Innovative Insurance Products in Food Safety:

Pricing Revenue Insurance in the Fresh Spinach Industry

by

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ABSTRACT

The lack of food safety in a grower's produce presents the grower with two risks; (1) that an item will need to be recalled from the market, incurring substantial costs and damaging brand equity and (2) that the entire market for the commodity becomes impaired as consumers associate all produce as being risky to eat. Nowhere is this more prevalent than in the leafy green industry, where recalls are relatively frequent and there has been one massive E. coli outbreak that rocked the industry in 2006. The purpose of this thesis is to examine insurance policies that protect growers from these risks. In doing this, a discussion of current recall insurance policies is presented. Further, actuarially fair premiums for catastrophic revenue insurance policies are priced through a contingent claims framework. The results suggest that spinach industry revenue can be insured for $0.02 per carton. Given the current costs of leafy green industry food safety initiatives, growers may be willing to pay for such an insurance policy.

DEDICATION

To all those who have supported me in all my endeavors:

Mom, Dad, Alan, and a truly special Jeep Cherokee Laredo 4x4.

ACKNOWLEDGMENTS

This thesis is the product of the hard work of many people. I am very blessed to have so many people in my life who care so much about me that they will take time from their own work to help me craft such a personal thesis. With that, I would like to acknowledge my committee members. I am grateful to Dr. William Nganje for getting the process started on this thesis. I came to him with a very vague idea and through working with him I was eventually able to create this work. Dr. Timothy Richards contributed a lot to this thesis. Not only did he contribute his time, but also his expertise, guidance, and even code. Through the process of creating this thesis, I have come to understand the benefits of rigorous research and I have learned not to compromise or cut any corners and for this, I am forever grateful to Dr. Richards.

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INTRODUCTION

Motivation

Food safety is an issue for which consumers and producers are equally interested. The consumer seeks a product that has no health risk and the producer seeks to meet that need with a product that exposes the firm to as little business risk as possible. It is therefore desirable for all parties involved to trade with products that are 100% safe (that is, completely absent of any risk). This, however, is not realistic. Despite developments in food safety technology, stricter regulations, and increased awareness of food safety issues, food products will always carry some risk of disease or injury to those who consume it, and thus will continue to represent a substantial business risk to producers and handlers in the supply chain.

When a firm encounters an eminent need to prevent the consumption of a dangerous food product, one mechanism that has been increasingly used is the product recall (Skees et al., 2001). Recall events are costly to producers as well as firms further down the value chain, and ultimately can result in the shutdown of a business. Such events which correspond to a contamination and outbreak may also have a direct impact on other businesses producing similar products as seen in the E. coli outbreak in spinach in 2006. [1] The outbreak ultimately cost the spinach industry an estimated $200 Million because consumers associated all spinach as being risky to eat (Richards et al., 2009).

[1] For a full timeline of the 2006 E. coli outbreak in spinach see Appendix A.

In the face of such drastic outcomes, growers indeed desire some level of food safety for their own operations, which is in turn enjoyed by all firms in the industry. This inherent non-excludability of individual food safety investments gives rise to the problem of free riders. That is, firms which benefit from a safer industry, but do not make investments themselves. While this problem presents firms with disincentive to invest in food safety, each firm still has a need to maintain some level of food safety in order to protect itself (Richards et al., 2009). Food safety, then, is a public good where the benefits of having the greatest food safety standards are mitigated (though not entirely) by the firm with the weakest food safety standards. The result of this weaker-link public good effect is that investment in food safety is slow despite the drastic consequences of an outbreak and recall (Richards et al., 2009).

In order to create uniform food safety standards for all firms, certain industries have taken measures such as marketing agreements to encourage and enforce food safety standards that are above those required by government through regular auditing. While this is often viewed as the best public/private strategy to improving food safety, it only raises the minimum requirement and does not give incentive for any one firm to invest more than it needs to in order to meet those standards. Further, these agreements are strictly voluntary so that firms not participating in the agreement do indeed benefit without actually investing in compliance with industry standards. From a liability standpoint, Buzby and Frenzen (1999) find that legal incentives to invest in food safety are weak, with far less than 0.01% of all foodborne illness cases being litigated and of those only 56% of plaintiffs were awarded any compensation (a median of $2000 before legal fees). In order to protect consumers with little legal recourse, the FDA has been given expanded powers including mandatory recall authority (FSMA, 2011).

In recent years new risk transfer tools have become available for the specific purpose of mitigating the effects of product recall events. Various insurance companies have developed recall insurance policies that cover individual expenses and loss of profit in some cases. While policies of this kind help mitigate the risks of a recall at the firm level, they do not protect the industry against devastating market declines resulting from a food safety scare. The effect of the systematic risk of a recall on the market has been recognized in the 2012 Farm Bill which contains a provision for research related to food safety insurance in specialty crops (S.3240, 2012). Thus an insurance policy which protects industry participants from precipitous declines in revenue resulting from a food safety scare could complement existing marketing agreements, and serve to address food safety as a weaker-link public good.

Objectives

The objective of this research is to put forth a model for insurance designed to mitigate food safety risks, and bolster incentives to invest in food safety. In doing this, this thesis provides an overview of the specific recall insurance policies currently available. While these insurance products help indemnify food safety risks at the firm level, they do not provide broad-based protection against rapid declines in price and/or disruptions in volume which may arise from a recall event. Therefore, a revenue insurance policy that is triggered by industry-wide price and/or volume declines as a result of a recall event is evaluated. In doing this, this research examines several candidate revenue insurance policies and estimates actuarially fair premiums using a contingent claims framework. The conceptual and empirical analysis is conducted in the context of an operation that produces and ships leafy greens (specifically, fresh spinach), an industry in which contamination and recall events are serious and relatively frequent. [2] The remainder of the thesis is outlined as follows: the next section provides a survey of the literature pertaining to the nature of public goods, food safety, and the role of insurance in food safety. The theory behind a firm's response to risk is discussed and a discussion of insurance policies currently on the market is presented. Models of revenue insurance are then presented and actuarially fair premiums are simulated. These actuarially fair premiums are considered vs. the current costs of the check-off program for leafy greens. Doing this provides insight into the cost of such an insurance scheme to the growers relative to current industry assessment rates.

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[2] Leafy green produce items include the following: arugula, butter lettuce, chard, escarole, iceberg lettuce, red leaf lettuce, spinach, baby leaf lettuce, cabbage (green, red and savoy), endive, green leaf lettuce, kale, romaine lettuce, spinach, and spring mix (LGMA 2012).

BACKGROUND AND LITERATURE

Cornes (1993) puts forth a model for the production of a non-excludable public good that can be used to explain contributions to food safety on the part of an individual grower of a perishable commodity. Cornes (1993) concludes that, in terms of producing optimal levels of a public good, losses in efficiency are especially high when the preferences to the allocation of income toward the public good are heterogeneous across firms in the industry. Cornes (1993, p. 270) writes, "It is precisely in such situations that there may be strong incentives for individuals to bind themselves to an alternative institutional structure for public good provision." To the extent that decisions regarding food safety depend on the actions of rival firms, the problem of weaker-link public goods is a game theory problem and the cooperative agreement suggested by Cornes (1993) is a solution. Assuming that the negotiation among all growers is beneficial (and compulsory) to all, cooperation is an appropriate strategy to avoid the situation that is least desirable (in this case, industry-wide loss and shut down of firms due to product contamination).

Although cooperation to avoid such an event may indeed be desirable, it may not provide the most profitable solution (Luce and Raiffa, 1957). Antle (1995) suggests that in this case, there may be incentive to cheat (in the form of freeriding) on the cooperative agreement and thus Gresham's Law of Product Quality applies. This is where consumers cannot tell the difference between products that increase the probability of injury and those that do not, such that reputations for quality cannot be established. Thus, if the cost of producing a higher quality product (in terms of food safety) is greater than the cost of producing a lower quality product, then the lower quality product may chase the higher quality product out of the market until the market for the safe product is completely gone (Antle, 1995). If indeed cooperation among all parties is beneficial, but subject to market forces in competition, the question then becomes a matter of how best to structure such a cooperative mechanism. Though Cornes' work suggests that an institution outside of the consumers of the public good can best address the weaker-link phenomenon, his work leaves the structure of such an institution to another paper.

Richards et al. (2009) focuses on measuring the public good effect in the spinach industry and suggests that the weaker-link public good phenomenon inherent in food safety may be addressed using a combination of policies, one of which could be an insurance institution from which growers receive a payout in the event of a recall. Skees et al. (2001) draws on policies on the market to inform a discussion on the potential of recall insurance to enhance food safety in that recall insurance could motivate earlier recalls and more diligent implementation of food safety standards, which ultimately can lead to a safer industry. The only known model for such insurance in the literature comes from Turvey (2006); a book chapter that provides a conceptual loss-function for disease in livestock. This provides insight into the mathematical feasibility insuring such risks to the extent that principles of a disease outbreak in livestock (i.e. the frequency, duration, and intensity of a contaminant) are applicable to disease outbreaks in other products.

Turvey's (2006) work also uses a contingent claims framework to price revenue insurance with path-dependent options. Turvey's (2006) conceptual analysis is adapted by Mojduszka (2004) in a more general sense to analyze the role of food recall liability insurance to promote food safety, and proposes that insurance is an important component of interdependent public-private food safety controls which are the dominant strategies for ensuring food safety today. Henson and Hooker (2001) analyze firm-level compliance decisions and note that these decisions are made through a complex interplay between market forces, food safety regulation, and product liability law. This interplay of regulatory and market forces induces a strategic response to food safety regulation which present firms with negative incentives to deviate.

Strategies to address quality standards in food have often revolved around information gathering and sharing. For example, buyers in the fresh produce industry have traditionally employed inspectors who go to the farm and report on issues of quality to buyers. This auditing function, known in the industry as "bird-dogging," is common practice among retailers who require information on particular commodities before purchase. While bird-dogging has long served buyers with information, it is primarily a way of assessing desirable physical qualities, which are relatively easy to ascertain, and not for the testing of product for contaminants. Indeed, buyers trying to assess such a risk would necessarily incur increased search costs as inspectors would need to be trained in chemical analysis and conduct such analysis across many producers. Further, the hiring and training of such inspectors could create its own public good effect among buyers. That is, if one or a few buyers employ trained inspectors who do an adequate job in assessing contaminants, why should another buyer pay to conduct the very same analysis? Addressing this issue are private third-party food safety auditors employed by producers to maintain a certification which signals to buyers that the product conforms to a set of food safety standards. While many producers participate in this kind of auditing, it is not a uniform requirement across all firms.

In order to efficiently provide information regarding the safety of food products across all firms, nearly all producers and handlers in the leafy green industry (99%) have agreed to mandatory government audits in an initiative called the California Leafy Green Products Handler Marketing Agreement (CALGMA) and the Arizona Leafy Green Marketing Agreement (AZLGMA). Both agreements assess money from industry members to provide education, training, government auditing, and certification services in the industry. For a firm to be certified under an agreement they must submit to mandatory government audits which seek to enforce the AZ/CALGMA's rigorous food safety standards. If during the course of such audits it is found that a member is not in compliance, the agreement board issues a fine or decertifies the organization. Certified members carry the marketing agreement seal on all sales documents as a signal to buyers and end consumers that the product adheres to the safety standards of the agreement.

