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Incentives For Poultry Integrators To Contract Bio-Secure Producers And Implication For Government Indemnification Program

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INCENTIVES FOR POULTRY INTEGRATORS TO CONTRACT BIO-SECURE PRODUCERS AND IMPLICATION FOR GOVERNMENT INDEMNIFICATION PROGRAM

By

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These recent events of H1N1 flu outbreak illustrate the potential ramifications of infectious diseases on modern society and how society responds to these threats. This thesis addresses the specific case of avian influenza in U.S. poultry production. By building an expected utility maximization model for integrators contracting with growers of varying bio-secure levels, one can investigate the relationship between the bio-secure choice of the poultry industry and their production performance. The model is empiricized using the Phoon, Quek, and Huang (PQH) simulation technique to conduct numerical analysis. The model selects the optimal percentage of bio-secure farms for the integrators to contract, output price reductions due to disease outbreak, and different probabilities of disease outbreak. Results allow the examination of whether alternative USDA/APHIS indemnification rules can sufficiently influence integrators willingness to improve their bio-security level.

Key words: Avian influenza, infectious disease, government indemnification, poultry integrator

DEDICATION

I would like to dedicate this research to my parents, Zhang Xiaoning and Lu Xinxing.

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CHAPTER I

INTRODUCTION

The 2009 spring outbreak of the influenza A (H1N1) virus once again brought attention to the potential threat of avian influenza in a modern society. An epidemic of a new strain of the influenza virus was identified in April 2009 and has been commonly referred to as "Swine Flu." Through the summer of 2009, a total of 6,044 people had been confirmed infected and 63 people had died of H1NI virus infection. In response, the World Health Organization (WHO) raised its pandemic alert level to "Phase 5" (Phase 6 is the maximum), signaling their concern that a pandemic was imminent (Global Alert and Response, 2009).

These recent events illustrate the potential ramifications of infectious diseases on modern society and how society responds to these threats. This thesis addresses the specific case of avian influenza in U.S. poultry production. By building an expected utility maximization model for integrators contracting with growers of varying bio-secure levels, one can investigate the relationship between the bio-secure choice of the poultry industry and their production performance. The model is empiricized using the Phoon, Quek, and Huang (PQH) simulation technique to conduct numerical analysis. The model selects the optimal percentage of bio-secure farms for the integrators to contract, output

price reductions due to disease outbreak, and different probabilities of disease outbreak. Results allow the examination of whether alternative USDA/APHIS indemnification rules can sufficiently influence integrators willingness to improve their bio-security level.

1.1 Background information on influenza

Influenza is a disease common to man and a limited number of lower animal species mainly including horses, pigs, domestic and wild birds, wild aquatic mammals such as seals and whales, minks and farmed carnivores. However, influenza is also a potentially devastating disease in both humans and animals; therefore, it is a very important topic of study in both human and veterinary medicine. By definition, pandemics are major epidemics characterized by the rapid spread of a novel type of virus to all areas of the world and resulting in an unusually high number of illnesses and deaths in humans in most age groups (WHO, 2009).

There are 3 types of influenza viruses -- A, B and C. Types B and C are human viruses that mainly affect young children, causing a mild disease. The virus causing the 2009 influenza epidemic is a variant of the type A virus. Variants of the Type A virus have caused three other major global pandemics during the 20th century: Spanish Flu in 1918, Asian Flu in 1957, and Hong Kong Flu in 1968-69.

The Type A virus is the most critical type, because it could cause cross-species infections. Variants of influenza virus A are identified and named following a number of different conventions: 1) according to the isolate that they resemble (and thus are presumed to share lineage with); 2) according to their typical host; 3) according to their

subtype; and 4) according to their virulence. For example, influenza from a virus similar to the isolate A/Fujian/411/2002(H3N2) is called Fujian Flu, human flu, and the H3N2 flu. Variants named according to the host species include Bird Flu, Human Flu, Swine Flu, Horse Flu, and Dog Flu. Avian variants have also sometimes been named according to their virulence in poultry, especially in chickens. Examples include Low Pathogenic Avian Influenza (LPAI) and Highly Pathogenic Avian Influenza (HPAI), which is also called deadly flu or death flu.

Birds, especially aquatic birds, represent a vast reservoir of type A influenza viruses. These viruses have the capacity to spread to many lower mammalian species and sometimes cause high morbidity and mortality. A small number of cases of animal influenza in humans have been described in the past. In these cases the virus originated from pigs, seals, ducks and chickens.

1.2 Background information on avian flu

In birds, HPAI is a particularly contagious and aggressive disease that causes rapid systemic illness and death in susceptible birds. Domestic chicken and turkeys are most severely affected. Mortality in these birds often exceeds 50 % (WHO, 2008). From 1959 to 2003, only 21 outbreaks occurred worldwide, mainly in the Americas and Europe. Although all had serious consequences for the poultry industry, most remained geographically limited.

Avian influenza (AI), sometimes called Avian Flu, or commonly Bird Flu, refers to “influenza caused by viruses adapted to birds” (Harder and Werner, 2006). “Bird flu”

is a phrase similar to “Swine flu,” “Dog flu,” “Horse flu,” or “Human flu” in that it refers to an illness caused by any of the many different strains of influenza viruses that have adapted to a specific host. All known viruses that cause influenza in birds belong to the species Influenza A virus (Wiki, 2009). All subtypes of influenza A virus are adapted to birds, which is why for most practical purposes, the avian flu virus is synonymous with the Influenza A virus. Wild birds worldwide carry the viruses internally, but usually do not get sick. However, avian influenza is very contagious among cultivated birds and can make some domesticated birds, including chicken, ducks, and turkeys very sick and are frequently fatal.

Infected birds shed influenza virus in their saliva, nasal secretions, and feces. Susceptible birds become infected when they contact secretions directly or through contact with surfaces that have been contaminated by infected birds. Domesticated birds can also be infected by direct contact with infected waterfowl, other poultry, or through contact with surfaces (such as dirt or cages) or materials (such as water or feed) that have been contaminated with the virus.

Infectious avian influenza in domestic poultry causes two main forms of disease that are distinguished by low and high extremes of virulence. The “low pathogenic” form may go undetected and usually causes only mild symptoms, (such as ruffled feathers and a drop in egg production). However, the high pathogenic form spreads more rapidly through flocks of poultry and in chicken, may cause diseases that affect multiple internal organs, and has a mortality rate that can reach 90-100%, often within 48 hours (CDC, 2009).

Although avian influenza outbreaks in poultry have weakened economies and jeopardized food security, the greatest concern for human health is the risk that the current conditions could give rise to a human influenza pandemic. In general, avian influenza poses a low risk to people, since the viruses do not usually infect humans. However, "confirmed cases of human infection from several subtypes of avian influenza infection have been reported since 1997" (CDC, 2007). Most cases of avian influenza infection in humans are due to contact with infected poultry (e.g. domesticated chicken, ducks, and turkeys) or with surfaces contaminated with secretion and excretions from infected birds. The spread of avian influenza viruses from one person to another has been rare.

Avian influenza occurrence in the U.S. is relatively low; Table 1.1 shows U.S. avian influenza cases in the past 26 years.

The current absence of HPAI in poultry in the U.S. is maintained through constant surveillance of poultry flocks in commercial poultry operations, which is monitored by the state officials. Detection of an HPAI virus results in immediate depopulation of the flock. Less pathogenic viruses are controlled by vaccination, which is done primarily in turkey flocks (Wiki, 2009). The highly pathogenic avian influenza A (H5N1) epizootic (animal outbreak) in Asia, Europe, the Near East, and Africa is not expected to diminish significantly in the short term. It is likely that H5N1 virus infections among domestic poultry have become endemic in certain areas and that sporadic human infections resulting from direct contact with infected poultry and/or wild birds will continue to

occur. So far, the spread of H5N1 virus from person-to-person has been very rare. However, this epizootic continues to pose an important public health threat (CDC, 2009).

