Hysterisis in Food Safety Investments

Timothy J. Richards, William E. Nganje and Ram Acharya

Morrison School of Management and Agribusiness, Arizona State University Mesa, Arizona, USA

trichards@asu.edu

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Introduction

Concerns regarding the safety and integrity of the fresh produce supply chain are becoming all too common in the media. In 2006, an outbreak of E. coli O157:H7 from farms in Central California sickened almost two hundred people and lead to the deaths of three. Estimated costs to the industry ranged from $100 per month to $200 million until spinach sales returned to normal. By some accounts, the spinach industry has yet to recover and may not for years to come. The incident, however, has lead to a host of initiatives from industry officials, legislators and fresh produce retailers to ensure the safety of fresh produce. The necessary technology and best practices knowledge exists, yet some growers have not made the investment required to ensure that such outbreaks do not happen again in the future.

Investments in supply chain technology are clearly subject to cost-benefit decision criteria by growers. Their failure to adopt the necessary technology, therefore, raises a number of questions regarding the efficiency of the decision making process. If growers follow traditional net present value (NPV) investment criteria, 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, much of the potential savings (or avoided losses) accrues to the industry as a whole. If an outbreak was to occur, there is a strong likelihood that the equity of the firm would be immediately valueless. This puts a floor on the potential losses that biases expected losses upward. On an industry-wide basis, however, the value of the externality created is many times greater than the potential loss of firm-specific value.

Second, and perhaps more importantly for firm-specific decision making, 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 or not entails a significant real option value. Considering investments in a real option framework is by now commonplace in the investment literature (Dixit and Pindyck, 1994), but has only recently been applied in an agricultural supply-network management context. 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: (1) the underlying volatility of returns to growing the crop, (2) the probability of a discrete shock to returns, such as a food borne disease outbreak, and (3) the inherent profitability of growing, packing and selling the crop. Waiting for a stochastic returns series to rise above an investment “trigger” level, therefore, gives rise to a phenomenon known as economic hysteresis (Dixit, 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. In this study we estimate the impact of hysteresis on the timing of investments in food safety technology, as a means of explaining why growers and processors appear to be slow to adopt necessary protection against food borne disease outbreaks.

We demonstrate the impact of hysteresis using an ex ante analysis of investments in food safety technology by a representative spinach farm in the Central Valley of California. We incorporate many realistic features into the investment-decision simulation model: (1) stochastic returns to growing spinach, both in terms of price and yield, (2) the probability of a discrete shock to returns caused by a future food borne disease outbreak, (3) the potential for on-farm diversification to reduce the volatility of farm-level returns and, thereby, exacerbate the hysteretic effect. With this simulation model, we provide estimates of the likely severity of the hysteresis effect in food safety investments and whether this phenomenon constitutes a likely explanation for the observed unwillingness to invest.

In the first section of the paper, we describe a theoretical model of hysteresis in food safety investments. The empirical application of this model is outlined in the second section, including a description of the data used and the simulation techniques that were employed. The simulation results are presented and discussed in the fourth section, while a fifth provides come conclusions and policy implications for how food safety measures can be crafted to ameliorate the impacts of uncertainty and hysteresis.

Economic Model of Food Safety Investment

In order to evaluate an investment in food safety technology, defined in very general terms, it is first necessary to be very clear about the cash flows and initial investment involved. The initial investment, or cash outlay, is relatively simple. Given that our focus is at the level of the industry, the investment involves a collective commitment of \$4.0 million at t = 0 to establish industrywide certification standards and monitoring body. This investment also includes all of the necessary detection technology for the testing staff to determine the presence of the most likely set of pathogens at each facility (reference literature for value of investment). 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: (1) reducing the probability and severity of a one-time event occurring like the E. coli outbreak in the Fall of 2006, and (2) preventing the erosion of goodwill (demand) over time that results from a permanent loss of some consumers or foodservice buyers. This latter effect means the preservation of both shipments and prices that would otherwise be significantly lower following a disease outbreak. In 2006, shipments in the five weeks prior to the outbreak averaged 1.216 m lbs, falling to 0.626 m lbs per week during the scare. Similarly, prices were \$0.486 per lb prior to the food scare, while they averaged \$0.197 / lb during the food scare. 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 that 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 10.0% downward shift in demand at each price level. While arbitrary, this assumption is supported by interviews with industry officials.