In this way, the marketing agreement shifts search costs for buyers to the producers who employ a single entity (the government) to gather and share information that would otherwise be costly to consumers to ascertain themselves. While the effectiveness of such agreements is a subject for another paper, it illustrates that auditing and information sharing arrangements are pivotal in food safety policy. However, such agreements are entirely voluntary and there is an ongoing effort by federal regulatory forces to encourage membership on a national level. To this end, the USDA has proposed a new marketing agreement for leafy greens open to all producers in the country. The proposed marketing agreement is known as the National Leafy Green Marketing Agreement (NLGMA) and seeks to include all other firms outside of those in California and Arizona which deal in leafy green produce. Because the proposed marketing agreement is voluntary, producers and handlers must choose to take part in it and, due to the weaker-link public good nature of food safety, full industry participation becomes imperative in order to achieve its stated objectives.

If a firm chooses to submit to a marketing agreement, it pays a per unit check-off price and it will likely need to invest in food safety measures to bring itself into compliance with the agreement. As Richards et al. (2009) show, this is indeed a problem of public goods and economic hysteresis. However, if it is possible to embed insurance premiums into the marketing agreement, growers may be more apt to participate as their participation would prevent their firm from ever being completely wiped out in the face of an outbreak. Indeed, the chief benefit of participating in a marketing agreement for food safety is to reduce the chances of an outbreak that has a detrimental impact on the market for a commodity. So it stands to reason that if the agreement included an insurance policy, growers may be more apt to join. However, a grower's decision to insure is entirely empirical. Given the volatility of returns in leafy greens, most such growers are highly diversified and, perhaps more importantly, often choose the gamble over the insurance contract. Thus it is important to consider the grower's appetite for risk along with the price of insurance.

The Grower's Appetite for Risk

At the grower level, decisions made with regard to food safety are defined by the grower's appetite for risk. Food safety (the absence of risk in food) is provided up to the point at which the marginal benefit of improving the product is equal to its marginal cost. Because this will never be at a level of zero risk, growers will seek to allocate income to maximize utility under risk. While no universal utility function for this exists, Von Neuman and Morgenstern's axiomatic approach (later used by others including Luce and Raiffa, 1957) proves that a utility function for decisions under risk can be constructed from the preferred choices of the decision maker (Luce and Raiffa, 1957). Barry and Robison (1987) summarize the four basic axioms of Von Nueman and Morgenstern's theory:

Ordering of choices: For any two choices A_1 and A_2 the decision maker either prefers $A_1$to A_2, prefers A_2 to A_1, or is indifferent.

Transitivity of choices: If A_1 is preferred to A_2, and A_2 is preferred to A_3, then A_1 must be preferred to A_3.

Substitution of choices: If A_1 is preferred to A_2, and $A_3$is some other choice, then a risky choice $pA_1 + (1-p)A_3$ is preferred to another risky choice $pA_2 + (1-p)A_3$, where p is the probability of occurrence of A_1 or A_2.

Certainty equivalent of choices: If A_1 is preferred to A_2, and A_2 is preferred to A_3, then some probability exists that the decision maker is indifferent to having A_2 for certain or receiving A_1 with probability p and A_3 with probability $1-p$. Thus A_2 is the certainty equivalent of $pA_2 + (1-p)A_3$ (Robison and Barry, 1987, p. 18).

While an explicit utility function cannot be measured, the expected utility approach characterizes the nature of the decision environment (Robison and Barry, 1987). It is these axioms which guide a grower's decision to invest in food safety technology or not, to invest money in food safety training or not, or even to insure against a recall event or to self-insure against such an event. So that any policy prescription seeking to address food safety must conform not only to the grower's acceptable expected value criteria, but must also maximize the expected utility of the risk. That is, the investment decision to begin auditing firms (and what number of firms for that matter) and to insure against food safety scares does indeed lie on a continuum of choices and the extent to which one choice is preferred to another is characterized by the grower's level risk aversion. While evaluating the preferences of growers in this manner is outside the scope of this thesis, it is no doubt necessary in understanding the logic of insurance as a risk response and the implications thereof.

The Grower's Insurance Decision

A grower of produce can choose to insure against a recall event or not. In equilibrium, the value of the choice to insure will equal the choice to not insure in the long run, but at any given point the grower faces the following decisions and states of nature (Robison and Barry, 1987, p. 214):

States of Nature	*Probability*	*Insurance*	*No Insurance*
Recall	p	$W+W_0-\pi$	W_0
No Recall	$1-p$	$W+W_0-\pi$	$W+W_0$

Figure 1. Insurance Decisions and States of Nature

where W represents the value of an asset susceptible to a recall event, W_0 represents the value of all assets not susceptible to a recall event, and π represents the premium paid for recall insurance, and p is the probability of the event (Robison and Barry, 1987). [3] Therefore, the expected value of insurance is equal to the value of

[3]For simplicity, an asset susceptible to recall is referred to as a "risky" asset and assets not susceptible to recall are referred to as "riskless" or "safe" assets. Even

the insured asset plus all non-insured assets, less the premium paid for the insurance. The expected value of no insurance is the probability of a recall event times the value of non-risky assets plus the probability of no recall times the value of risky assets plus non-risky assets (Robison and Barry, 1987). This is mathematically represented as follows:

$$
\begin{gathered}
E(Insurance) = W + W_0 - \pi \\
E(No\ Insurance) = p(W_0) + (1-p)(W + W_0).
\end{gathered}
\tag{1}
$$

Simplifying and finding the difference between the two alternatives gives the actuarial difference. That is, the expected value of insurance less the expected value of no insurance is equal to the probability of a recall event times the value of the risky asset less the premium:

$$E(Insurance) - E(No\ Insurance) = pW - \pi. \tag{2}$$

While this represents the maximum that the grower will pay for product recall insurance, it does not represent the grower's appetite for risk (Robison and Barry, 1987). A grower prefers a riskless asset that has a return equal to a risky asset. However, there exists a level of return on a risky asset (which is larger than that of the riskless asset) at which the grower is indifferent between the two alternatives because each provides the same level of utility (Robison and Barry, 1987). This difference between the expected return on a risky asset and a safe asset is called the risk premium. Subtracting the risk premium from the expected return of a risky asset gives the Certainty Equivalent (CE). In the context of the recall insurance decision, both alternatives have a Certainty Equivalent expression as:

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though both are subject to many types of risk, this example is constrained to the insured risk.

$$CE = E(W_i) - \left[\left(\frac{\lambda}{2}\right)\sigma^2(W_i)\right] \tag{3}$$

where, $\left(\frac{\lambda}{2}\right)\sigma^2(W_i)$ represents the risk preferences of the grower multiplied by the variance of outcomes and the value of either alternative (i.e. no insurance or insurance). This implies the risk premium increases as the risk associated with the alternative, σ^2, increases and with the level of risk aversion, $\frac{\lambda}{2}$, or both (Robison and Barry, 1987).

The Insurer's Risk Pool

With an insurance contract, the insurer bears the risk of the insured event. While this means that the insurer experiences the same states of nature as the grower, the insurer benefits from economies of risk (Robison and Barry, 1987). [4] Assuming that all risks underwritten by the insurer are independent and follow identical distributions, the insurer is able to average its expected losses from each firm, *X*, over the total number of growers, *n*, in the risk pool:

$$E\left(\frac{X_1 + X_2 + X_3 \ldots + X_n}{n}\right) = pW. \tag{4}$$

Like the individual grower, the expected value from a recall event is equal to the probability times the value of the risky asset (Robison and Barry, 1987). However, the variability in outcomes is reduced due to economies of risk such that its certainty equivalent loss for which a premium would be required can be represented as:

[4] Economies of risk (or economies of scale with respect to risk) is a fundamental concept in risk pooling. It refers to an insurance firm's ability to decrease the variability of its returns as the size of the pool increases. For further reading on this subject see Robison and Barry, 1987; Cummins, 1991; Harrington and Niehaus, 2004.

$$CE(average\ loss) = E(W) - \left[\left(\frac{\lambda}{2}\right)\left(\frac{\sigma^2}{n}\right)(W)\right]. \quad (5)$$

Provided that the number of insured growers is greater than 2, this is less than the risk premium paid by the grower and thus the insurance arrangement is mutually beneficial (Robison and Barry, 1987).

While the model in (4) assumes homogeneity in the types of risk and independence of one another, these are conditions that are desirable, but not required for an insurance pool (Cummins, 1991). With positively correlated and heterogeneous risks, a pool can still be solvent, however the magnitude of risk reduction from pooling is lower than if the risks were independent (Harrington and Niehaus, 2004). The relationship between the premium paid by a grower and the economies of risk enjoyed by the insurer allows any insurance to function as an effective risk management tool and minimize moral hazard. In this way, insurance can be structured to fit the needs of growers of perishable commodities and provide incentive to create more food safety. Currently, no industry has such a risk pool and insurance arrangement. Policies addressing food safety on the market today are underwritten on an individual level by only a handful of insurers.

Recall Expense Insurance

When dealing with the risk of a contamination in a grower's produce, it is necessary to consider three principles; frequency, duration, and intensity (Turvey, 2006). Frequency reflects the probability that a contaminant is present in the grower's produce while duration is the amount of time that the grower's produce is infected by the contaminant. Intensity is the degree of severity of the contaminant as a function of duration. Contaminants that could affect a grower's produce have different durations, intensities and frequencies with some having a long duration and moderate losses, while others have very short durations and high losses (Turvey, 2006). In the context of leafy green contaminants, in 2012 alone there were 20 recalls of products for three different bacteria: Listeria monocytogenes, Salmonella, and E. coli.

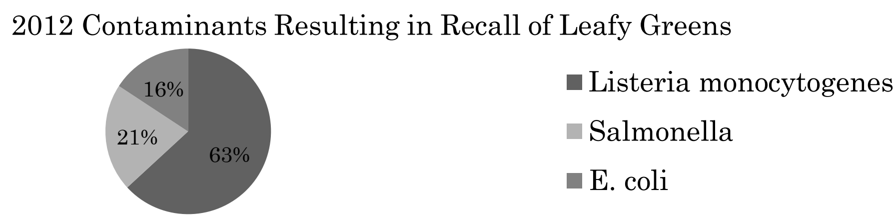

Figure 2. 2012 Contaminants Resulting in Recall of Leafy Greens

From Figure 2, it is easy to see that not all recalls will be caused by the same contaminant and thus the costs associated with a given recall event will be different and random with respect to frequency, duration, and intensity of the contaminant. For example it is well understood that E. coli bacteria is more lethal than Salmonella and Listeria. However, the Listeria outbreaks are more frequent, so they could present more of a risk in terms of hospitalizations. The most recent spinach recalls (2011-2012) certainly reflect varying degrees of intensity (Table 1).