Table 1.1

Avian Influenza Outbreaks in U.S. from 1983—2008

TIME	*PLACE*	*TYPE*	*DETAILS*
1983-84	Pennsylvania and Virginia	H5N2	The HPAI outbreak resulted in humanely euthanizing approximately 17 million chickens, turkeys and guinea fowl in Pennsylvania and Virginia to contain and eradicate the disease. [1]
Spring/ Summer 2002	Virginia, West Virginia and North Carolina	H7N2	Infected 210 flocks of chickens and turkeys. More than 2.7 million birds were slaughtered.
November 2003	New York	H7N2	A patient who was infected by AI.
February 2004	Texas	H5N2	Detected and reported in a flock of 7,000 chickens in south-central Texas. This was the first outbreak of HPAI in the U.S. in 20 years.
February 2004	Delaware, New Jersey	H7N2	On two chicken farms in Delaware and in four live bird markets in New Jersey supplied by the farms
March 2004	Maryland	H7N2	Surveillance samples from a flock of chickens in Maryland tested positive for H7N2.
March and April 2006	Norfolk	H7N3	A poultry worker developed conjunctivitis caused by H7 avian influenza and three others tested negative. Thousands of birds were culled after the H7N3 strain was discovered.

1.3 Invasive species management issues for government

Invasive species are defined as non-native species whose introduction is likely to cause economic and environmental damage. Invasive species include nonnative, alien, or exotic plant pests (such as insects, weeds, or pathogens); animal and zoonotic disease pathogens, which can transmit diseases between animals and humans; or other organisms that can cause economic or environmental harm to U.S. agriculture, range, and forest systems if they enter the U.S. (USDA/ERS, 2009). According to the definition of invasive species, both Avian Flu and the Swine Flu can be classified as invasive species.

The United States Department of Agriculture (USDA) and other Federal and State Government agencies have programs to prevent entry and to detect, monitor, and manage invasive species that enter the U.S. or spread to new regions. The Economic Research Service (ERS) conducts and funds research to support these efforts through the Program of Research on the Economics of Invasive Species Management. Concern regarding the impact of invasive species has grown substantially in recent years as evident by the trends in government expenditures in response to outbreaks. The Economic Research Service (ERS) reports that “emergency” indemnities by the Animal and Plant Health Inspection Service (APHIS) for invasive species totaled approximately $348 million for 2001. In addition, in the same year, the Risk Management Agency (RMA) provided more than $2 billion in crop insurance subsidies, and Congress provided over $2 billion in ad-hoc disaster relief funds. Other expenditures on animal disease risk mitigation, such as money spent by Cooperative State Research, Education, and Extension Service (CSREES) in extension education programs on management of invasive species is not included.

Likewise, the economic impacts of decreased land values or the impacts on supply chains and support businesses that depend on the agricultural production affected by invasive species are not included in the disease impact figures. In fact, APHIS estimates the annual damage and control costs of invasive species is around $138 billion per year (Pimentel, Zuniga and Morrison, 2005).

It is obvious that the impact of invasive species is substantial not only in lost production, but also in costly measures to prevent and respond to outbreaks and infestations. In many cases there are significant externalities associated with the control of invasive species. Thus, the U.S. government has regularly interceded in these issues. However there are significant concerns regarding what are the most cost effective government strategies to use in response to occurrences of invasive species.

1.3.1 Government's policy for invasive species

Currently, there are two major approaches to compensate producers when they suffer financial loss due to invasive species: (1) *ex post* indemnification programs as typically administered by the APHIS, (2) *a priori* insurance or indemnification programs as offered by RMA which would require enrollment and government infrastructure that predefine indemnification and premium schedules. A third alternative that has been proposed is a tiered indemnification or insurance design that ties higher coverage to explicit risk reducing production practices. Nevertheless, there is no specific model to advise government as to when and how to use these three alternative approaches to

handle invasive species with reasonable government cost while maximizing the utility of the producers who suffer from the economic impacts of the disease.

1.3.2 Comparison of government's policy for invasive species

An *ex post* indemnity is a sum paid by government to producers by way of compensation for a particular loss caused by an invasive species. With *ex post* indemnification the government can avoid the creation of institutions and programs, which is particularly efficient when the probability of loss faced by producers is quite small. At an early stage of infestation, producer inexperience could lead to an underestimation of the risk of disease, which results in little or no willingness to pay for insurance. Thus, *ex post* indemnification may be the best course of the action at this stage of infestation and spread. Although *ex post* indemnification programs do not require significant prior infrastructure, the *ad hoc* nature of these programs often results in inefficient or inequitable indemnities (Ott, 2006).

Ex ante insurance is defined as the transfer of the risk of a loss, from one entity to another, in exchange for a premium. Insurance requires institutionalized premiums and indemnity structures for insurable risks. With insurance, losses should at least in principle take place at a known time, in a known place, and from a known cause. With more frequent infestation, the probability of loss increases. Producers that have more direct experience with losses are likely to have a positive willingness to pay for insurance. Assuming insurability, insurance may be the most efficient government response at this stage of infestation. Insurance allows producers and government officials to define an

efficient and equitable program because more time and information is available to develop and implement the program. An insurance program has the potential to reduce government cost by charging premiums. However, low participation may be a problem, particularly if the probability and economic cost of occurrence is low. Low participation may also be exacerbated by adverse selection or moral hazard when significant asymmetric information exists between the insurer and insured (Shaik et al., 2006).

In considering *ex post* indemnification and ex ante insurance, a modification of the two designs may increase incentives for producers to implement disease mitigating practices. Instead of fixed compensation from a government indemnification or insurance program, the amount of compensation the producer receives becomes a function of their behavior. For example, when producers adopt certain preventive practices, they are eligible for "full" indemnification; otherwise they are eligible for a lower level of indemnification. The merit of tiered indemnification or insurance is that producers have a stronger incentive to adopt prevention measures. However, the disadvantage of a tiered design is that it requires a level of observability in order to be effective.

CHAPTER II

PROBLEM STATEMENT

According to the discussion in the first chapter, this paper focuses mainly on the potential modification of current U.S. government measures in managing invasive species, as well as the relationship between the bio-security choices of poultry producers and their production performance. In this paper, there are two important subjects (government and poultry integrators) and two key goals (control the spread of infectious diseases and maximize integrators' utility).

2.1 Issues in government indemnification program

The government wants to build an economically efficient indemnification program for avian influenza that can control disease introduction and spread. Based on this issue, this paper has multiple objectives.

The first objective of this paper is to assess efficient risk protection measures for government to protect the affected producer. This means government provision of indemnification is provided to add economic stability for producers, no matter whether it is from an altruistic motive or based on industrial policy to avoid economic damage to a particular industry or region.

The second objective of this paper is to help government decision makers to understand the incentives that will encourage behavior which will help mitigate the spread of disease. For instance, APHIS indemnification is often provided to encourage reporting of disease before its spread. Similarly, there are attempts to provide incentives for prophylactic efforts which reduce the chance of disease occurrence or spread. These efforts can in many cases be considered externalities which are not fully rewarded in the marketplace.

2.2 Issues in the poultry industry's bio-secure choice

The third objective of this paper is to investigate the relationship between a grower's bio-security and his/her production performance. This should provide poultry integrators with useful information for making production decisions, thus indirectly helping them to maximize their expected utility.

The U.S. is the largest poultry producing country in the world and second largest exporter of poultry meat. With almost 18 percent of total poultry production being exported, the U.S. poultry industry is heavily influenced by currency fluctuations, trade negotiations, and economic growth in importing markets. Due to the significance of U.S. exports, an outbreak of avian influenza that reduces access to international markets may cause significant economic damage to the U.S. poultry industry. Although poultry integrators have had many incentives to improve their bio-security practices, there are potential constraints on the availability of bio-secure farms in a production region, and the externality of applying bio-secure production practices cannot be fully rewarded.