With the assumptions made above, we define a stochastic process for the returns to an investment in food safety technology. Consistent with the two effects outlined above, the potential savings consists of an reversion of the demand curve of 10.0% as well as an elimination of the one-time shock to prices and shipments. Assuming a vertical short-run supply curve for spinach, the incidence of the 10.0% shift in demand is assumed to lie entirely on prices, while the one-time shock affects both prices and shipments. For the continuous part of the returns process, however, prices and shipments are negatively correlated with a correlation coefficient of -0.40.

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. Suppose an industry organization faces the problem of determining whether to invest in quality screening technology or processes that would greatly reduce the probability of a food borne disease outbreak. Whether a for-profit firm, or an agent for a group of profit-maximizing growers, assume the organization chooses the amount of investment, I, in order to maximize the present value of returns to an investment in technology or processes that reduce expected losses due to a food recall:

$$V(p,c,I) = \max_I \int_{t=0}^{\infty} e^{-rt}[\theta(p_t - c_t)Q_t(I)]\,dt - I_0 \qquad (1)$$

where I0 is the amount of investment in food safety at time 0, Q is the volume of industry sales, p is the grower price, c is (constant) marginal cost and è is a parameter that reflects the expected savings in lost profit due to a disease outbreak (assumed to be 10.0%). Managers of the association are assumed to maximize (1) subject to an equation of motion for annual net returns,

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where annual returns are given by:

$$(p_t - c_t)Q_t(I)$$

R_t Output is determined by the amount of investment in food safety, while prices are assumed to be determined on the market and thus exogenous to the manager's problem. Consequently, net returns evolve according to a Brownian motion process of the form:

$$dR_t = \mu dt + \sigma dz, \qquad (2)$$

where ì is the drift rate per unit of time, dt, ? is the standard deviation of the process, and dz is an increment of a standard Weiner process with zero mean and variance equal to dt. Returns are assumed to follow a Brownian motion because per-period changes in returns are normally distributed, independent from each other, 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 (2) 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 (2) is modified to include a mean-reversion term so that:

$$dR_t = \kappa(R_t^m - R_t)dt + \sigma dz, \quad (3)$$

where ê is the rate of reversion to the mean. Further, returns are also subject to periodic "spikes" or periods of virtually instantaneous change due to disease outbreaks or some other source of negative market information. We model these instances as jumps in the stochastic process estimated above (Merton, 1976; Ball and Torous, 1983, 1985; Jarrow and Rosenfeld, 1984;

Jorion, 1989, Naik and Lee, 1990; Bates, 1996; Hilliard and Reiss, 1999), so the most general form of the returns equation becomes:

$$dR_t = (\kappa(R_t^m - R_t) - \lambda\varphi)dt + \sigma dz + \varphi dq, \quad (4)$$

where jumps occur according to a Poisson process q with average arrival rate ë and a random percentage shock, ö. The random shock, in turn, is assumed to be log-normally distributed with mean ö - 0.5ä^2 and variance, ä^2. The Poisson process q describes a random variable that assumes a value of 0 with probability 1- ë and 1 with probability ë.
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 (4) 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, Q, and dz becomes dv, where vt is a Q-Weiner process (Alaton, et al., 2002). Second, we form an expectation of the intrinsic value of the derivative under the 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.[1]

More formally, given a constant market price of risk, ø, a constant rate of interest, r, and assuming each contract
pays one dollar per unit of returns, the martingale that defines the underlying index becomes:

$$dR_t = (dR_t^m/dt + \tau(R^{m_t} - R^m) - \lambda\varphi - (\delta + \psi)\sigma)dt + \sigma dv + \varphi dq, \quad (5)$$

where dv is now a Q-Wiener process (Alaton, et al., 2002). Hull (2005), however, argues that if the underlying is indeed statistically independent of the market portfolio, then the market price of risk is zero. Because this is likely to be case for localized insect populations, we set ø = 0 in (5) and proceed to price the derivative using the risk free discount rate.

1. Although risk neutral valuation is typically applied in cases where the underlying is log-normally distributed, all that is required is that the adjusted probability distribution under which the expectation is taken be the one that is consistent with the underlying following a martingale (zero drift stochastic process) (Harrison and Kreps 1979). For a recent application of this approach, and a review of whether or not the martingale restriction holds in practice, see Turvey and Komar (2006).

