the option. Consequently, for a given returns stream, the smaller the initial investment, the greater the option value. As we show below, this effect has important implications for the optimal timing of an investment in food safety.

In fact, the economic significance of the real option values shown in table 3, relative to the amount of the investment, suggests a hysteretic effect is likely to arise. Table 4 reports the difference between the optimal time to invest under traditional net present value returns, where weekly returns need only rise above the current trigger value to instigate an investment, and the time to invest under "full cost" or real option trigger values. In the real option case, current returns must rise above not only the weekly-equivalent opportunity cost of the initial investment, but the value of the real option as well. Immediate investment implies the grower has decided to exercise the option, so current returns must be sufficiently high to offset the value of the option being given up. Table 4 shows the difference between these "time to invest" values under a number of assumptions, again regarding the key model parameters: the underlying volatility of the process and the size of the initial investment. In interpreting these results, it is important to remember they are derived under the implicit assumption that growers are rational decision makers—i.e., they follow the investment rule that is economically correct (real option rules), and not the rule that is suggested by traditional finance theory (traditional NPV rules).

With this distinction in mind, the results in table 4 reveal that growers wait far longer to make an investment in food safety measures than if they were to follow traditional rules. Because of our rationality assumption, we observe the delay inherent in their behaving as if they recognize the embedded real option, not the outcome of a myopic, traditional investment decision. More specifically, under the base scenario ($\sigma = 0.003$, $X = \$4.5$ mil.), growers take 2.22 weeks from an initial period before investing under traditional NPV rules, but 7.17 weeks under full-cost or real option investment rules. Because growers are assumed to be governed by "correct" decision-making criteria, this extra delay explains our observation that growers are investing at a slower rate than we would expect, or hope. Further, note that the time to invest falls with the size of the initial investment, but far less rapidly than the rise in option values shown in table 3. As the costs of developing food safety programs fall with improvements in technology and greater understanding of the process, there will be more value in waiting to invest. Although the option value does not outweigh the accelerating effects due to lowering the investment barrier (compare tables 3 and 4), this higher option value reduces the incentive government agencies may have to speed investment by subsidizing the initial cost. Notice also that the time to invest falls as the level of uncertainty in the returns process rises. Because option values rise in the volatility of the returns to the underlying investment, this outcome is somewhat surprising. Clearly, if the returns process is more volatile, the likelihood that the trigger level is exceeded rises even though the trigger itself becomes higher due to the embedded option. Whether this is true as well for the public good effect is an important question for the next set of simulations.

Table 4. Optimal Time to Delay Investment in Food Safety Technology, California Spinach: Traditional NPV, Real Option, and Public Good Criteria (weeks)

		Standard Deviation of Stochastic Process, σ				
Investment	Investment Rule	0.001	0.002	0.003	0.004	0.005
X = \$1.5 mil.	Traditional NPV	2.22	2.09	1.89	1.87	1.85
	Real Option	23.77	10.11	6.84	5.81	5.01
	Public Good	11.02	3.34	1.97	1.63	1.46
X = \$3.0 mil.	Traditional NPV	2.71	2.22	2.11	2.09	2.03
	Real Option	23.77	10.30	6.92	5.82	5.01
	Public Good	23.22	11.02	5.35	3.34	2.41
X = \$4.5 mil.	Traditional NPV	3.93	2.38	2.22	2.16	2.09
	Real Option	23.97	10.45	7.17	5.82	5.08
	Public Good	32.50	17.03	11.02	6.48	4.69
X = \$6.0 mil.	Traditional NPV	5.08	2.71	2.28	2.22	2.17
	Real Option	23.97	10.64	7.19	5.84	5.08
	Public Good	41.97	23.22	14.68	11.02	7.27
X = \$7.5 mil.	Traditional NPV	6.51	3.19	2.43	2.22	2.22
	Real Option	24.30	10.86	7.24	6.16	5.34
	Public Good	47.65	27.14	18.43	13.79	11.02

Notes: The variable X represents the amount of investment in food safety, in millions of 2007 dollars. All table entries are in weeks measured from $t = 0$. The base case assumes $N = 120$ firms in the industry. The stochastic process used to generate returns is a mean-reverting, jump-diffusion, Brownian motion.