Consequently, this research is aimed at finding the relationship between the level of bio-security and production performance. Another goal is to decide the distribution of the bio-secure and bio-insecure growers under different probability of AI outbreak for integrators to maximize their expected utility. Also, this paper will investigate how to design the indemnification and insurance program for the poultry industry to handle the outbreak of invasive species.

In order to make the problem clearer, it is necessary to discuss current problems in the poultry industry.

The definition of poultry is domesticated fowl raised for meat or eggs. In the Agricultural Resource Management Study (ARMS), poultry includes chickens, turkeys, ducks, geese, emus, ostriches, and game birds. Most poultry operations usually raise only one type of poultry for a single purpose. For example, farms will raise hens to produce eggs for human consumption or for breeding purposes. In 1997, nearly 99,700 farms were producing poultry and poultry products (egg, broiler, and turkey, NASS/USDA). While broiler chicken production is concentrated primarily in the southern and southeastern U.S., turkey production occurs primarily in the Corn Belt and in North Carolina. Egg production is distributed throughout the U.S.

The poultry industry has grown from largely backyard operations which provided supplemental income for families to a vertically integrated industry (EPA's Ag, 2006). In 1900, chicken was typically eaten only on Sunday, but now, it has become an everyday food item, and poultry consumption in the U.S. has greatly increased. In 2004, annual

poultry production was 45,796,250 pounds and the total gross value of production was $20,446,086.

Broiler production is organized by firms commonly called integrators such as Perdue, ConAgra, Tyson and Sanderson Farms (Knoeber, 1989). In the broiler industry, integrators usually have possession of hatcheries, feed mills, slaughter plants, and additional processing plants. Basically, the firms are vertically integrated into all production stages except for the raising of broilers. This phase of production depends on a network of growers assembled through production contracts. According to these production contracts, farmers are paid for their growing service on the basis of pounds of live broiler produced. This is essentially a piece rate. However, the size of the "per pound" payment varies among growers and is determined by producers' performance. Farmers are often paid on the basis of their performance relative to other producers who deliver broilers to the integrator within a specified time period. Under a relative performance standard, all producers receive a base fee, but those who deliver more poultry output for the number of chicks placed receive higher payments. As a result, differences in relative performance are driven by differences in chick mortality and feed efficiency (MacDonald, 2008).

There are two ways to evaluate the relative performance of growers: linear relative performance evaluation (LRPE) and tournaments. Most contracts follow the LRPE approach, with the growers' reward based upon the strength of his/her performance relative to the average of all other growers. However, some contracts follow the tournament approach, giving rewards on each grower's individual ranking.

The poultry industry has already done a great deal of work to improve the bio-secure level of their growers (James, 2008). But it is possible that there are insufficient high bio-secure growers in a region or that growers are contracted without full information regarding the level of bio-security they need to maintain. Therefore, integrators may optimally contract with some low bio-secure performance growers. According to previous discussion, the payment to growers is related to their relative feed-output efficiency. It appears the industry does not typically reward growers for having good bio-secure performance.

Furthermore, if there is an outbreak of AI or other diseases, the low bio-secure growers may have greater losses than high bio-secure growers due to a higher morbidity and/or mortality rate. However, even if good bio-secure growers are not infected and their output does not decline, they may still be affected by the decrease in the demand and price of poultry products. The good bio-secure growers' revenue could still shrink. In other words, there is a negative externality associated with disease outbreak that may be exacerbated by the presence of low bio-secure growers. On the other hand, good bio-secure growers can reduce the prevalence of diseases, which can be considered as positive externality. There is typically neither a penalty for negative externality nor a reward for a positive one. How to improve incentives for better grower bio-security is an issue that needs to be solved. Thus, it is a problem for integrators to decide the distribution of bio-secure and insecure growers in order to maximize the integrator's profit, as well as decrease the probability of disease outbreaks.

CHAPTER III

LITERATURE REVIEW

There are a number of empirical studies related to the issues addressed in this thesis available in the literature. To facilitate the literature review this chapter is organized in three sections. Section one discusses previous research of poultry industry contracts and the bio-secure situation. Section two discusses the background of economic research in infectious animal disease and invasive species. Section three addresses data collection and process measures, as well as, previous research on risk perception.

3.1 Literature review about the poultry integrator contract

Several papers address poultry integrator contracts with producers. Some of them discuss the political economy of regulating broiler contracts. Others are about the legal liability of stakeholders in contracts. A large number of papers focus on the tournament rules in broiler contracts. Levy and Vukina (2004) compare welfare of tournament and piece rates in contracts with heterogeneous ability agents and demonstrate that tournaments that mix players of unequal abilities create a league composition effect. Vukina (2000) discussed existing market organization of the poultry industry. The paper explains the reasons for vertical integration and the emergence of contracts “with independent farmers are risk sharing, technological progress and innovation

dissemination". Vukina (2006) identified two possible sources of broiler contract market failure that may justify regulation: (a) asymmetric bargaining power between integrators and contract growers; and (b) imperfect information.

Other papers investigate the advantages and efficiency of different tournament types. Vukina and Zheng (2006) compare ordinal and cardinal tournament games in broiler contracts by analyzing the contract settlement data of a poultry company who contracts the production of broiler chickens with a group of independent growers. They found that the model with risk-averse agents fits the data better than the model with risk-neutral agents and that switching from a rank-order tournament to a cardinal tournament, while keeping the growers' *ex-ante* expected utility constant, improved efficiency. The principal (company) gains from the switch, whereas some of the agents (growers) gain and others lose depending on their realized productivity shocks.

Knoeber and Thurman (1994) use the data on the performance of broiler producers facing both tournament and linear performance evaluation compensation structures to test the predictions of tournaments: that changes in the level of prizes that leave prize differentials unchanged will not affect performance; that, in mixed tournaments, more able players will choose less risky strategies; and that tournament organizers will attempt to handicap players of unequal ability or reduce mixing to avoid the disincentive effects of mixed tournaments. Their result is consistent with each prediction. However, none of these papers discuss the relationship between a farm's bio-secure level and their tournament performance.

3.2 Economic research and models of invasive species and infectious animal disease

3.2.1 Invasive species

Very few studies dealing with invasive species exist in economics literature. Of those that are available, they primarily concentrate on theoretical considerations with relatively little empirical analysis.

Shogren (2000) addresses the issue of incorporating economics into risk reduction strategies for invasive species using a model of endogenous risk. The model represents the choices available to a policy maker regarding the allocation of resources to reduce the risk of invasive species by both mitigation and adaptation. Throughout the paper, the point is made that economics should be included in risk assessment to improve the effectiveness of such assessment. The study finds that a higher risk of invasive species increases adaptation, but the effect on mitigation depends on whether or not mitigation and adaptation are substitutes or complements. The paper does not provide any empirical examples.

Thomas and Randall (2000) look at the role information and revocability play in non-indigenous species (NIS) management by focusing on intentional releases. By combining the concept of revocable actions and incentive compatible behavior, Thomas and Randall present a protocol that first identifies the potentially affected parties and implements a Coasian liability principle when the affected parties are known and property rights clearly established. This involves the establishment of an independent oversight authority and an insurance scheme for both public and private interests wishing

to intentionally release non-native species. When the affected parties are large in number and/or dispersed, the protocol suggests a limited role for the oversight authority to act on behalf of affected parties. The authority would deny permits to releasing agents that fail to post bonds sufficient to compensate in worst-case damage scenarios. The oversight authority may decide to permit a methodical step-by-step process of controlled releases designed to make maximum feasible use of revocability and learning-by-doing. The success of such an approach is less dependent on reliable prediction of the consequences of a release based on ex ante information, and more on pre-commitment to avoid irrevocable actions. Moral hazard is avoided by the establishment of an independent oversight authority to make permitting decisions and the *ex ante* assignment of liability to releasing agents.