Table 1

Description of Spinach Recalls (2011-2012)

Date	Brand	Product	Contaminant(s)	Reported Illnesses	Company
4/6/2011	Fresh Express	Spinach	Salmonella	0	Fresh Express
10/21/2011	Church Brothers, LLC	Bags of clipped spinach	Salmonella	0	Church Brothers, LLC
10/24/2011	Fresh and Easy	Spinach	Listeria monocytogenes	0	Fresh & Easy Neighborhood Market Inc.
12/23/2011	Better Brand, Krisp Pak, Avon Heights	Fresh Spinach	E. coli	0	Avon Heights Mushrooms, Inc.
9/19/2012	Kroger Fresh Selections	Spinach	Listeria monocytogenes	0	Kroger
11/2/2012	Wegmans	Spinach	E. coli	16	Wegmans Foods Markets, Inc
11/8/2012	Fresh Express	Spinach	Salmonella	0	Fresh Express Incorporated

The spinach recalls from 2011-2012 were largely initiated as precautionary measures and not in response to any reported illnesses. Indeed, the only recall for which illnesses were reported was as a result of E. coli contamination which affected 16 people, highlighting the severity of that particular bacterium.

In a study released in 2013, the Center for Disease Control (CDC) found that of all the reported foodborne illnesses, contaminated leafy green commodities account for the highest proportion (22.3% of all foodborne illnesses). However, in terms of hospitalizations and death, leafy greens rank #2 and #6 respectfully (Painter et al., 2013). The rankings again highlight the heterogeneity and randomness associated with different contaminants and how they relate to the rates of illness, hospitalization, and death. While leafy green commodities are the leading cause of foodborne illness, they rank lower than dairy products in terms of hospitalizations and lower than poultry in terms of deaths.

Turvey (2006) incorporates the concepts of frequency, intensity, and duration into a conceptual model of recall expense insurance designed to defray costs associated with business interruption, testing, and other recall-related expenses. This conceptual model provides a valuation of insurance for every $1000 of coverage purchased. The model incorporates the duration of the recall event, with the probability of the duration assumed to be a gamma distribution with mean and standard deviation in terms of days. The intensity of the recall event is represented by an exponential function, which is the duration raised to a given level of intensity so that the higher the intensity, the faster the value of the insurance is driven to zero (Turvey, 2006). Because the frequency is a prior probability of the event occurring, underwriters can take a theoretical model such as this and adjust it for an individual firm.

The risk characterized by Turvey's (2006) loss function in essence protects against the recall risk and serves as a theoretical model for recall insurance. It demonstrates how frequency, intensity, and duration can be reflected in a contract to insure a producer against its own expenses. Insurance policies which insure individual businesses against the expenses associated with recalls already exist, so it is quite possible for a grower to find coverage of this kind.

While, insurance policies that cover expenses as a result of a recall do indeed exist, they are in their infancy. Insurers have little experience with this form of risk and so premiums remain relatively high (Henkel, 2012). The policies are innovative in that they are not liability coverage instruments, per se, in which the indemnity is only triggered after a consumer is injured. Rather, the recall insurance policies on the market cover recall expenses, which can be substantial and ultimately lead to financial distress. This is an important distinction because recalls do not necessarily imply that there is an outbreak in the population. In fact, many times recalls are initiated to prevent such outbreaks by stopping the consumption of the contaminated product, and this is indeed desirable. Table 2 provides a visual summary of a sample of the policies on the market today. Policies of this kind have been around in some form or another since 1993 (Skees et al., 2001), but have become more and more prevalent given the changing nature of the food industry and increased uncertainty. Generalizations are drawn from Table 2, individual policies on the market, to inform a discussion of recall policies that exist today.

Table 2

Product Recall Insurance Policies

Brand	Product Name	Expenses			Revenue Loss	Brand Rehab
		Pre-Recall	Recall	Third-Party Recall		
Aon	Product Contamination	x	x	x	x	x
Capitol Risk Concepts	Product Contamination/Product Recall	x	x		x	x
Chartis (AIG)	RecallResponse	x	x	x		
Catlin	Product Contamination	x	x	x	x	x
Crum & Forster	recallProtect+	x	x	x	x	x
Liberty International	Contaminated Products	x	x			
Lockton	Product Guarantee and Recall	x	x	x		
MRM	Recall Advantage	x	x	x	x	x
XL Insurance	Product Recall and Food Contamination	x	x	x	x	x

Sources: www.aon.com/risk-services/crisis-management/product_recall.jsp
www.aig.co.uk/product-recall_2538_367190.html
www.crclimited.com/coverages/prop-casualty/product-contamination.html
www.catlin.com/en/insurance/war-political-risk/product-recall
www.cfins.com/products/specialty/productrecall.html
www.liu-usa.com/omapps/ContentServer?pagename=LIUUSA/Views/Main&ft=2&cid=1138364256509
www.lockton.com/Services-And-Solutions/Product-Guarantee-And-Recall
www.mrmllc.com/
www.xlproductrecall.com/pr/controller.xl

With these policies, indemnities are triggered by the losses due to accidental or malicious tampering of a food product that either has resulted in or would result in bodily injury or property damage. Malicious tampering is considered to be the intentional adulteration of the insured's product such that there is reasonable cause to consider the product unsafe to consume. Accidental contamination can be the result of bacterial contamination as well as chemical contamination caused by a variety of things including faulty manufacturing. Human error can also be a covered recall event, where for example, an agent of the producer neglects to include an allergen warning on a product label and a recall is then needed. Another way that a covered recall event can occur is through a presumed contamination of a food product. Such a recall could occur as a result of product extortion, where a clear threat to maliciously tamper a food product is communicated to the company and a recall is then necessary. This could also come about through regulatory forces where an outbreak of a disease is observed, but health officials cannot say with certainty the exact source. Under the Food Safety Modernization Act (FSMA), the FDA can mandate a recall where a company has failed to voluntarily recall a food product. The law reads that a recall mandate can be implemented, "…based on information gathered through the reportable food registry … or through any other means, that there is a reasonable probability that an article of food … and the use of or exposure to such article will cause serious adverse health consequences or death to humans" (FSMA, 2011).

It should be noted, however, that there are mechanisms within the law that preclude this outcome. The firm in question is first notified to cease distribution and voluntarily recall the product. Should the firm refuse to recall the product, the FDA first holds a hearing in which the firm can discuss the recall order. The Secretary of Health and Human Services can then either amend or vacate the order after that point (FSMA, 2011). Further, because of the substantial indirect costs of the product recall (that is, the damage to the brand and liability) it is far more likely that a firm will voluntarily recall a product before the FDA mandates a recall.

The indemnities paid to the insured cover specific expenses associated with the recall and generally fall into three categories: pre-recall expense, recall expense, and third party expense. Pre-recall expenses are those incurred in ascertaining the potential for bodily harm or property damage as a result of consumption of the product. These include any type of chemical analysis or physical inspection of the product. Recall expenses begin with notification that generally includes the cost of any form of announcement as well as the cost of correspondence with the customer and the public. Within the firm, the recall insurance covers the expense of shipping the contaminated product and redistribution as well as additional warehousing/storage rent. Insurance generally covers the hire of additional employees, overtime paid to employees, and expenses of the employees (such as transportation and lodging) as well. Proper disposal of the product along with its packaging and, if need be, any unused packaging is also covered. A key element of these policies is the third party costs. Depending on the policy, these are the costs associated with the repair of a retailer's product, business interruption, retail slotting fees, and any cancellation fees arising from a scheduled promotional/advertising campaign or any other expense that is contractually required with a retailer. While many of the policies on the market today cover third-party costs, some offer it only as optional coverage where the insured must pay an additional premium (Henkel, 2012).

Some policies offer loss of gross profit coverage. This coverage can include losses from legal fees, net profits, and the replacement of contaminated product with non-contaminated product. There can be a specified time frame for which the insured's revenue is covered. For example, Crum and Forster's recallProtect+ policy can cover loss of profits over a span of 3, 6, 9, or 12 months after the covered incident.

An important factor in food recall events in terms of cost is risk communication. Particularly for those policies that indemnify the insured from loss of gross profit, risk communication is a key component in mitigating public outrage. The World Health Organization has recognized risk communication as an integral part of risk analysis in food safety and defines it as, "…an interactive process of exchange of information and opinion on risk among risk assessors, risk managers, and other interested parties" (World Health Organization, 2013). Insurers have a vested interest in seeing that risk is communicated such that the insured company maintains its credibility in the eyes of the public and losses of revenue are mitigated. In the policies examined, many insurers that offer this coverage have partnered with public relations firms. For example, Chartis' RecallResponse policy highlights its relationship with Edelman, one of the world's largest public relations firms, indicating that their strategic partnership during a crisis is essential to the future of the firm post-crisis. Coverage of this kind is typically restricted to a specific time interval and offered as additional coverage (Henkel 2012).

Each policy has capacity limits for recall expenses that tend to be different based on the policy. Chartis and Crum and Forster's policies have capacities up to $10 million while Catlin's policy has up to $25 million for accidental contamination and $50 million for malicious contamination. Aon's policy has a capacity up to $388 million (includes liability coverage), however this capacity does not seem typical of most policies, which are generally designed for companies whose revenues are less than $1 Billion.

While food product recall insurance is an effective risk management tool in mitigating the direct expenses of food recall events not otherwise covered in a liability insurance policy, again, these instruments are in their infancy. The covered risks discussed in this paper are available; however, most policies only cover a few of the risks and also the deductible may be very high relative to the size of the firm (Henkel, 2012). The question, then, is why a grower would not routinely purchase recall expense insurance? A potential answer may be because insuring such an infrequent risk that is random in terms of duration and intensity does not maximize the grower's utility for risk, and thus a grower may prefer to selfinsure. Such a policy may, however, be more attractive to a large grower/shipper that contracts its production through individual growers. Because recalls are initiated at the brand level, an integrated grower/shipper's risk associated with recall is different than that of an individual grower's insofar as the costs associated with pulling a branded and packaged item from the market are likely to be higher than an individual grower's. Further, this policy would only become active if the insured's produce is recalled. It would not, however, pay an indemnity in a situation where the market for the insured's produce is impaired or collapses as a result of another firm's produce being contaminated.

A grower may view the risk and the costs associated with a recall as something that can be monitored and managed within the firm through investments in information gathering (testing and auditing) and diversification (offering different products which are not correlated in terms of recall risk). From Table 1, it is clear that many of the recalls are very small in scope, with only specific branded items being recalled and oftentimes initiated before any illnesses are reported. A sufficiently large and diversified grower may be able to absorb the risk of any one commodity being recalled, provided the contaminant can be traced back effectively.

Catastrophic Revenue Insurance

While growers may use existing policies or self-insurance to protect against the expenses associated with a recall, growers are still exposed to the systematic risk that a food safety scare can impair the market for a commodity for an unknown period of time. Thus it may be equally, if not more important to insure against the systematic risk of a food safety scare. Unlike insuring just the expenses, this risk would be highly correlated with other losses in an insurer's portfolio of leafy green growers which is why a reinsurance arrangement similar to crop or flood insurance would likely be needed. [5]

Contingent claims valuation has been used in the literature to price agricultural insurance (Richards and Manfredo, 2003; Ramirez, Manfredo, Sanders,

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[5] Reinsurance is insurance for an insurance pool. A reinsurance arrangement allows the insurer to diversify risks without having to acquire more capital. For further discussion, see Harrington and Niehaus, 2004, p. 89.