Among all possible types of option, 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 is here the stream of returns generated by investing in better monitoring technology. The expected payoff to a call option is given by:

C_T, where rI is the annualized cost of the investment. This expectation must be found under Q-measure. Taking the expectation and discounting to the present from T at the rate r gives a call-option value of:

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$$V_c = \exp(-r(T-t))\Big((\mu_n - rI)\Phi(R_t) + (\sigma_n/\sqrt{2\pi})\exp(-\sigma^2/n)\Big), \qquad (6)$$

where ìn and ón are the mean and variance, respectively, of the returns process and Ö is the standard normal distribution function.[1] The expectation in (6) 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. Under traditional, Marshallian rules of investment, the decision maker invests when expected net revenue rises above the opportunity cost of invested capital, or:

$R_t > rI.$ When the embedded option is taken into account, however, the decision criteria must change to reflect the fact that net revenues must also cover the opportunity cost of exercising the option:

$$R_t > rI + V_c.$$

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Because Vc is always positive, this decision rule implies that the full-cost Rt trigger is higher under real option relative to Marshallian 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 Marshallian 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 objective functions.

Data and Methods

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The stochastic process in (4) 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. 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 reflects at least once instance of a "spike" in demand. This fact helps to identify the jump

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1. The mean and variance found under Q-measure include the market price of risk and jump terms, but their specific form are not material here. They have been derived, however, and are available from the authors.
2. Dixit and Pindyck (1994) provide an exact solution in terms of the parameters of the stochastic process governing net revenues

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 (4) are obtained by maximum likelihood estimation over the entire sample data set, using the likelihood function:

$$L(R) = -T\lambda - \frac{T}{2}\ln(2\pi) + \sum_{t=1}^{T} \ln\left[\sum_{n=0}^{N} \frac{\lambda^n}{n!}\frac{1}{\sqrt{\sigma+\delta^2 n}}\exp\left(\frac{-(dR_t-(\kappa(R_t^m-R_t)-\sigma/2-n\delta^2/2-n\varphi))^2}{2(\sigma+\delta^2 n)}\right)\right], \qquad (7)$$

where T is the total number of time-series observations, and N is defined as a number of jumps sufficiently large to include all potential jumps in the observed data (six proved sufficient in this application). 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).

Results and Discussion

Table 1 provides the estimation results 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. 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 1, each of the structural parameters is significantly different from zero, and of the expected sign. Specifically, the estimate of ë, the Poisson arrival parameter, suggests that a shock to demand can be expected to occur 0.59 times during every 288 week period, or approximately once every ten years. This is consistent with industry experience. When a shock does occur, returns are expected to fall by 10.7%, on average. Although the E. coli scarce in 2006 reduced demands by far more than 10.0%, this 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 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.

Table 1. Stochastic Returns Process Estimates: MLE

Variable	Estimate	t-ration
ë	0.590*	9.372
ó	0.002*	6.736
ä	0.023*	4.137
ì	0.061*	5.362
ê	0.342*	13.026
ö	-0.107*	-5.439
Year 1	-0.001	-0.732
Year 2	0.002	0.189
Year 3	-0.024	-1.728
Year 4	0.011	0.749
Year 5	-0.012	-0.654
LLF	222.607	

In this table, a single asterisk indicates significance at a 5.0% level. Comparing the estimated LLF value to the null model LLF gives a chisquare test statistic value of 145.321.

The parameter estimates in table 1 were then used to simulate real option prices embedded in food safety investments. Table 2 shows the option values obtained under a number of alternative assumptions regarding key model parameters. Assuming base uncertainty (ó) and shock (ö) values of 0.002 and -0.107, respectively, the baseline real option estimate is approximately $8.8 million. This means that any proposed investment in food safety of $5.0 million must generate a returns with NPV of $8.8 million before it will rationally be undertaken, which is fully 66.0% greater than under traditional NPV rules. As the level of uncertainty rises, the real option value grows, reaching nearly $10.6 million under the base shock scenario at a standard deviation of 0.004. On the other hand, the real option results appear to be less sensitive to changes in the value of the demand-shock parameter. In fact, given that these results are generated through a Monte Carlo simulation procedure, the variation in option value from one assumed value of ö to the next is within any reasonable error-bound. Future experimentation with this model will consider larger potential shocks to demand to investigate whether or not the option value is indeed not sensitive to the potential loss if a future disease outbreak should occur again.