Perrings et al. (2002) frame the issue of control of invasive species as a public good and discuss why both the causes of invasive species and the solutions are primarily economic in nature. They find that, "Economic drivers such as property rights, trade rules, and prices often influence these decisions. Human behavior influences the probability of invasive species becoming established as well as their spread, specifically how people respond to the threat of invasive species by either mitigation or adaptation." The control of the risk of invasive species has a public good element, in the sense that the benefits of control are neither rival nor exclusive. In other words, control protects one person or group without excluding benefits on another or reducing the benefit implying the need for government involvement. Further, effective control of invasive species is only as good as the weakest provider of control. If even one nation or state does not

provide adequate control, a species can spread and cause damage to all. This argues for a coordinated response among affected parties, both the sources and recipients of the invasive species.

Horan et al. (2002) address the appropriate level of pre-invasion control of invasive species and show how decisions can be made both when full information is available and when there is a high degree of uncertainty about invasions. They start with the premise that decision models based on standard economic expected utility theory provide little guidance in the case of invasive species. This occurs because of the probabilities associated with invasions. Specifically, they exhibit both a low probability of occurring but often have catastrophic consequences when they do occur. Expected utility theory is insensitive to this type of risk. Risk management models are thus better suited for analyzing strategies of pre-invasion control. They set up two models, one under full information and one under ignorance. The first, the risk-management model, assumes that firms are potential carriers of an invading species. Each firm makes choices on production and bio-secure control. Based on its choices and environmental conditions, there is some probability that a species will be introduced and will successfully invade the new ecosystem. Invasions from one firm are independent of those from other firms. The probability of invasion increases with the number of firms and decreases with bio-secure measures. The model minimizes the expected social cost of invasions and control using the cost of control and the expected damages from invasion. At the optimal level of control, the marginal cost of taking a control action equals the marginal expected benefits, as measured by the reduction in damages. The risk of invasion and damage

impact this marginal level of expected damages. This model assumes, however, that the risk of invasion (the probability of invasion given choices of firms) is known.

In the second model described, the risk is unknown, and uncertainty and ignorance of the risk is explicitly modeled. The model assumes that a decision maker will focus on those potential outcomes that will come as the least surprise. The model also assumes that costs and expected damages are minimized, but some of the conclusions differ from the previous model. When uncertainty is present, more resources should be devoted to high damage events that are considered more certain even with a low probability, and fewer resources to those events considered less likely to happen regardless of the amount of damages. While the risk management model supports firm-specific levels of control, the uncertainty model advocates that control be spread equally across firms, thus supporting most current policies that are based on uniform mandated technologies.

Evans (2003) lays out the economic dimensions of invasive species and why economics is increasingly called upon to understand the issues. The causes of biological invasions are often related to economic activities and furthermore, the economic consequences of invasive are broader than just direct control costs and damages. Evans notes that the impacts of invasive species can be classified into six types: production, price and market effects, trade, food security and nutrition, and financial costs.

3.2.2 Infectious animal disease

Homans (2007) addressed the role of detection in invasive species management. By increasing resources to detect invasive species, managers may increase their chances

of finding a species at a smaller population level, lessening the extent of damages and making subsequent control potentially less expensive and more effective. This paper presents a model that captures the stochastic and dynamic aspects of this trade-off by incorporating a detection stage in which the agency managers choose a search effort prior to the post-detection control stage. The analysis of the model illustrates that the optimal detection strategy depends primarily on the 'detectability', or ease of detection, and the biological relationships of each distinct species. This paper is useful for us as it provide a point of view that the optimal management of invasive species cannot leave out effective detection.

Elbakidze (2006) examines the economic tradeoff between the costs of pre-event preparedness and post-event responsiveness to the potential introduction of an infectious animal disease. In a simplified case study setting, he examines the conditions for optimality of an enhanced pre-event detection system considering various characteristics of a potential infectious cattle disease outbreak, costs of program implementation, severity of the disease outbreak, and relative effectiveness of post-event response actions. His results show that the decision to invest in pre-event preparedness activities depends on such factors as probability of disease introduction; disease spread rate, relative costs, ancillary benefits, and effectiveness of mitigation strategies. The research path of this paper is very similar to our project, but our project will include more comprehensive research aspects than this one.

Gramig has done a great deal of work in livestock disease indemnity management. Gramig (Gramig, Benjamin M., Horan, Richard D. and Wolf, Christopher

A., 2009) livestock disease indemnity design when moral hazard is followed by adverse selection. They focus on farm level bio-secure choices and reporting of disease status. By building a theoretical model and doing sensitivity analysis, they conclude that by using a single mechanism to induce bio-security and reporting simultaneously, the incentives for each individual private action are not clear. In order to induce early reporting of infected livestock, first, "while there is not an explicit fine for not reporting, there is a penalty to waiting to report since dead animals receive no payment. This feature can help to achieve incentive compatibility with reduced or eliminated monitoring costs." Second, "partial compensation for already-infected animals shifts some of the risk to farmers, as do payments. An indemnity plan that does not shift risk in this fashion may actually create incentives for infection, which could be one problem associated with status quo U.S. policy."

Hennessy (2005) considers two sorts of bio-secure risk that producers can seek to protect against. One concerns the risk of spread: that neighboring producers do not take due care in protecting against being infected by a disease already in the region. In this case, producer efforts substitute with those of near neighbors. For representative spatial production structures, he characterizes Nash equilibrium protection levels and shows how spatial production structure matters. The other risk concern is disease entry: that producers do not take due care in preventing the disease from entering the region. In this case, producer heterogeneity has subtle effects on welfare loss due to strategic behavior. Efforts by producers complement each other, suggesting that inter-farm communication will help to resolve the problem. Hennessey (2006) addresses economies of feedlot scale,

bio-security, investment, and endemic livestock disease. From the analysis of Nash behavior, he concludes that disease externalities can induce more adoption of a cost-reducing technology by larger herds so that animals become more concentrated across herds. Larger herds are also more likely to adopt bio-secure innovations, explaining why larger herds may be less diseased in equilibrium.

Hennessy (2007) uses a global game model of coordination under public and private information concerning the critical mass required to get the conclusion that eradication programs can be very expensive, as livestock culling may be involved. They usually fail, as the beneficiaries of the programs have little goodwill. His analysis confirms the possibility of multiple equilibrium outcomes to an eradication program while also characterizing some aspects of the involved roles that public and private information can play in determining the probability of success. This suggests that progression in a disease eradication program may not always be attributed to variable weather and other technical factors that affect spread. Financial markets, human communications, and adjusting beliefs may be just as important. The physical and biological epidemiology will also interact with human decisions, the information these decisions generate, and the beliefs the information support.

Mahul and Gohin (1999) address the sunk costs caused by the bio-security production measures for livestock producers. They found two main factors influence the producers' decision: the low probability of occurrence of the highly contagious animal disease and the potential for some negative effect by vaccination programs which could cause additional losses that cannot be recovered. "Therefore, the gain from waiting for

new information, namely the quasi-option value, should induce animal health authorities to delay the decision to vaccinate if the probability of a widespread epidemic is not too high."

In 2007, Pro-Poor Livestock Policy Initiative (PPLPI) published a research report focused on the industrial livestock production and health risks. This paper is concerned with the linkage between livestock production and global public health, and argues that without commensurate private and public investment in bio-exclusion and bio-containment measures, these industrial systems can result in increased public health risk. Their arguments highlight the potential for the existence of externalities associated with infectious animal disease prevention.