2006). These works utilize options pricing models to value revenue insurance for farmers in specialty crops and are particularly informative in creating such an instrument.

An insurance contract for revenue whose payoff is contingent upon a food scare is isomorphic to a put option. A put option is a financial instrument whose holder pays a premium to have the right, but not the obligation to sell an underlying asset at a specified price (the strike price). In adapting this to a revenue insurance model, the "price" of the underlying is the revenue at a particular week for the spinach industry. Thus, a catastrophic revenue insurance policy which indemnifies growers for revenue losses resulting from a food safety scare can be adapted from the conceptual model of a vanilla put option:

$$V_I = b(t) \int_0^K f(R_t)\,(K - R_t) dR_t \tag{6}$$

where $b(t)$ is the discount factor, e^{-rt}, where r is the risk-free rate of interest, and K is the cut-off revenue level (or, in the context of a put option, the strike price). The revenue, R_t, triggers an indemnity in the amount of the difference between cut-off revenue, K, and the revenue at maturity, R_t. This would mean that the insured purchases a policy that matures at the end of the year. At the end of the year, if revenue is below the strike price, a payment in the amount of the difference is paid from the insurer. Such a policy offers the insured flexibility in that any combination of unfavorable prices and volume can trigger an indemnity.

The major shortcoming with the vanilla put option model is that its payoff depends on the magnitude of the underlying asset value and its strike at maturity. Thus, such an option may not be triggered if, at the time of maturity, prices and volumes of the commodity have recovered from an outbreak event. Having the option to receive a payout whose value takes into account the effect of the event at maturity would indeed be more appropriate. Following Turvey's (2006) work, this thesis examines a class of exotic options known as path-dependent options. As the name implies, these options are designed to capture how the settlement prices of the underlying asset were reached (Zhang, 1998). There are three types of path-dependent options that are appropriate for consideration in the context of catastrophic revenue insurance: Asian options, lookback options, and barrier options.

An Asian option is an option whose value is derived from an average of underlying revenues over a given period of time (Zhang, 1998). In effect, an Asian option is the equivalent of buying multiple vanilla options, but is much cheaper as it reflects an average of each vanilla option purchased (Zhang, 1998). The value of the option is an average taken over time based on the expected realization of a constant strike less the average underlying revenue:

$$(e^{-rt})E\{Max[0,(K-\overline{R_t})]\} \tag{7}$$

such that should the average revenue over the specified period of time, $\overline{R_t}$, fall below the strike, *K,* an indemnity is triggered in the amount of the difference between K and $\overline{R_t}$ (Glasserman, 2004). Because the option is triggered by circumstances which drive the average revenue below the strike, this option is the most practical for catastrophic revenue purposes and offers good coverage to the insured. It is limited, however, by the fact that should prices and volume rebound in subsequent weeks, the option still may not be triggered yet the grower may have still been impacted by the event.

As opposed to an Asian option, a lookback put option captures the extremes of revenue movements by allowing the policy holder to receive a payout based on the minimum revenue observed over the life of the option, not the average (Zhang, 1998). In this way, the lookback option is identical to the vanilla put option in (6), except that the underlying revenue at maturity is replaced by the lowest price observed over the life of the option thus giving the holder of the option the maximum possible payout (Zhang, 1998). So that the payoff at expiration of the option is:

$$(e^{-rt})E\{Max\{(K) - min(R_{ti})\}. \qquad (8)$$

Where $min(R_{ti})$ is the minimum observed revenue over the life of the option. The major limitation of this is that because it is based upon the highest valued occurrence (i.e. the lowest revenue), the premium will be significantly higher than the Asian option (Turvey, 2006). Although the premium will be higher, this option may be useful in that it offers the most coverage of all the options examined.

Barrier options are another form of path-dependent options that may be effective in structuring revenue insurance. These options only become active if the underlying asset's value reaches a certain level (Hull, 2000). In the context of the revenue insurance arrangements examined in this thesis, the "knock-in" barrier put option is the most appropriate. This is simply a vanilla put option that only becomes active if the revenue at expiration, R_{tn}, falls below the barrier, $\tau(b)$,

$$(e^{-rt})E\{1[\tau(b) \leq t_n](R_{tn} - K)\}. \qquad (9)$$

Barrier options are attractive because they limit exposure to time value (Turvey, 2006). The reason for this is that barrier options have the same value as any option, when active, but no value when not active (Turvey, 2006). Their value, then, is based upon two probabilities: the probability that the barrier will be reached and the probability that an indemnity is triggered. These options offer some flexibility with respect to the risk preferences of the grower insofar as the barrier option can be combined with an Asian or a lookback.

In the context of spinach revenue insurance, the barrier at which the put option becomes active would likely be a recall event rather than some circumstance of prices or quantities. This barrier event could coincide with a systematic market effect or not. In the case of the 2006 E. coli outbreak in spinach, however, the exact source was not identified until an entire month later at which point DNA analysis confirmed that four fields in San Juan Bautista, CA were the only source of the outbreak. By this time the entire market had basically come to a stand still for two weeks, leaving growers without a market for their spinach for that amount of time.

METHODOLOGY

Options Pricing with Monte Carlo Methods

In their seminal work Black and Scholes (1973) provide a closed form solution for the pricing of options as a function of 5 factors: (1) the underlying cash market price, (2) the option strike price, (3) the time to maturity, (4) the risk-free rate of return, and (5) the volatility of returns from the underlying asset (Black and Scholes, 1973; Zhang, 1998). This equilibrium based pricing model assumes that stock prices follow a Geometric Brownian Motion (GBM), with settlement prices distributed log-normally and returns distributed normally (Hull, 2000). The Black Scholes model and its assumptions have served as the traditional way to price options.

The Black-Scholes model provides a closed form solution to estimating the theoretical value of a European style option, but it cannot be used to conveniently value path dependent options in the context of revenue insurance for fresh spinach. Monte Carlo simulation methods, however, provide a convenient and flexible way to estimate the value of path-dependent options. [6] Monte Carlo methods for pricing options were first presented by Boyle (1977). In contrast to the closed-form approach, Monte Carlo methods offer particular flexibility in application (Glasserman, 2004). Essentially, the Monte Carlo approach generates large numbers of random movements in the underlying asset's price from which the option price is ultimately derived. The advantage of this is that the distribution from which the options prices are drawn is specified with relative ease. Further, this is

[6] Hull, 2000 shows a closed form solution for path-dependents.

particularly useful for analyzing path-dependent options where the underlying process can contain jumps or revert to a mean.

There are 5 basic steps to obtain options prices using Monte Carlo simulation: (1) a sample path is obtained from the risk-neutral world, (2) the payoff is calculated, (3) sample paths are repeatedly taken and payoffs calculated, (4) the mean of the sample payoffs is calculated in order to obtain the expected value of the payoff, and (5) the expected value of the payoff is discounted at the risk-free rate of interest (Hull, 2000). In the context of revenue insurance, the changes in revenue are specified and added to the revenue from week to week. A payoff is calculated based on whether or not a payoff is triggered. This is simulated 5000 times for robustness, so that the average payoff is the expected value of the option over many, many weeks. [7]

An important aspect of pricing these policies is the setting of the strike revenue. In order to accommodate many scenarios, the strike is first set at the long-term average weekly revenue then increased to show the effect of moving the strike upward. With the "knock in" barrier options, the strike revenue is allowed to vary according to the average weekly revenue at the time the barrier is crossed.

As discussed in the previous section, the barrier is defined as a recall event in the spinach industry. While the 2006 E. coli outbreak and subsequent recall was the largest one in the history of the leafy green industry, not all recalls have a noticeable effect on prices or volumes. In fact, of the seven most recent spinach recalls, none had any clear impact on the market for fresh spinach. Figure 3 shows prices and volumes of spinach with all the spinach recalls highlighted from 2011-2012.

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[7] For a full example of how to model in a spreadsheet framework see Appendix B.

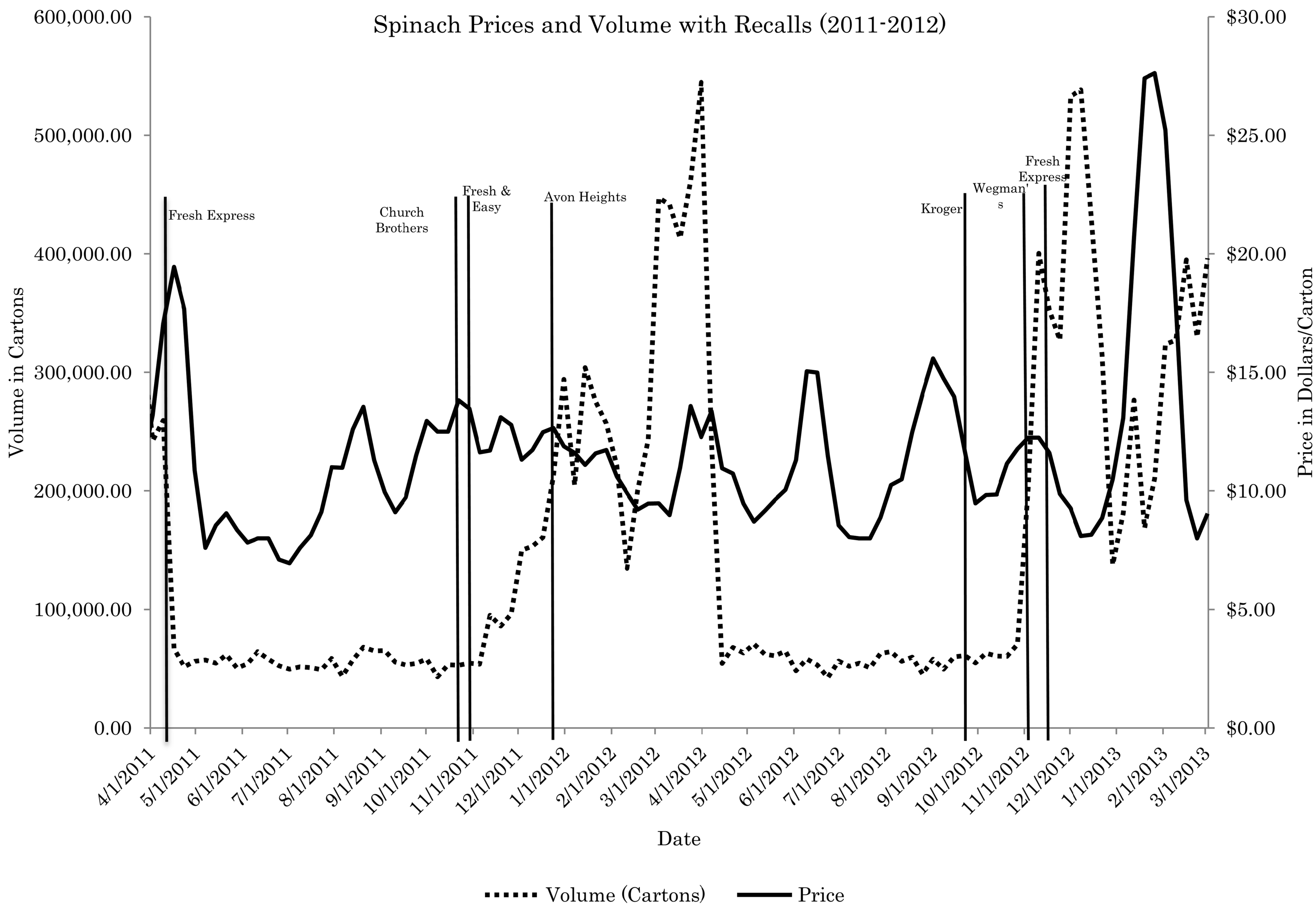

Figure 3. Spinach Prices and Volume with Recalls (2011-2012)