The relative importance of the hysteretic and public good effects is given by the next line in table 4 under the base scenario. In this table, the time to invest under the public good assumption is simulated using NPV investment criteria. We do not combine the real option and public good effects, because our intent is to estimate the relative effects of each. Therefore, clean experimentation requires that we consider the public good effect in isolation. Assuming a weaker link technology and 120 firms in the industry (we conduct sensitivity analysis on this assumption below), free riders will not invest until week 11.02, some 154% longer than under the real option assumption and 496% longer than under NPV investment rules. The public good nature of food safety, therefore, appears to be economically more important in explaining the apparent delay in food safety investments than the embedded real option. However, the more volatile the expected savings from food safety investments become, the less important is free-riding relative to hysteresis. In fact, when $\sigma = 0.005$, the real option effect becomes greater than the public good effect. Both the public good and real option effects should be reduced as the probability of exceeding an "upper trigger" level of returns rises, but the time to invest under the real option criteria is longer to the extent that the real option itself has to be covered by this new, higher trigger.

Similarly, if the size of the project falls relative to the expected returns, free ridership becomes less important than hysteresis in an absolute sense and, in the cases where the initial investment is either \$3.0 million or \$1.5 million, growers will indeed invest more quickly in the public good than in response to private incentives. While this result seems counter-intuitive, investments in public goods are driven by the relationship between private marginal benefits and marginal costs. At lower levels of investment, the marginal benefit is high relative to the marginal cost, so individual contributions rise relative to the base scenario. Because individual growers derive benefit from everyone's contribution, in the extreme case

Table 5. Optimal Time to Delay Investment in Food Safety Technology, California Spinach: Sensitivity of Public Good Investment Effect to Market Structure, Initial Investment Amount = $4.5 million (weeks)

	Standard Deviation of Stochastic Process, σ				
No. of Firms	0.001	0.002	0.003	0.004	0.005
N = 40	19.60	8.51	4.32	2.75	2.13
N = 80	26.13	13.54	7.48	4.71	3.27
N = 120	32.50	17.03	11.02	6.48	4.69
N = 160	37.59	19.60	12.76	8.51	5.79
N = 200	39.69	22.89	14.51	10.12	6.91

Notes: Firm numbers are indicated by N. Weeks to invest is assumed to be a continuous value. The base scenario assumes a $4.5 million investment level. The stochastic process used to generate returns is a mean-reverting, jump diffusion, Brownian motion.

they are more willing to participate than if they expected only to derive benefit from their own investment. As potential returns to the investment become more volatile, the implicit value of protection increases accordingly. Essentially, growers are "scared into" contributing to the cooperative food safety effort as the cost of waiting for someone else to provide the public good becomes greater.[10]

Our insights into the importance of the public good nature of food safety investments depend on the structure of the industry, given the fact that individual contributions are inherently strategic and hence depend upon the strength of rivalry within the industry. Table 5 provides a sensitivity analysis of the time-to-investment results with respect to the number of firms in the industry and, once more, the volatility of returns. As expected, with fewer firms in the market, each individual firm is more likely to contribute to an industry-wide food safety effort. With the weaker link assumption, fewer firms implies that each firm is able to appropriate more of the benefits of its own investment and will be less likely to be negatively impacted by the failure of others to invest. As in the sensitivity results shown in table 4, the individual incentive to invest rises in the uncertainty of investment returns. Because the public good investment rule does not take into account the real option effect, this result is due entirely to the fact that there is a higher probability of the investment trigger being reached if upward movements in the returns process are stronger.

Finding that both the hysteretic and public good effects diminish with the volatility of the returns process is an important result. While we would expect the extent of the hysteretic effect to rise in the level of ongoing uncertainty, the net effect here is the opposite. If the real option value rises, then a higher investment trigger value means it will take longer for the random returns process to incite new investments. Higher volatility always leads to higher option prices. In the current example, however, higher option values are offset by the higher probability that returns will spike upward and cause immediate investment to become rational. This finding, in turn, is due to the nature of returns to protecting oneself from a food safety incident.

Consistent with the returns process modeled above, food contaminations occur as Poisson events that are prone to occasional, and often sharp, spikes. In order to increase the rate at which investments are made, therefore, regulators or industry members should take somewhat

[10] A reviewer suggested the possibility that food safety episodes in other, related markets may also provide incentives for growers to contribute to cooperative food safety efforts.

counterintuitive measures. Rather than reduce the underlying volatility of returns (to reduce the real option value embedded in investments) as conventional wisdom would suggest, greater uncertainty would provide a better incentive for growers to contribute. Facing a higher probability of sharply lower returns from selling the commodity, and thus higher returns from investing in protection, growers will invest much faster. In this way, each grower will be less likely to become the weakest of the weaker links. In fact, in light of the *salmonella* scare in the summer of 2008, growers appear to be responding to exactly this incentive as they lobby for more regulation—they are now willing to give up the absence of government regulation that differentiates produce growers from other farmers in order to ensure food safety, as a public good, is no longer optional (Venkataraman, 2008).