3.2.3 Avian Influenza

Several research papers address different aspects of AI. Beach, Poulos, and Pattanayak (2007), conducted theoretical research and sensitivity analysis of household response to an AI outbreak by building profit maximization models for

poultry farmers. They did not parameterize the model, which shows the difficulty of finding valid data on this topic.

Brown, Madison, Goodwin, and Clark (2007) estimate the potential effects on U.S. agriculture of an AI outbreak by using the Food and Agriculture Policy Research Institute (FAPRI) sector model. The authors identify three uncertainties of effects of an AI outbreak in the U.S.: "(1) how widespread the area of outbreak becomes and the length of time it takes to contain it, (2) the change in U.S. consumer demand for poultry products as a result of the outbreak, and (3) the response of other countries to an AI

outbreak in the U.S." Then, the authors divide the AI outbreak into two scenarios--four state scenario and eight county scenario – and report poultry output and export in 2008—2016. Also, the authors analyze the effects of the AI outbreak on the poultry sector, meat sectors, feedstuffs, farm income, and consumer expenditures. The estimation results show a very large difference in the economic effects of the larger four-state scenario versus the smaller eight-county scenario. This illustrates that billions of dollars are potentially at stake regarding the severity and length of an outbreak. "These figures greatly overshadow the amount of money currently spent on preparing for an outbreak." From this paper we can have some numerical sense of the AI outbreak's influence; however, they did not estimate the probability for AI outbreak.

Bouma et al. (2009) finds that (1) the period of latency of H5N1 influenza virus in unvaccinated chickens is short; (2) the infectious period of H5N1 virus in unvaccinated chickens is approximately two days; (3) the reproduction number of H5N1 virus in unvaccinated chickens need not be high, although the virus is expected to spread rapidly because it has a short generation interval in unvaccinated chickens; and (4) vaccination with genetically distant H5N2 vaccines can effectively halt transmission. Simulations based on the estimated parameters indicate that herd immunity may be obtained if at least 80% of chickens in a flock are vaccinated. Their research result is different from the poultry industry's response, as the industries do not think there is effective vaccination for AI. However, these data give us an intuition that when an AI outbreak happens, in a very short time, it can spread rapidly and result in high levels of mortality.

3.3 Risk perception

Baron (2004) discussed how one should communicate risk information. In his paper, he notes the limitations that result from mis-estimation of probability, the need to deal with many risks at once, and the existence of individual differences in risk preference. He reviews the problem of cognitive biases, such as the tendency to favor harms of omission over harms of direct action, and concludes with suggestions of making communication comparative, informative about individual differences, paternalistic about biases, libertarian and quantitative, which can solve the miscommunication of risk information in market. Although this paper is not specifically about invasive species risk communication, it is relevant to the behavior of either integrators or growers offered insurance or an indemnification program.

The invasive species event is typically a very low probability occurrence with potentially severe negative consequences. Howard, Mathan and Daniel (2001) explore the way people process information on low probability-high consequence negative events. They conclude, based on the outcomes of a battery of experiments, that fairly rich context information must be available for people to be able to judge differences between low probabilities. In particular, it appears that one needs to present comparison scenarios that are located on the probability scale to evoke people's own feelings of risk.

CHAPTER IV

CONCEPTUAL FRAMEWORK

According to the 2006 Agricultural Resource Management Survey--version 4, production contracts often require growers to carry out certain production practices (USDA/ERS, 2006). The survey asked about several practices related to testing of flocks for avian influenza, salmonella, and other pathogens. The results show that 63.6% of respondents asserted that avian influenza testing has been required, 11.6% did not test, and 25.8% did not know because some tests may have been conducted by the integrators. So, according to the survey, the industry has already improved the bio-security level in broiler operations relative to past practices. However, assuming integrators are at least somewhat risk averse; the integrator's goal is to maximize expected utility from the production operation rather than minimize disease spread. These objectives may overlap, but they are not likely to be entirely consistent with each other. Just as maximizing yield may not maximize profit, a risk averse integrator will consider the risk-return tradeoffs in controlling disease. There is limited incentive for integrators to ask their contract farmers to increase bio-security, unless expected utility loss due to disease is larger than the cost of prevention strategies.

4.1 Model

The conceptual framework in this paper is to build a model of broiler integrator contracting decisions assuming that their objective is to maximize expected utility. Some assumptions of the model include 1) risk aversion on the part of the integrators; 2) integrators' behavior is affected by indemnify payments; 3) outbreaks of AI and other diseases will negatively influence the price of poultry products, implying that bio-security level is related to the integrators' net return by changing output price; and 4） the integrator has a fairly accurate knowledge of the bio-security level of their contracted farms because company representatives frequently inspect the farms.

Historically, AI is a low probability disease in the U.S.; however integrator bio-security is not driven solely by concern for this one disease. Rather, integrators are concerned with several potential avian diseases. In order to completely reflect the relationship between bio-security level and poultry production performance, another disease Laryngotrachcitis (LT) is added into the model. LT occurs more often than AI and is a severe and highly contagious disease (American Poultry Association, 2009). Importantly, it is not a disease indemnified by USDA/Aphis if an outbreak occurs. Though not a human health risk, it is often a fatal disease to chicken and pheasants. LT affects mainly adult birds and is characterized by inflammation of the trachea and larynx. It is often marked by local necrosis and hemorrhage and by the formation of purulent or cheesy exudates interfering with breathing. Outbreaks of LT are occurring with greater frequency and heightened virulence resulting in greater financial losses (Simon, 2008). LT outbreaks not only cause a loss for producers from decrease production, but also

influence poultry product price due to trade bans from importing countries. The model includes the price reduction caused by AI, LT, or other diseases as an exogenous variable.

Growers are assumed to fall into one of two bio-security categories: bio-secure or bio-insecure, denoted by subscripts S and U. It is assumed that the outbreak probability of AI and other diseases is different for each category of bio-security. Also, given the same cost, the output of bio-secure and bio-insecure growers will be different, as the bio-secure producer is assumed to spend more effort and money on bio-secure measures that do not generally improve productivity. Accordingly, the net return is different for farms with different bio-secure levels. In the model, there are four probabilities to represent the likelihood of AI and other disease outbreak for bio-secure and bio-insecure subjects.

This expected utility maximization model is built on the net return of the integrators, which is choosing what mix of bio-secure and bio-insecure growers with whom to contract. Expected utility is affected by the chance of diseases outbreak, the price of poultry products, the price change when a disease occurs, the share of bio-secure output not lost during an outbreak, the production cost, the output level, the government indemnification or reduction level, and the risk aversion parameter. Net return can be thus written as:

NR= income from sales of poultry product – cost + government indemnification.

The definition of the variables in the conceptual framework is listed in the below table.

Table 4.1

Definition for variables in conceptual framework

Variables	Definition
ψ_s	AI outbreak probability for bio-secure farms
ψ_u	AI outbreak probability for bio-insecure farms
Φ_s	Other diseases outbreak probability for bio-insecure farms
Φ_u	Other diseases outbreak probability for bio-insecure farms
N_s	Number of bio-secure farms
N_u	Number of bio-insecure farms
α	Share of bio-secure output not lost during an outbreak
d	Deductible
Mu	Indemnity penalty
PR	Outbreak price reduction (%)
r	Risk aversion coefficient
Q_s	Output of bio-secure farms, no loss
Q_u	Output of bio-insecure farms, no loss
N	Sample size
W	Initial wealth
A	Dummy variables If ψ_s > certain number (0< the number<1), there is an outbreak of AI and A=1; else, there is no AI outbreak, A=0.
B	Dummy variables If ψ_u > certain number (0< the number<1), there is an outbreak of AI and B=1; else, there is no AI outbreak, B=0.
C	Dummy variables If Φ_s > certain number (0< the number<1), there is an outbreak of AI and C=1; else, there is no AI outbreak, C=0.
D	Dummy variables If Φ_u > certain number (0< the number<1), there is an outbreak of AI and D=1; else, there is no AI outbreak, D=0.