Because no clear correlation between these particular recall events and systematic effects can be seen, the intensity and duration of each event play a large role in whether or not there is a market decline in the industry. Because very few recalls have a severe systematic impact, this frequency is much lower than the recall event, but corresponds to a 79.1% decline in revenues as calculated by Richards et al. (2009). The overall probability of such an event occurring is mathematically represented as follows:

$$\frac{19\ recalls}{427\ weeks} * \frac{1\ outbreak}{19\ recalls} \approx .0023 \tag{10}$$

This implies that a recall with an outbreak on the magnitude of the 2006 case occurs 1 time out of every 427 weeks. The barrier options, then, reflect the probability of a recall initiated in any given week with a probability of 19/427. The outbreak with a demand shock (or jump) is given a probability of 1/19, provided a recall has been initiated.

In using Monte Carlo methods in estimating the value of the insurance contracts (options) described above, spinach industry revenue is assumed to follow a Brownian motion process (Richards et al., 2009):

$$dR_t = \mu dt + \sigma dz \tag{11}$$

where μ represents the mean drift rate of the process for each unit of time, *dt.* The volatility of the process is represented by σ and dz represents the standard Weiner process (Hull, 2000; Glasserman, 2004; Richards et al. 2009). This model is simplistic, however, in that allows the revenue to evolve in either direction (negative or positive) without bound. Because this is not a reasonable assumption for commodities, the model is adjusted so that any trends away from the mean revert back toward the mean in the long run (Richards et al., 2009). This is represented by adjusting the process in (11) as follows:

$$dR_t = k(R_t^m - R_t)dt + \sigma dz \tag{12}$$

where k is the rate at which the price reverts back to the mean and R_t^m is the mean revenue (Richards et al., 2009). This model is used to characterize changes in revenue for the spinach industry every week.

DATA

A time series of weekly spinach revenue from 2005 to 2013 was developed from reported USDA – AMS prices and volumes. The prices represent an average of the high and the low per carton price of bulk spinach in California and Arizona for each week. [8] The total volume of cartons represents all shipments from Arizona and California in order to stay consistent with the pricing data. All values are observed at the shipping point of the spinach, meaning the prices and volume of cartons reflects the point at which the product first changed hands. While spinach is grown and shipped from other places, California and Arizona represent the bulk of shipments and is recorded regularly by the AMS, which does not count the number of cartons from Mexico. The time series encompasses the effect of the E. coli outbreak in US spinach at which point the data shows no movement of spinach between September 23, 2006 and September 30, 2006, and notes that on the day of the outbreak that, "Supplies insufficient to quote."[9]

Revenue is calculated by multiplying the average of each week's price by that week's entire volume of cartons. This is the total revenue of the entire fresh bulk spinach industry. Because there are no values recorded for the two weeks ending on September 23rd and September 30th industry revenue is assumed to be zero which is consistent with the AMS reporting. Figure 4 is a chart of the revenue data.

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[8] Bulk spinach are boxes containing 24 bunches of spinach. Note that the data do not reflect bagged spinach values.
[9] Source: USDA-AMS Market News Portal: http://1.usa.gov/WZWOWR

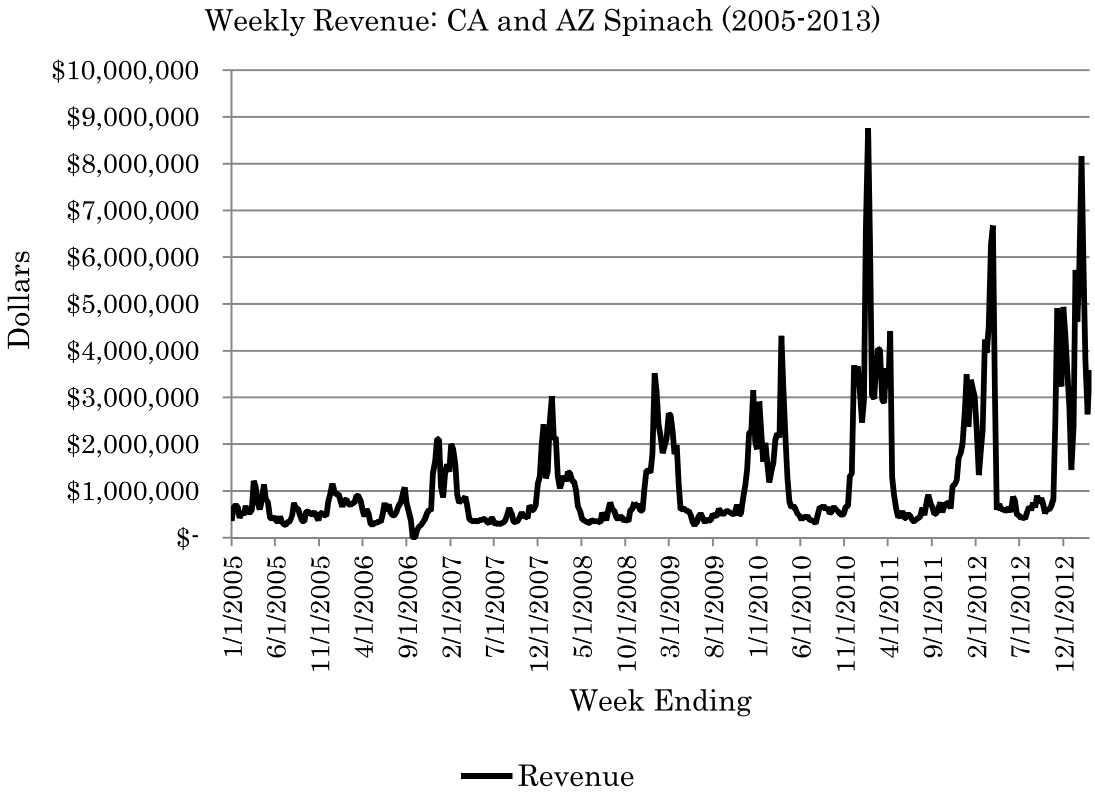

Figure 4. Weekly Revenue: CA and AZ Spinach (2005-2013)

Figure 4 not only highlights how volatile weekly spinach revenues are, but also the seasonality of the spinach production. Spinach is produced year round in the coastal areas of California. However, from December through March the industry produces much higher volumes as production areas in Imperial Valley, California and Arizona add to the amount of spinach coming from the coastal regions. For this reason, upward spikes in revenue are primarily driven by increases in the volume. On a yearly basis, revenue of fresh bunched spinach has shown large increases over time as seen in Figure 5.

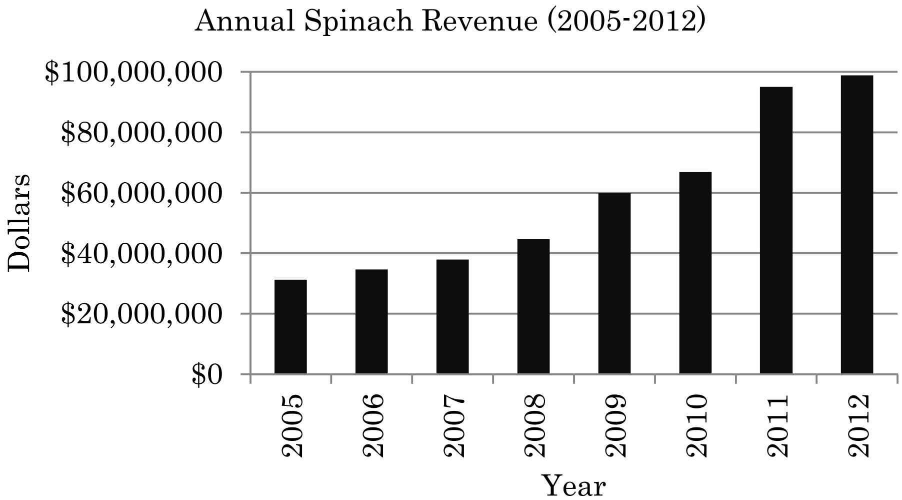

Figure 5. Annual Spinach Revenue (2005-2012)

As shown in Figures 4 and 5, revenues from spinach, though highly volatile, have grown tremendously from $31 million in 2005 to $98 million in 2012. Despite the outbreak in 2006, total industry revenue still grew relative to 2005 to about $34 Million. In the next section, the pattern of this growth in revenue is fitted and option values are estimated.

RESULTS

Stochastic Process Estimation

In order to estimate the price of the spinach insurance policies outlined previously, the nature of the revenues is first characterized. By fitting a stochastic process to the weekly revenue data for spinach and estimating the structure of the process, values for the exotic options discussed can then be calculated from a simulated forecast. The processes fitted are a Brownian Motion and a Brownian Motion with Mean Reversion as is consistent with the literature (Richards et al., 2009). While Richards et al. (2009) explicitly fit a jump process to spinach revenue, for the purposes of testing a variety of options, this thesis follows the treatment of jump processes put forth by Turvey (2006). Jumps are indeed important to the process of the underlying, however in terms of catastrophic market collapses (which the proposed insurance is designed for) a jump is modeled outside of the process itself using prior probabilities and reflected in the barrier options as suggested by Turvey (2006). The parameters of the BM process (11) and BM-MR process (12) as well as the overall fit of both processes were estimated using SHAZAM Econometrics Software and are presented in Table 3.

Table 3

Stochastic Process for Spinach Industry Revenue: January 2005-March 2013

Process:		BM		BM-MR	
Variable	Definition	Estimate	t-ratio	Estimate	t-ratio
μ	Average growth rate	0.009	0.272	0.009	0.287
σ	Standard deviation of the process	0.399*	29.177	0.373*	30.751
κ	Rate of mean reversion	N/A		0.124*	5.530
Log-Likelihood function		-406.684		-392.789	

*Significant at the 5% level. The processes are estimated via maximum likelihood.