Table 2. Real Option Values for an Investment in Food Safety Technology ($,000)

	ó					
		0.0005	**0.001**	**0.002**	**0.003**	**0.004**
	-0.010 -	$9,529.30	$8,945.90	$9,313.90	$10,543.00	$11,122.00
	0.050 -	$9,558.60	$8,922.80	$8,984.60	$9,726.50	$11,091.00
	0.107 -	$9,512.40	$9,015.90	$8,837.80	$10,251.00	$10,559.00
ö	**0.150 -**	$9,513.10	$8,884.50	$9,145.40	$9,637.30	$11,178.00
	0.200	$9,482.40	$9,056.10	$9,271.20	$9,432.60	$11,160.00

The Values in this table represent the real option value of a $5.0 million investment i n food safeety technology or processes in California spinach.

The economic significance of the real option values shown in table 2, however, suggest that a hysteresis effect is likely to arise. Table 3 shows 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 weeklyequivalent opportunity cost of the initial investment, but the value of the real option as well. Immediate investment implies that the grower has decided to exercise the option so current returns must be sufficiently high to offset the value of the option that is being given up. Table 3 shows the difference between these to "time to invest" values under a number of assumptions, again regarding the key model parameters: the underlying volatility of the process, the Poisson counter and the magnitude of the assumed jump in returns should a food safety event occur. In interpreting these results, it is important to remember that our implicit assumption is that growers are rational decision makers. That is, 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 realization in mind, the results in table 3 show that growers can be expected to wait far longer to make an investment in food safety technology than is expected under traditional rules. Specifically, under the base scenario (ó = 0.002, ö = -0.107), growers would be expected to take 3.725 weeks from an initial period before investing under traditional NPV rules, but 19.373 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.

Table 3. Optimal Investment Timing for NPV and Real Option Criteria

Traditional NPV Rules		0.0005	0.001	0.002	0.003	0.004
-0.010		3.509	4.137	4.647	4.549	3.490
ö	-0.050 -0.107	5.490 4.988	3.157 3.255	3.784 3.725	4.039 3.373	4.637 4.549
	-0.150	2.961	3.588	3.706	3.667	4.000
	-0.200	3.843	4.529	3.314	3.274	4.157
	Real Option Rules	**0.0005**	**0.001**	**0.002**	**0.003**	**0.004**
ö	-0.010 -0.050	18.490 20.119	19.529 19.392	23.706 21.549	24.353 21.843	23.412 23.490
	-0.107	23.118	19.647	19.373	22.314	20.529
	-0.150	22.020	19.725	21.451	21.451	27.706
	-0.200	22.882	19.941	19.392	20.157	25.333

The values in this table represent the real option time before investment should be undertaken. The base scenario isó = 0.002 and ö =-0.107

Consistent with the option-value sensitivity analysis presented in table 2, the extent of the hysteretic effect rises in the level of on-going uncertainty, but is somewhat insensitive to changes in the shock to returns. If the real option value rises, then a higher investment trigger value means that it will take longer for the random returns process to incite new investments. Higher volatility always leads to higher option prices. In order to increase the rate of investment, therefore, it is necessary to either take measures that reduce the underlying volatility of returns, or to provide incentives for growers to adopt measures that improve the profitability of returns to food safety investments. We explore some alternatives in the concluding section below.

Conclusions

In this study, we show that investments in food safety technology or processes involve a significant real option value. More importantly, the existence of this option value gives rise to a hysteretic effect. If a real option exists, then current returns must exceed not only the currentperiod opportunity cost of the investment total, but the value of the option as well. Waiting for the stochastic returns process to exceed this new, higher trigger means that 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 there are many other reasons growers may be reluctant to commit large sums of money to a new project like this, such as liquidity constraints, free riding on the other investors or a lack of market knowledge, our option value explanation provides a compelling, rigorous argument based in the theory of derivative pricing.

The policy implications of these results are clear. The existence of a real option means that investments will be rationally delayed by private decision makers relative to what would seem to be optimal under traditional NPV rules. If policymakers believe that 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 should be put in place. 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. Policies that reduce uncertainty are likely more difficult 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 or increasing fines for handlers found to be in violation of existing food safety standards. Ultimately, however, the problem remains one that industry members should recognize themselves and be able to address within the existing framework of marketing orders and information-sharing agreements within state-based commodity commissions.

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Timothy J. Richards, William E. Nganje, and Ram Acharya Morrison School of Management and Agribusiness Arizona State University Mesa, Arizona, USA