4.2 Specifications of equations

4.2.1 Net return equations

The total net return is determined by the number of bio-secure and bio-insecure farms multiplied by the net return of each. Net return for a bio-secure farm is defined as NR_s. For four different disease outbreak scenarios, NR_s is calculated as follows:

(1) AI outbreak, no other disease outbreak:

$$NR_s \quad P \quad (1-PR) \quad \alpha * Q_s - C_s + (1-\alpha)\,1-d \quad P \quad (1-PR) \quad Q_s \tag{4-1}$$

(2) AI outbreak, and other disease outbreak:

$$NR_s \quad P \quad (1-PR) \quad \alpha * Q_s - C_s + (1-\alpha)\,1-d \quad P \quad (1-PR) \quad Q_s \tag{4-2}$$

(3) No AI outbreak, no other disease outbreak:

$$NR_s \quad P \quad Q_s - C_s \tag{4-3}$$

(4) No AI outbreak, but other disease outbreak:

$$NR_s \quad P \quad (1-PR) \quad Q_s - C_s \tag{4-4}$$

Net return for a bio-insecure farm is defined as NR_u. For four different disease outbreak scenarios, NR_u is calculated as follows:

(1) AI outbreak, no other disease outbreak:

$$NR_u \quad P \quad (1-PR) \quad \alpha * Q_u - C_u + Mu * (1-\alpha)\,1-d \quad P \quad (1-PR) \quad Q_u \tag{4-5}$$

(2) AI outbreak, and other disease outbreak:

$$NR_u \quad P \quad (1-PR) \quad \alpha * Q_u - C_u + Mu * (1-\alpha)\,1-d \quad P \quad (1-PR) \quad Q_u \tag{4-6}$$

(3) No AI outbreak, no other disease outbreak:

$$NR_u \quad P \quad Q_u - C_u \tag{4-7}$$

(4) No AI outbreak, but other disease outbreak:

$$NR_u \quad P \quad (1-PR) \quad Q_u - C_u \tag{4-8}$$

Total net return, defined as NR can be written as follows:

$$NR = N_s * NR_s + N_u * NR_u \tag{4-9}$$

*4.2.2 Expected Utility (*EU*) equation with* NR *as choice variables*

For expected utility, the constant relative risk aversion (CRRA) utility function is adopted (Horan et al., 2002), and varying degrees of risk aversion are investigated. The CRRA utility function is given by:

$$U(C) = \frac{C^{1-r}}{1-r}, \forall r > 0, r \neq 1 \tag{4.10}$$

$$InC, \forall r \quad 1 \tag{4.11}$$

There are three other properties that are important. First, the CRRA utility function is increasing in C^{1-r} if $r < 1$ but decreasing if $r > 1$. Hence, dividing by $1-r$ ensures that the marginal utility is positive for all values of r. Second, if $r \rightarrow 1$, the utility function converges to $\ln C_t^2$. Third, $U'''(C) > 0$ implies a positive motive for better bio-secure measures. Therefore, this utility function is adapted to studying the integrators' behavior.

The form of the expected utility function is decided by the risk aversion coefficient. If it equals to 1, the expected utility is

$$EU \quad \sum U\ NR \quad \sum \frac{1}{N} * \left[Ln\ NR + W \right] \tag{4-12}$$

When the risk aversion coefficient is not equal to 1, the expected utility is:

$$EU \quad \sum U\ NR \quad \sum \frac{1}{N} * \left[\frac{NR + W^{\ 1-r}}{1-r} \right] \tag{4-13}$$

4.2.3 Certainty Equivalent (CE)

The certainty equivalent (CE) is the amount of payoff (or utility) that the integrator would have to receive to be indifferent between that risky outcome and a certain amount. For a risk averse integrator the certainty equivalent is less than the expected value of the risky outcome, as the integrator prefers to reduce uncertainty. CE can be calculated by taking the expected utility value and solving for the certain value corresponding to that level of utility. Also, given the CRRA assumption the formula for the CE depends on the risk aversion coefficient, which is as follows:

$$(1) \quad r \quad 1, CE \quad Ln^{EU} \tag{4-14}$$

$$(2) \quad r \neq 1, CE \quad \left[EU \quad 1-r\right]^{\frac{1}{1-r}} \tag{4-15}$$

When the CE is known, the amount that an integrator is willing to pay for reducing the uncertainty may be computed as the difference between the expected value of the risk and the certainty equivalent.

4.3 Sensitivity analyses

In the sensitivity analyses, we want to know the change of the expected utility and the certainty equivalent according to the change of variable value.

It is assumed that $\frac{\partial EU}{\partial \Psi} < 0$, $\frac{\partial EU}{\partial \Phi} < 0$ because when the probabilities of disease outbreak increase, expected utility will decrease, as the higher outbreak chance will lead to lower expected output and price.

Moreover, $\frac{\partial EU}{\partial PR} < 0$ because as the price reduction rate increases, the lower price will cause expected utility to decline.

In addition, $\frac{\partial EU}{\partial d} < 0$, since a lower deductible level will provide higher indemnification income. When, *d* increases, the indemnification level decreases, reducing net return and lowering expected utility.

These hypotheses will be evaluated in the empirical model.

CHAPTER V

EMPIRICAL SIMULATION MODEL

In this chapter, the conceptual framework will be parameterized using historical and subjective data. Given this data, the integrator choice of a mix of bio-secure and bio-insecure growers will be empirically simulated using the multivariate simulation technique.

5.1 Data source

In order to parameterize the conceptual model, historical data from USDA as well as annual financial reports of Tyson and Sanderson Farm are used. To be consistent with the conceptual model, three assumptions are made regarding the data used in the analysis.

First, the annual output and cost in the model is for one production operation unit. Operation unit is defined as one broiler farm. The typical operation unit, as measured by the median—half of operations produced more and half less—produces 402,500 birds and 2.2 million pounds per year (MacDonald, 2008). That is, in a typical poultry operation, usually there are 402,500 birds produced each year. If average weight of the birds is 5.46 pounds, the total production amount to 2.2 million pounds per year. This output is assumed to be the output level for bio-insecure farms. For a given cost, a bio-secure farm is assumed to produce less output than a bio-insecure farm. Specifically, the

output of a bio-secure farm is assumed to be 98% of a bio-insecure farm's output, which is 2.16 million pounds per year. This difference is based on personal conversations with poultry experts who subjectively indicated a likely 1-3% reduction in output for bio-secure farms.

Second, the broiler integrator's utility in one year can be characterized by a CRRA function with historical and subjectively estimated data.

Third, in the broiler industry, integrators usually have possession of hatcheries, feed mills, slaughter plants, and additional processing plants. For integrators, there is no difference in cost for bio-secure and bio-insecure farms. Growers decide the allocation of the input, which means the growers make their own decision about using more input to get more output or to improve their bio-security performance. Cost can be divided into two types: one for input which leads to greater production, the other for input which improves bio-security performance. For a given cost, these two inputs are competitive. So, the bio-secure farms are assumed to have less output because they use inputs such as labor to maintain a higher level of bio-security. This is supported by personal communications with Mississippi State University, diagnostic lab, and industry veterinarians' familiar with broiler production.

In order to parameterize the model, some data is obtained from the USDA's database or poultry integrators' annual report. For parameter P which represents output price, data is taken from USDA's "U.S. Broiler Industry: Background Statistics and Information" (ERS, 2009), which define broilers (chickens under 13 weeks old) constituting virtually all commercial chicken production. The average retail price for

broiler products (composite) in 2008 was $1.747 per pound, and in the same year the average wholesale price for broiler products (composite) was $0.711 per pound. Because this model is focused on the utility of the integrator, the wholesale price will be adopted.