As shown in Table 3, the BM-MR process is the preferred model and indicates that revenues in spinach have increased by 0.9% on average. The rate of mean reversion is estimated at about 12% per week meaning that any upward or downward deviations from the mean are fully removed about every 9 weeks. [10]

Vanilla, Asian, Lookback, and Barrier Option Premiums

The estimated parameters for the BM-MR process are used with (12) to simulate the path of weekly spinach revenue over a 52 week period using Monte Carlo methods. This is facilitated using Pallisade's @RISK software (see Appendix B). Premiums of the various options are calculated by taking the average realization of each payoff (outlined previously) and then discounting the payoffs at the current risk-free rate of interest, 0.25%.[11] The strike price for each fixed strike option is simply the average weekly revenue over all the weeks in the data which is

[10] The maximum-likelihood function as well as the SHAZAM code were provided by Dr. Timothy Richards. To see the maximum-likelihood equation, please see Richards et al, 2009.

[11] This rate is consistent with the Federal Reserve's target for the federal funds rate. However, at the time of this thesis the actual Federal Funds Rate was less than the target (approximately 0.15%). Consistent with option pricing theory, the risk-free rate of interest has a relatively low impact on option prices.

approximately $1.25 million. In the variable strike scheme, the strike price is established by taking the weekly average at the point the option is invoked. Under the barrier scheme the option is activated (or "knocked in") any time there is a recall announcement in spinach. The frequency is taken from a count of all recalls occurring within the time horizon of the revenue data as calculated in (10).

Table 4 shows the various options values at increasing strike revenues starting at the long-term weekly average of $1.25 million.

Table 4

Fixed Strike Option Values

Strike Price	Option Value		
	Vanilla	Asian	Lookback
$1,250,000	$284,742	$133,647	$1,080,425
$1,500,000	$425,254	$285,678	$1,326,802
$2,000,000	$817,298	$739,065	$1,829,987
$3,000,000	$1,734,421	$1,729,415	$2,825,206

The results in Table 4 show that the price of the insurance increases with the amount of revenue covered. As expected, with a strike of $1,250,000, the Asian option is the least expensive at $133,647 and the lookback is the most expensive at $1,080,425. The vanilla option, priced at $284,742, is lower than the lookback, but higher than the Asian. This is because it reflects the probability that the weekly revenue will be below the strike at maturity while the lookback reflects the worst observed weekly revenue. Increasing the strike price has a very noticeable effect on the option values, increasing them considerably. This is because the higher the strike, the more likely it is that a payout will be triggered. While the price of insurance seem high at a strike of $3 million, this may be a reasonable premium if industry revenues reach a level where insuring that amount of coverage would be needed.

Table 5

Option Values for Barrier Schemes

Option Scheme	Option Value		
	Vanilla	Asian	Lookback
Barrier with Fixed Strike ($1.25 Million)	$262,234	$117,019	$974,541
Barrier with Variable Strike	$308,290	$129,175	$987,253
Barrier with Variable Strike and Jump	$305,120	$129,766	$987,496

Adding the barrier with a frequency of 19/427, in each case reduced the value. Again the Asian option is the cheapest at $117,019 followed by the vanilla and the lookback at $262,234 and $974,541 respectively. These options are cheaper relative to the non-barrier options because the barrier must be reached first before a payout can be considered, regardless of revenue movements.

Allowing the strike price to vary with respect to the weekly average at the point of time the barrier is crossed makes the option more expensive. Again, the Asian option is the least expensive at $129,175 followed by the vanilla option at $308,290, and the lookback at $987,253. While these options are less expensive than the fixed strike options with no barrier, they are more expensive than the fixed strike barrier options. This is because it allows the strike price to grow with the process. The mean strike during the simulation is about $1.25 million, the standard deviation is $441.6 thousand, and the maximum strike observed was $2.79 million.

Allowing revenue to be reduced according to the prior probabilities in (10) does not alter the option value by a meaningful amount (relative to the fixed strike barrier), but does increase the Asian to $129,766 and the lookback to $987,456 reflecting the fact that the probability of a massive market decline is very small, but does increase the option value in that it is more likely that the option will be triggered with the reduction. Because the vanilla option reflects the probability of a payout at maturity and does not take into account the path of revenue over the life of the option, adding the shock to the barrier reduces the option value, but only to $305,120. For a full description of the estimation procedure see Appendix B.

In order to get a sense of perspective as to the cost of such insurance to growers, it is informative to compare the estimated premiums to the current handler assessment rates on a per-carton basis. Because revenues have historically been driven by large increases in volume, it is necessary to consider the amount of spinach produced over time before gauging the per-carton cost.

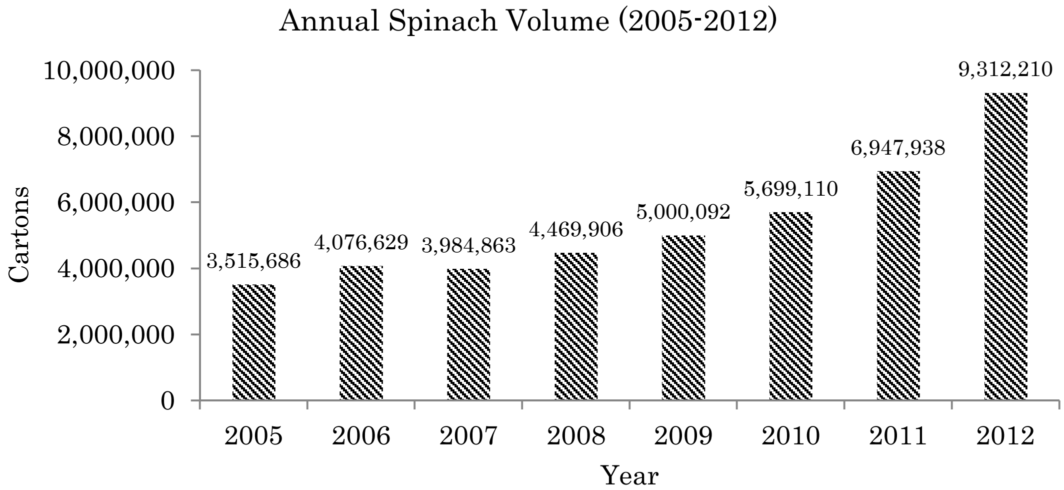

Figure 6. Annual Spinach Volume (2005-2012)

As shown in Figure 6, the volume of cartons has been increasing with 2012 having the largest carton total over the series with about 9.3 million cartons shipped. Using the average of 5,375,804 cartons over this time period results in a conservative estimate of the grower cost per carton under each revenue insurance scheme.

Table 6

Per Carton Cost of Insurance

Option Scheme	Per Carton Cost		
	Vanilla	Asian	Lookback
Fixed Strike ($1.25 million)	$0.053	$0.025	$0.201
Barrier with Fixed Strike (1.25 million)	$0.049	$0.022	$0.181
Barrier with Variable Strike	$0.057	$0.024	$0.184
Barrier with Variable Strike and Jump	$0.057	$0.024	$0.184

*Based on average annual volume of spinach produced from 2005-2012.

The results in Table 6 indicate that the Asian option values are indeed the most affordable insurance policies at about $0.02 to $0.025 per carton while the lookback would cost about $0.18 to $0.20 depending on the scheme. The vanilla option is priced between 4 to 6 cents depending on the scheme. However, the vanilla put option is probably the least appropriate for insurance purposes.

Given that all current AZ/CALGMA signatory producers and handlers pay around $0.02 per box, a comparable insurance premium perhaps indicates that growers would be willing to pay around this price to avoid the negative impacts of a food scare. Further, these option values are comparable to the program estimates for the proposed NLGMA which are between $0.01 and $0.05 in per-carton assessments to signatory handlers with additional assessments as determined by the board of the marketing agreement (USDA-AMS, 2011). Because the insurance premiums estimated represent the cost of only spinach revenue insurance (a commodity which makes up only 7% of all leafy green production), the price of the insurance on a per-carton basis may decrease if the insurance were made to cover all the other items under the leafy green marketing agreement. This, however, must be empirically tested.

Although much research is needed to operationalize such an insurance policy, it is no less informative to consider the per carton cost of the insurance in the context of a spinach growing operation. Using a University of Arizona Cost Study for a one acre spinach farm in Maricopa County (2001), a sample cost/return summary is assembled (Table 7).

Table 7

Total Cash Costs and Returns of AZ Spinach Farm (One Acre, Maricopa County)[12]

Budgeted Income (494 Cartons @ $14.18)		**$7,004.92**
Cash Land Prep & Growing Expenses	705.39	
Cash Harvest & Post Harvest Expenses	2311.14	
Operating Overhead	7.63	
Operating Interest (10%)	9.83	
Total Cash Operating Expenses	**3033.99**	
Cash Overhead Expenses	250.69	
Land Cost/Rent or Lease	200.00	
Water Assessment	10.14	
Total Ownership Costs	**460.83**	
Total Cost	**3494.82**	
Net Returns		**$3,510.10**
Break Even Price @ 494 Cartons		$707
Break Even Quantity @ $14.18		246.46

The cost study budgets for an average yield of 494 cartons and an average price of $14.18. At a per carton cost of $0.025 per carton for the insurance policy priced as an Asian option, and $0.184 per carton for insurance policy priced as a lookback, this brings the total expense for insurance to $12.35 and $90.90 respectively under the budgeted yield. Adding the proposed insurance expense will increase the break-even point of the operation.

[12] Source:
http://cals.arizona.edu/arec/pubs/vegetablecrops/central/20012002/cspinach2001.pdf

Table 8

Total Cash Costs of One Acre AZ Spinach Farm w/Revenue Insurance (Asian Option)

Budgeted Income (494 Cartons @ $14.18)		**$7,004.92**
Cash Land Prep & Growing Expenses	705.39	
Cash Harvest & Post Harvest Expenses	2311.14	
Operating Overhead	7.63	
Operating Interest (10%)	9.83	
Total Cash Operating Expenses	**3033.99**	
Cash Overhead Expenses	250.69	
Land Cost/Rent or Lease	200.00	
Revenue Insurance ($0.025/Carton)	12.35	
Water Assessment	10.14	
Total Ownership Costs	**473.18**	
Total Cost	**3507.17**	
Net Returns		**$3,497.75**
Break-Even Price @ 494 Cartons		7.10
Break-Even Quantity @ $14.18		247.33

Adding the insurance for the Asian option scheme increases the minimum price and quantity that the farm needs to operate. The break-even price at the budgeted yield increases by three cents to $7.10 while the break-even quantity increases by one carton.

Under the lookback scheme, the insurance has a much more meaningful impact on the farm's expenses and thus the minimum price and quantity needed to operate. Table 9 shows the impact of that a particular coverage.