Conclusions

As evidenced by the seemingly endless stream of foodborne disease outbreaks originating in fresh fruits and vegetables, suppliers appear to have been slow to invest in adequate food safety processes, both collectively and individually. In this study, we assume this apparent unwillingness to invest may be due to two plausible causes: the real option value that follows from the uncertainty inherent in foodborne disease outbreaks, and the possibility that a safe food supply is a weaker link public good—investments in which individual suppliers can only appropriate some of the benefit if others do not invest at all. If present, either of these phenomena would likely lead suppliers to underinvest in food safety, or wait longer to invest than would otherwise be the case.

The existence of a real option gives rise to a hysteretic effect. If a real option exists, then current returns must exceed not only the current-period opportunity cost of the investment total, but also the value of the option. Waiting for the stochastic returns process to exceed this new, higher trigger means the decision to make the investment will be delayed until the random process happens to exceed the upper trigger limit. This delay is hysteresis, or inertia of the status quo. Although we consider each independently in this study in order to assess the relative strength of each, the hysteretic effect may compound the public good nature of food safety investments.

Suppose a supplier invests in sufficient food safety measures to ensure she will never ship contaminated produce. Another firm, however, does not invest and delivers a shipment responsible for sickening hundreds of people. The resulting market collapse essentially destroys the value of the investment made by the first supplier. Because she expects this scenario to occur, she will not invest in the first place. In this way, the supply of safe produce is a weaker link public good and investments in food safety are thus doubly cursed.

We focus our analysis at the grower level, although the public good and hysteretic nature of food safety investments likely generalize to all supply-chain members. We simulate both the hysteretic and public good effects using a theoretical model of food safety investment, calibrated to describe the 2006 *E. coli* outbreak in California spinach. Real options and the weaker link public good effects are found to have a significant deleterious effect on investments in food safety, but at realistic parameter values, the public good effect is much stronger. Somewhat surprisingly, both the hysteresis and public good problems are weaker the more volatile are the expected returns to food safety investments. Moreover, the public good effect depends critically on the structure of the market, with firms in more competitive industries less likely to invest than those in more concentrated markets.

The policy implications of these results are somewhat counterintuitive. In terms of the hysteresis problem, investments will be rationally delayed by private decision makers relative to what would seem to be optimal under traditional NPV rules. If policy makers believe this constitutes a market failure—a dynamic externality akin to a common property problem—then measures that either reduce the sunk costs of making food safety investments or reduce the uncertainty of the expected returns would seem reasonable. However, our simulation results show the opposite to be true. By increasing the expected cost of a foodborne disease outbreak, growers have a greater incentive to contribute to the public good, regardless of the higher option value involved. Policies that force growers to become more responsible for the uncertainty which they, indirectly, cause are likely relatively simple to implement. Examples include increasing funds for federal testing (to raise the probability that violators are caught), providing incentives for the development of better trace-back technology, government oversight of third-party certification, or increasing fines for handlers found to be in violation of existing food safety standards. These solutions, both market-based and regulatory in nature, would help remove both obstacles to food safety investment.

On the other hand, Cornes (1993) shows that the likelihood of a market failure (under-contribution) is greater under a weaker link aggregation technology if the agents are heterogeneous, and uses an agricultural example to illustrate. Namely, if a grower is already wiped out by a pest, then he or she is less willing to contribute to pest control. In our application, although we do not address the heterogeneity issue directly, the policy solution suggested by Cornes' model consists of an insurance or disaster payment program that would pay out in the case of a food safety incident. By assuring growers and handlers they would never be wiped out by a food safety problem, they would be more willing to contribute to a cooperative effort aimed at preventing the worst from happening.

Independent of the returns process, reducing the initial cost of investment would lessen both the hysteresis and public good effects. Examples of policies that may reduce the fixed costs of investment include establishing standards for monitoring technology, licensing third-party testing services to reduce search costs, or providing extension services to inform growers and processors of alternative technologies that may be available. In terms of the public good problem, the obvious solution is a system of mandatory marketing agreements or other institutional arrangements based on the CLGMA model. While this marketing agreement is voluntary, the press report cited above suggests mandatory marketing orders would now be politically acceptable. Ultimately, however, the problem remains one that industry members should recognize themselves and be able to address under the existing framework of marketing orders and information-sharing agreements within state-based commodity commissions.

One area for future research on this topic would address the incentives faced by members of the fresh produce supply chain to invest in food safety programs. While this paper focuses on the efforts taken by growers/handlers only, food safety problems can indeed also arise at the wholesale and retail levels. Whether incentives are better directed at the retail or first-handler level involves game-theoretic considerations which are beyond the scope of this paper, but likely relevant to the design of appropriate food safety policies.

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