Poultry meat exports from the United States totaled 5.5 billion pounds in 2003, two percent above 2002 levels. Continuing disease-related problems and Russian trade policy uncertainty prevented exports from being higher. Exports were reported to decline more than 11 percent in 2004 because outbreaks of Avian Influenza (AI) in early 2004 led to bans on U.S. poultry meat exports (Leuck, Haley, and Harvey, 2004). The monthly wholesale broiler price from April 2001 to July 2009 is shown in this figure.

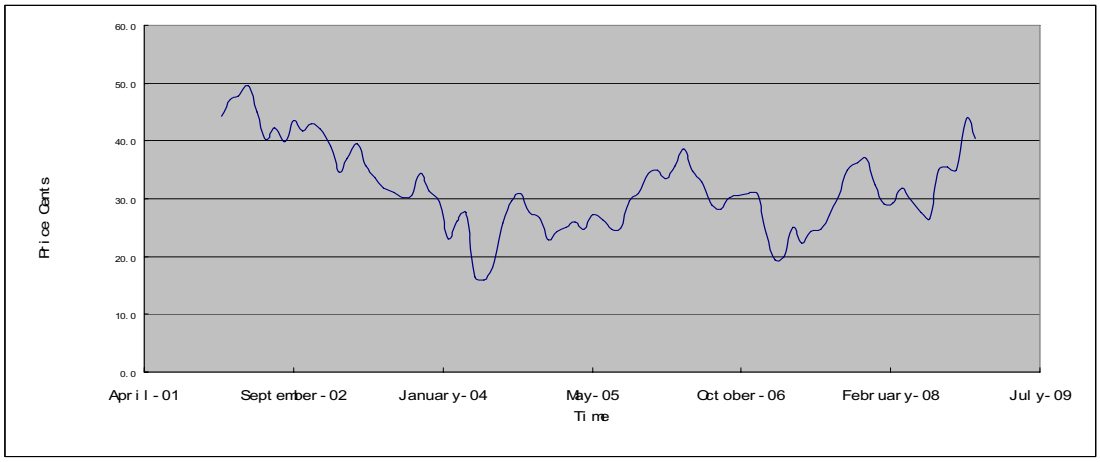

Figure 5.1

The wholesale broiler price 2001/04-2009/07

*Source: USDA Poultry Price Fact

This monthly data is adopted to calculate the average wholesale price for 2001, 2002, 2003, and 2004. Table 5.1 shows the outbreak record of diseases along with the

poultry product price. This data suggests that the price of poultry product has been strongly influenced by AI and other diseases outbreak.

Table 5.1

Disease outbreak and Annual Average Price for U.S. poultry

Year	Disease outbreak	Average Wholesale Price
2001	No	43.40 (cents)
2002	Russia banned U.S. poultry products because the use of antibiotics in broiler production and microbial rinses in U.S. processing plants.	43.85 (cents)
2003	2003 began with an outbreak of Exotic Newcastle Disease in California and parts of Arizona and Nevada, resulting in some regionalized bans on poultry products. This was followed by an outbreak of AI in Connecticut.	34.08 (cents)
2004	Outbreaks of AI in early 2004 in Delaware, Maryland, New Jersey, Pennsylvania, and Texas.	24.80 (cents)

Source: USDA Historical Price Spread

The model requires a variable to measures the change of broiler price when a disease outbreak occurs. From the Table 3, when there is a poultry disease outbreak, the price change is:

$$PR \quad \frac{34.08 - 24.80}{34.08} \quad 0.374194 \approx 37\% \qquad (5\text{-}1)$$

This value is used as the default price decline in the simulation. In the model, there are two price when disease outbreaks occur, because there are many more frequently disease, as Infectious Laryngotracheitis which can cause great decline of poultry product. The outbreak of these diseases can reflect the bio-secure level. So, by

adopting the price when other disease outbreak occurs, the model will be more comprehensive.

The cost "C" is another variable which needs to be parameterized. From the 2008 annual financial report of Tyson Inc., the operating cost for chicken production is reported to be $118 million. Summed up, the values for the parameters are shown in Table 5.2.

Table 5.2

Definition of the variables

Parameters	Values
P	$0.711/pound
PR	37%
C	$118million
Qs	2.16 million
Qu	2.2million

5.2 Parameterized conceptual model

Taking the values of the parameters into the conceptual framework, net return for bio-secure farms (NR_s), for 4 different disease outbreak scenarios are:

(1) AI outbreak, no other disease outbreak:

$$NR_s \quad P \quad (1-PR) \quad Q_s - C_s + \alpha \; 1-d \quad P \quad (1-PR) \quad Q_s$$

$$=0.71*(1\text{-}37\%)*2{,}160{,}000 \quad \left[1+\alpha \; 1-d \right] - 118{,}000{,}000$$

(2) AI outbreak, and other disease outbreak:

$$NR_s \quad P \quad (1-PR) \quad Q_s - C_s + \alpha \; 1-d \quad P \quad (1-PR) \quad Q_s$$

$$=0.71*(1\text{-}37\%)*2{,}160{,}000 \quad \left[1+\alpha \; 1-d \right] - 118{,}000{,}000$$

(3) No AI outbreak, no other disease outbreak:

$NR_s \quad P \quad Q_s - C_s$

=0.71*2,160,000 - 118,000,000

(4) No AI outbreak, but other disease outbreak:

$NR_s \quad P \quad (1-PR) \quad Q_s - C_s$

=0.71*(1-37%)*2,160,000 - 118,000,000

Net return for bio-insecure farms (NR_u), for 4 different disease outbreak scenarios are:

(1) AI outbreak, no other disease outbreak:

$NR_u \quad P \quad (1-PR) \quad Q_u - C_u + Mu * \alpha \; 1-d \quad P \quad (1-PR) \quad Q_u$

=0.71*(1-37%)*2,200,000 $\left[1 + Mu * \alpha \; 1-d \right]$- 118,000,000

(2) AI outbreak, and other disease outbreak:

$NR_u \quad P \quad (1-PR) \quad Q_u - C_u + Mu * \alpha \; 1-d \quad P \quad (1-PR) \quad Q_u$

=0.71*(1-37%)*2,200,000 $\left[1 + Mu * \alpha \; 1-d \right]$- 118,000,000

(3) No AI outbreak, no other disease outbreak:

$NR_u \quad P \quad Q_u - C_u$

= 0.71*2,200,000 - 118,000,000

(4) No AI outbreak, but other disease outbreak:

$NR_u \quad P \quad (1-PR) \quad Q_u - C_u$

= 0.71*(1-37%)*2,200,000 - 118,000,000

Total net return (NR) is the sum of net return for bio-secure farm (NR_s) and bio-insecure farm (NR_u), which is related to the value of dummy variables A, B, C, D. These dummy variables represent different scenarios of disease outbreak. A and B represent the outbreak of AI for bio-secure and bio-insecure farm, respectively. If A=1, it means there is AI outbreak for bio-secure farm. If B=1, it represents an AI outbreak in bio-insecure farm. C and D stand for the outbreak of other diseases for bio-secure and bio-insecure farm, respectively. If C=1, there is an outbreak of a disease other than AI for bio-secure farm. If D=1, there is an outbreak of a disease other than AI for bio-insecure farm. Each of the four dummy variables can be either 1 or 0. There are 16 combinations of different A, B, C and D values, which represents the different scenarios of AI and other disease outbreak situation. The probability of each scenario is shown in Table 5.3. These probabilities are based on expert opinion and the historical data. Note that unsecure farms are riskier for both diseases and that LT is somewhat more common than AI.