Table 9

Total Cash Costs of One Acre AZ Spinach Farm w/Revenue Insurance (lookback option)

Budgeted Income (494 Cartons @ $14.18)		**$7,004.92**
Cash Land Prep & Growing Expenses	705.39	
Cash Harvest & Post Harvest Expenses	2311.14	
Operating Overhead	7.63	
Operating Interest (10%)	9.83	
Total Cash Operating Expenses	**3033.99**	
Cash Overhead Expenses	250.69	
Land Cost/Rent or Lease	200.00	
Revenue Insurance ($0.184/Carton)	90.90	
Water Assessment	10.14	
Total Ownership Costs	**551.726**	
Total Cost	**3585.72**	
Net Returns		**$3,419.20**
Break Even Price @ 494 Cartons		7.26
Break Even Quantity @ $14.18		252.87

The total cost of the insurance to the farm is about $90.90 per acre for its budgeted production of 494 cartons. Relative to the cost of the Asian option scheme, this is more expensive, but still, the minimum break-even point is moved up only slightly; by about $0.16 for the break-even price at the budgeted quantity and about five cartons for the break-even quantity a the budgeted price. This shows that under normal circumstances, the cost of such an insurance product for a one acre farm is not unreasonable, though further research is needed to operationalize the policy. For example, the insurance priced in this thesis assumes coverage on 100% of average weekly revenues. Farmers may indeed prefer a lower level of coverage which would further decrease the cost of insurance, yet still protect the grower's revenue at some level in the face of a food safety scare that negatively impacts market prices and volume of trade.

An important concept to remember when discussing revenue insurance as a tool in agribusiness risk management is that an operation should not make money from any revenue insurance policy. Rather, the insurance should protect revenue in the face of an extreme event that reduces revenue to levels that would invoke considerable financial losses in the face of an event like a food safety scare. A naïve example illustrates this concept. Assume a spinach grower purchased an insurance policy to cover 100% of his or her budgeted revenue (e.g., $7,004.92 per acre such as the case of the above representative spinach farm). An indemnity will be triggered if a recall occurs and the market for the grower's spinach is impaired, such that revenues are below the indemnified amount. If the market collapse results in a 79.1% decrease in industry-wide revenues (as seen in the 2006 outbreak in spinach), this would mean that the grower would likely realize similar losses, thus only take in $1,464.03 (79.1% of $7,004.92), far less than the $3,585.72 needed to break-even. The indemnity to bring the farm back up to the budgeted amount of $7,004.92 would be a payment of $5,540.89. This would bring the farm revenues back to normal levels after the food safety scare. [13]While the insurance policy would indeed be a valuable tool to the grower during a food safety crisis, historically, these events are

[13] Again, it is important to remember that this is a very simple example used to demonstrate the concept of how revenue insurance can be used for risk management purposes. Thus the exact indemnity amount would be a function of the coverage level, as well as the difference between the pre-determined strike revenue and the average revenue over a given time period consistent with an Asian option (or the difference between the strike revenue and minimum revenue over a given time period in the case of a lookback option).

rare. Thus the $12.35 expense year-after-year may seem unwarranted, particularly with the volatility of revenues the spinach industry experiences normally. However, in the presence of a severe food safety scare, the policy would allow the grower to maintain revenue at or above break-even levels. In many cases, this may be the difference between the operation staying in business, or closing down for good. In the long-run then, this risk management tool could serve to keep many growers in business, particularly smaller, less capitalized growers such as the one described in the Arizona Spinach enterprise budget presented above

It is important to note that these estimates do not represent the cost of actually running and administering such an insurance pool, which could be substantial. While the true cost of insurance would indeed reflect this, the purpose of this thesis is to examine the feasibility of insuring the risk and to estimate actuarially fair premiums, thus any estimation as to the administrative cost of the pool itself is outside the scope of this thesis. It is likely, however, that a market can be found for such a risk either through large private reinsurers or through the government, specifically, the USDA Risk Management Agency (RMA) that pilots such products. The risk would be very attractive to reinsurers because it is a large, economically significant risk that is uncorrelated with other risks such as natural disasters. Further, the risk is already being monitored by government officials through the AZ/CALGMA. Perhaps most importantly, the risk of an outbreak in leafy greens will likely decrease over time as trace-back and food safety technology improves. If indeed reinsurance arrangements can be achieved, the total cost of running such a pool would be shared with reinsurers.

CONCLUSION

Summary

The risk of a foodborne pathogen presents producers with significant economic challenges. Though the safety of food provided to consumers lies squarely on the shoulders of each individual producer, should any one producer deviate from that responsibility, the livelihood of all others are at stake. Nowhere is this more prevalent than in the leafy green industry. Contaminated leafy green items have resulted in more foodborne illnesses than any other food item. Additionally, the industry has been rocked by one massive E. coli outbreak in spinach which resulted in three deaths and over 200 reported illnesses, not to mention the considerable damage done to consumer confidence thereafter.

In order to prevent such events from happening, growers and handlers have come together in the two states where nearly all leafy greens are grown; California and Arizona. These growers and handlers have formed two statewide food safety initiatives in the form of marketing agreements which assess a per carton check-off to administer and enforce food safety standards put forth in either agreement. However, recalls still occur and thus the risk of an outbreak is still present.

Current insurance policies offer food companies excellent coverage for just about any expense incurred as a result of a recall. These policies are indeed innovative and offer clear incentives to growers who purchase such policies to lower their premium by investing in food safety. These, however, are limited in that they are not required by all producers and handlers and address the risk on purely a firm level. Insurance addressing the systematic risk of market collapse may be just as important, if not more important to insure than the pure expense of a recall event.

Using spinach industry revenue, a contingent claims approach to pricing weekly revenue insurance was implemented to estimate the value of a variety of different payout schemes. In doing this, a stochastic process for weekly changes in spinach revenue was fitted to estimate a 52 week forecast. This was simulated and priced using Monte Carlo methods. Consistent with the literature, this thesis draws on the use of path dependent options to price insurance. In particular, Asian, barrier, and lookback options were estimated and compared to current check-off prices. The Asian option insurance scheme is the cheapest between $0.02 and $0.025 per carton, while the lookback is the most expensive between $0.18 and $0.20 cents per carton. Adding a barrier based on the probability of a recall decreases the option value, while allowing the strike to vary according to an average of the weekly revenue at the point the barrier is reached makes it more expensive. Overall, the results compare favorably to current check-off amounts which are between $0.01 and $0.05 per carton. The cost of this insurance was evaluated at the farm level to show that it is of marginal impact to a small representative spinach growing operation.

Implications

Though the goal of this research is to present a model for catastrophic revenue insurance, such an arrangement undoubtedly warrants a discussion of moral hazard. That is, if the risk of a market collapse is mitigated through insurance, what incentive does any grower have to prevent such a situation? To some extent, this is seen in flood insurance where people who build houses on known flood plains are able to purchase subsidized flood insurance for their homes. This arrangement creates problems in that it allows homeowners to build in risky locations. In the context of food safety, this is a situation that is completely at odds with any food safety initiative or policy.

The question of how moral hazard can be mitigated is one that is inherent in any insurance arrangement and naturally requires a mechanism of monitoring and information sharing. Turvey, et al. (2002) study moral hazard among agricultural producers and simulate the use of inputs under an insurance contract. They find that ex-ante regulation of farmers induces the use of more inputs as it changes the optimizing behavior of the farmer (Turvey et al., 2002). For this reason, any insurance in food safety would likely come with prescribed regulations mandating Good Agricultural Practices, Good Manufacturing Practices, as well as other industry standards. Because such regulations are in place and monitored through marketing agreements, the model for insurance presented in this thesis would likely function best through a marketing agreement such as the AZ/CALGMA.

Members of these California and Arizona marketing agreements have (along with other produce industry associations) advocated for a national marketing agreement seeking to further unify food safety standards in the industry, giving rise to the proposal for the NLGMA. Despite this effort to prevent outbreaks, opponents to the proposed agreement argue that the cost of compliance to small farmers are too high, and further, that such outbreak events, as well as the numerous recall events each year, emanate from large producers of pre-cut, bagged products. For this reason, the national marketing agreement put forth by the USDA has been criticized for charging small farmers for a risk largely caused by large manufacturers.

Whether the risk of an outbreak lies with manufacturers or farmers is the subject for another study, but in either case small farmers of leafy greens certainly benefit from the bagged salad industry which has greatly expanded the market for leafy greens. The risk of an outbreak from either end of the supply chain is indeed related, and the chief benefit of the marketing agreement to growers is the reduced probability of such events occurring.

As such agreements are voluntary, the insurance model presented could provide a way to expand membership and add value to signatory members, particularly to small farmers. If the check-off assessment required by signatory growers included an insurance premium, it is possible that small farmers and other handlers would be more likely to join the agreement as their participation would prevent them from ever being completely wiped out from a food safety-scare. This is important because participation in such an agreement across all firms is not only desirable going forward, but also necessary to mitigate the problem of free riders.

Further, given the infrequent nature of such a risk, it is likely that insurance claims will not be triggered and thus the pool will be profitable. Any surplus of funds from the insurance arrangement may be used by the marketing agreement to fund activities such as research, promotion, and advertising. In the proposal for the NLGMA, special provisions are made so that the board of the proposed national agreement may initiate a supplemental rate in addition to the normal assessment rate to address a specific problem, however, in total this cannot exceed $0.05 per carton. Funds from an insurance arrangement may offer some flexibility with regard to special projects as the need occurs.

Future Research

From a theoretical standpoint, the insurance arrangement in this thesis makes very logical sense, however it gives rise to many questions. First, is there any proof that insurance can improve food safety? This would likely require a careful empirical examination of companies that have recall insurance vs. those that do not. Secondly, is it really true that farmers would be more likely to participate in a marketing agreement with such an insurance arrangement embedded into the check-off price? Interestingly, current crop insurance policies for leafy greens have some of the lowest participation rates of any crop insurance program, suggesting that perhaps growers will not be willing to pay for insurance. It would be valuable to survey current and potential members of marketing agreements to see if this would be the case. Finally, is the current arrangement of marketing orders effective such that it does not warrant further modification? This is perhaps the most important area for future research and one that would be most valuable to industry players. If current marketing agreements are found deficient in some way, the appropriate solution may or may not be an insurance program such as the model presented in this thesis.

Relative to further research in pricing food safety insurance, the first area to expand research would be to price such insurance using American-style options. This would give the insured the right to collect a payout at the week in which the food safety event occurred as opposed to the European-style options presented in this thesis, which pay out only at maturity. Further, it would be insightful to know the impact of insuring multiple commodities using one contract. Indeed leafy green growers are highly diversified, so it is likely that insurance for all types of leafy greens would be preferred. This may decrease the price of the insurance through diversification. However, this needs to be empirically tested.

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APPENDIX A

TIMELINE OF 2006 E. COLI OUTBREAK IN SPINACH

Date	Reported Illnesses	Deaths	Recalls	Number of States Affected	Press Release Content
9/14	50	1	None	8	Initial announcement advising consumers that bagged spinach may be a possible source of E. coli outbreak. FDA recommends consumers not eat fresh spinach until further notice.
9/15	94	1	Natural Selection Foods, Pro*Act, and Coastline	20	3 companies initiate recalls, states affected expanded to 20.
9/16	102	1	Natural Selection Foods, Coastline	19	Pro*Act removed from recalled brands.
9/17	109	1	Natural Selection Foods, River Ranch, Coastline	19	River Ranch initiates recall.
9/18	114	1	River Ranch, Natural Selection Foods, Coastline	21	Two recalls in effect and expansion of distributed product area to include 21 states. FDA announced that in light of the outbreak, spinach will be included in its Lettuce Safety Initiative
9/19	131	1	River Ranch, Natural Selection Foods	21	Updated information on the outbreak and involved parties. Coastline removed from the recalled brands.
9/20	146	1	River Ranch, Natural Selection Foods, RLB Distributors	23	DNA fingerprinting indicates that the source of E. coli 0157 is linked to "Dole Baby Spinach." FDA continues to warn consumers to not eat fresh spinach.
9/21	157	1	River Ranch, Natural Selection Foods, RLB Distributors	23	Source of outbreak is determined to have come from spinach produced in Monterey, Santa Clara, and San Benito counties in California.
9/22	166	1	River Ranch, Natural Selection Foods, RLB Distributors	25	FDA announces that spinach from non-affected counties is safe as well as processed

					spinach.
9/23	171	1	River Ranch, Natural Selection Foods, RLB Distributors, Triple B Corporation, Pacific Coast Fruit Company	25	Two more companies announce recalls
9/24	173	1	River Ranch, Natural Selection Foods, RLB Distributors, Triple B Corporation, Pacific Coast Fruit Company	25	FDA advises consumers to not purchase spinach if they cannot verify that it was not grown in the affected counties.
9/25	175	1	River Ranch, Natural Selection Foods, RLB Distributors, Triple B Corporation, Pacific Coast Fruit Company	25	Updated information on the outbreak and involved parties.
9/26	183	1	River Ranch, Natural Selection Foods, RLB Distributors, Triple B Corporation, Pacific Coast Fruit Company	26	Affected states updated to include one more as well as a reported illness in Canada.
9/29	187	1	River Ranch, Natural Selection Foods, RLB Distributors, Triple B Corporation, Pacific Coast Fruit Company	26	FDA announces that all implicated spinach has been traced back Natural Selection Foods, LLC in San Juan Bautista, CA
10/12	199	1	River Ranch, Natural Selection Foods, RLB Distributors, Triple B Corporation, Pacific Coast Fruit Company	26	FDA releases test results indicating a genetic match between the E. coli. Strand implicated in the outbreak and that present in cattle feces on four fields of four ranches in San Benito and Monterey Counties, CA.

Source: http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/2006/default.htm

APPENDIX B

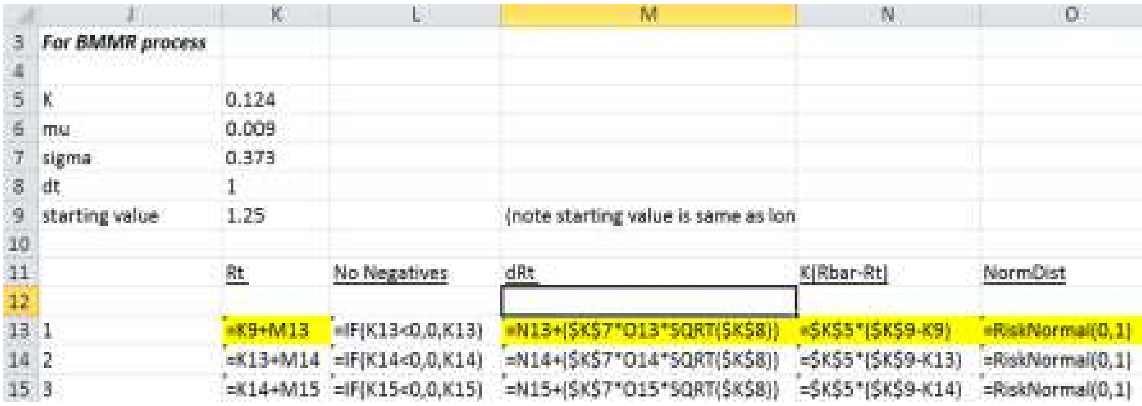
SPREADSHEET MODELING

The parameters for the Brownian Motion and Brownian Motion with Mean Reversion were estimated using SHAZAM Econometrics software. The parameter estimates are then used to extrapolate the BM-MR process. This is done using Pallisade's @RISK for the Monte Carlo simulation. This appendix illustrates the process of modeling in greater detail.

	J	K	L	M	N	O
5	K	0.124				
6	mu	0.009				
7	sigma	0.373				
8	dt	1				
9	starting value	1.25		(note starting value is same as long term mean)		
10						
11		Rt	No Negatives	dRt	K(Rbar-Rt)	NormDist
12						
13	1	1.443699918	1.443699918	0.193699918	0	0.519302729
14	2	2.345068	2.345068	0.901368082	-0.02401879	2.480929951
15	3	1.49907617	1.49907617	-0.84599183	-0.135788432	-1.904030558
16	4	0.955978893	0.955978893	-0.543097277	-0.030885445	-1.37322207
17	5	0.750603496	0.750603496	-0.205375397	0.036458617	-0.648348564
18	6	1.039280595	1.039280595	0.2886771	0.061925167	0.60791403
19	7	1.067900152	1.067900152	0.028619556	0.026129206	0.006676542

Figure 7. Spreadsheet Setup of BM-MR

Figure 7 shows how the spreadsheet was set up for the process. The estimates are entered and referenced in each cell as part of the formula in (12). The Monte Carlo is started through the Weiner process which includes a normally distributed error term in Column O. In @RISK, the command for this is =RiskNormal(0,1).



	J	K	L	M	N	O
3	*For BMMR process*					
4						
5	K	0.124				
6	mu	0.009				
7	sigma	0.373				
8	dt	1				
9	starting value	1.25		(note starting value is same as lon		
10						
11		Rt	No Negatives	dRt	K(Rbar-Rt)	NormDist
12						
13	1	=K9+M13	=IF(K13<0,0,K13)	=N13+($K$7*O13*SQRT($K$8))	=$K$5*($K$9-K9)	=RiskNormal(0,1)
14	2	=K13+M14	=IF(K14<0,0,K14)	=N14+($K$7*O14*SQRT($K$8))	=$K$5*($K$9-K13)	=RiskNormal(0,1)
15	3	=K14+M15	=IF(K15<0,0,K15)	=N15+($K$7*O15*SQRT($K$8))	=$K$5*($K$9-K14)	=RiskNormal(0,1)

Figure 8. Spreadsheet Formulas for BM-MR Changes

Each week's change is calculated by referencing the parameters in Column K and creating the changes in revenue according to (12) with a normally distributed error term in Column O. Because some revenue values will end up being negative (this is bound to happen wth 5000 iterations), a simple "if" statement makes the revenues "0" if negative in Column L.

To estimate the options values, the strike price is set, then the simulation is allowed to iterate 5,000 times. If the revenue is less than the strike, a payout is made. The average of these payouts is the option price. An example of the vanilla put is provided in Figure 9.

	I	J	K
59		47	1.237271295
60		48	1.105351856
61		49	1.2243873
62		50	1.630582497
63		51	2.032119644
64		52	2.030730525
65			
66		Vanilla Put	
67		Strike	1.25
68		strike - rev	-0.780730525
69		max(strike - rev; 0)	0
70		option price	0.290475937
71		Cost	$ 290,475.94

Figure 9 . Put Option Setup

For all options the setup consists of a strike price, the strike minus the revenue, the criteria (if the strike is less than the revenue the option is worthless), and the option price. The cost which is simply the option price scaled up by $1 million.

63	51	=K62+M63
64	52	=K63+M64
65		
66	Vanilla Put	
67	Strike	1.25
68	strike - rev	=IF(K64<0,K67-0,K67-K64)
69	max(strike - rev; 0)	=RiskOutput("BM payoff")+IF(K68>0
70	option price	=RiskMean(K69)
71	Cost	=K70*1000000

Figure 10. Put Option Setup Formulas

In this example, the option is triggered by the revenue at maturity (not path-dependent). To make this a path dependent option, would be to make K64 the average of the entire series (for the Asian) or the minimum of the entire series (for the lookback). The Barriers are constructed the same way, but conditions the option payout on the probability of the barrier being reached in each week (a Bernoulli trial).

	P	Q	R	S	T	U
7						
8		Jump %reduction				
9		0				
10						
11	Barrier (Recall)	Jump Revenue	Week	cumulative total	Moving Strike	Outbreak Jump
12						
13	0	1.430628145	1	1.430628145	1.430628145	0
14	0	1.355761102	2	2.786389247	1.393194623	0
15	0	1.474516266	3	4.260905513	1.420301838	0
16	0	1.177974353	4	5.438879866	1.359719966	0
17	1	1.548472107	5	6.987351973	1.397470395	0
18	0	1.382753026	6	8.370104999	1.3950175	0
19	0	1.373545155	7	9.743650154	1.391950022	0
20	0	1.119592784	8	10.86324294	1.357905367	0
21	0	[illegible]	9	[illegible]	[illegible]	0

Figure 11. Barrier and Variable Strike Setup

In order to condition the option values in Excel the barrier is given a probability and randomly assigned each week. To incorporate a shock to demand, the spreadsheet is setup to reference the Column P and reduce the revenue in that particular week by any percent desired, if there is a shock to demand (a value of "1") in Column U. So if there is "1" in the Barrier recall column, there is a chance (in Column U) that revenues will decline by some percentage. The frequency is based on a count of all recalls spanning the weekly data. This gives a frequency of 19 recalls every 427weeks. Of the recalls initiated one corresponded to a large, negative market impact so it is given a frequency of once every 19 recalls.

	P	Q	R	S	T	U
8		Jump %reduction				
9		0				
10						
11	Barrier (Recall)	Jump Revenue	Week	cumulative total	Moving Strike	Outbreak Jump
12						
13	=RiskBernoulli(19/427)	=IF(U13=0,L13,(L13-$Q$9*L13))	1	=Q13	=S13/R13	=IF(P13=1,RiskBernoulli(1/19),0)
14	=RiskBernoulli(19/427)	=IF(U14=0,L14,(L14-$Q$9*L14))	2	=Q14+S13	=S14/R14	=IF(P14=1,RiskBernoulli(1/19),0)
15	=RiskBernoulli(19/427)	=IF(U15=0,L15,(L15-$Q$9*L15))	3	=Q15+S14	=S15/R15	=IF(P15=1,RiskBernoulli(1/19),0)

Figure 12. Barrier and Variable Strike Setup Formulas

The pricing methodology remains the same, with a simple "if" statement embedded into the criteria so that "if" the barrier is reached (a value of 1 anywhere in the Column P), then an indemnity is allowed to occur. For the variable strike options, the strike price is the average at the week when the barrier is reached.

Barrier Put (Variable Strike)	
Strike	=RiskOutput()+VLOOKUP(1,$P$12:$T$64,5,FALSE)
strike - rev	=IF(Q64<0,K80-0,K80-Q64)
max(strike - rev; 0)	=RiskOutput("Var Strike Barrier")+IF(P65>0,IF(K81>0,K81,0),P65)
option price	=RiskMean(K82)
Cost	=K83*1000000

Figure 13. Barrier Option Values Formulas

The variable strike is identified using a "vlookup" statement which will return the average weekly value at the point the barrier is reached. The only real difference between the barrier option valuation is the addition of the IF statement which lets the option be triggered only if the sum of Column P is greater than zero. Doing this makes the option cheaper as the barrier must first be reached before an insurance payout is triggered.