Table 5.3

Probability of Losses

Dummy Variables	Probability
A=1	0.33%
B=1	3.30%
C=1	1.25%
D=1	2.96%

When risk aversion coefficient r equals 1, the expected utility for integrator is:

$$EU \quad \sum U\ NR \quad \sum \frac{1}{N} * \left[Ln\ NR + W \right] \tag{5-2}$$

When risk aversion coefficient r is not equal to 1, the expected utility is:

$$EU \quad \sum U\ NR \quad \sum \frac{1}{N} * \left[\frac{NR + W^{\ 1-r}}{1-r} \right] \tag{5-3}$$

5.3 Simulation models

The variables in the model are potentially correlated and with mixed marginal distributions. For example, price maybe drawn from a log-normal distribution, while disease outbreak probabilities maybe distributed according to another distribution. Considering this feature, there are two simulation techniques that are potentially appropriate for the model: Iman and Conover (IC) (1982) and Phoon, Quek, and Huang (PQH) (2004). Anderson, Harri and Coble (2009) compared these two techniques and concluded that rates derived from the IC procedures may be inaccurate because the procedure produces biased estimates of correlation between simulated variables. The PQH procedure can improve this situation; therefore, PQH simulation techniques are chosen for this model.

5.3.1 Simulation techniques

The PQH procedure is a distribution-free technique, which means it accommodates the simulation of correlated variables from mixed marginal distributions, including empirical distributions. By using information in the correlation matrix, the procedure consists of the simulation of correlated probabilities. These probabilities are used in an inverse transformation of the relevant marginal distribution to produce correlated variables from the simulation.

More specifically, the PQH simulation procedure is a simulation of non-Gaussian process based on a nonlinear transformation of an underlying Gaussian process (Phoon, Quek, and Huang, 2004). Basically, the procedure uses a Karhunen-Loeve (KL) expansion in the simulation of correlated normal deviates that are used as probabilities in an inverse transformation on the desired marginal distribution.

In the theory of stochastic processes, the Karhunen-Loève theorem is a representation of a stochastic process as an infinite linear combination of orthogonal functions, analogous to a Fourier series representation of a function on a bounded interval. The coefficients in the Karhunen-Loève theorem are random variables and the expansion basis depends on the process (Wiki, 2009).

PQH expand this procedure to the simulation of multivariate non-Gaussian processes. The PQH start with a rank correlation matrix for simulating random correlated variables, then, define marginal distributions, which is implemented in five steps.

(1) Convert rank correlation, S, to Pearson correlation,ρ, using

$$\rho \quad 2\sin\left[\pi / 6\ S\right] \tag{5-4}$$

(2) Use ρ to compute eigenvalues λ_k, as well as eigenvector $f_k(x)$, and confirm ρ is nonnegative definite.

(3) Use eigen solution in the KL expansion of a standard normal process to derive correlated standard normals, ω_k:

$$\omega_k \quad \sum_k \sqrt{\lambda_k}\xi_k\ \theta\ f_k\ x \tag{5-5}$$

where $\xi_k(\theta)$ independent standard normal variables and other variables are as previously defined.

(4) Change to the standard normal cumulative distribution function, and determine probability associated with each of the correlated standard normal deviates.

(5) Translate correlated probabilities from previous step into simulated outcomes by inverse transformation on the desired marginal distribution.

5.3.2 Simulation procedure

In the simulation procedure, SAS is used to empiricize the conceptual framework. The simulation code can be divided into two parts, which are the PQH procedure and implementation of the conceptual framework.

The SAS code starts with the do-loop for the numbers of bio-secure farm. There will be 1000 farms selected from the sample. The number of bio-secure farms begins at 50 and increases in increments of 50. Thus, there will be 20 utility and certain equivalent values in the result. The largest certainty equivalent will be picked up and the corresponding bio-secure farms number will be considered to be the optimal bio-secure farm choice.

The next step is to build the matrix for the correlations among the probability of avian influenza and other diseases for bio-secure and bio-insecure farms and the price. Personal communications with avian veterinarians at Mississippi State University were used to elicit these values. It is assumed the correlation between probability of avian influenza for bio-secure farm and bio-insecure farm is 0.15. The other disease may have higher outbreak probability, so the correlation between bio-secure farms and bio-insecure farms are set to 0.2. The poultry price has a negative relation with avian influenza and

other diseases, so the assumed correlation value between disease probability and poultry price is - 0.15. The correlation matrix is shown in table:

Table 5.4

The probability and price correlation matrix

	Probability of AI outbreak for bio-secure farms	Probability of AI outbreak for bio-insecure farms	Probability of other diseases outbreak for bio-secure farms	Probability of other diseases outbreak for bio-secure farms	Price
Probability of AI outbreak for bio-secure farms	1	0.15	0	0	-0.15
Probability of AI outbreak for bio-insecure farms	0.15	1	0	0	-0.15
Probability of other diseases outbreak for bio-secure farms	0	0	1	0.2	-0.15
Probability of other diseases outbreak for bio-insecure farms	0	0	0.2	1	-0.15
Price	-0.15	-0.15	-0.15	-0.15	1

The Beta distribution is used to model the disease prevalence or intensity (Anderson, Harri, Coble, 2009). Theses distributions are right-skewed with shape parameters set for α and β to reflect the low probability that disease levels will reach a critical mass. Also, a trigger value is used such that disease outbreak only occurs when disease reaches a threshold. Ultimately, the discrete probability of reaching the threshold of an outbreak is the relevant probability in the model. The Beta distributions and the threshold are set to reflect probabilities of disease outbreaks consistent with historical data and expert opinion. According to the opinions of poultry science experts, the probability of an AI outbreak in the U.S. is low, but other diseases, such as Infectious

Laryngotracheitis (LT) has a higher outbreak probability (Cumming, 2009). Consequently, the beta distribution parameters and dummy variable are set to generate a probability consistent with the historical observation of LT and AI. Finally, the mean and standard deviations of prices are set to levels taken from historic data: mean price, $0.71 per pound, and standard deviation of price, 0.12. The probit transformation is used to generate a lognormal price variable.

The second part of the empirical implementation of the conceptual framework starts with the probability of avian influenza and other diseases outbreak for bio-secure and bio-insecure farms, which translate the dummy variables A, B, C, and D into the SAS code. Given the values for each variable, one will get the result for the utility and certain equivalent.

To investigate integrator behavior, the base scenario of the model is calibrated such that the integrator is ambivalent to the distribution of bio-secure and insecure farms. Thus, the basic scenario is assumed to include 50% each of bio-secure and bio-insecure farms. The basic scenario has following values which are given in Table with explanation.

5.3.3 Simulation result and sensitivity analysis

In the basic scenario, the maximized certainty equivalent is obtained when integrator chooses 500 bio-secure and 500 bio-insecure farms. With this allocation, the integrator can achieve a $93.13 million certainty equivalent. At this point, the guaranteed payoff of integrator is "indifferent" between accepting the $93.13 million guaranteed payoff and a higher but uncertain payoff.

Table 5.5

The value given for simulation

Variables	Values	Reason
Risk aversion coefficient	2	The integrator is assumed to be risk averse and is moderate risk averse.
Sample size	100000	Make sure the sample is larger enough.
Initial wealth	$3000 million	Based on annual financial reports.
Output for bio-secure farm without loss	2.16million pounds	For a given cost, the bio-secure farm allocates more resource to their bio-secure measures and less in production. So their output is less than bio-insecure farm.
Output for bio-insecure farm without loss	2.2million pounds	For a given cost, the bio-secure farm allocates more resource to production. So their output is more than bio-insecure farm. However, the gap is not very large.
Share of output not lost if an outbreak	0.2	If diseases outbreak occur, the output will be 80% of the normal production situation.
Production cost for bio-secure farm	1.1million	From annual report of Tyson Inc.
Production cost for bio-insecure farm	1.1million	The cost for bio-secure and insecure is assumed to be same.
Deductible level	0.2	When outbreak of AI happens, government will give indemnification of 80% of original net return.
Indemnity penalty	1	A program parameter to investigate the effect of alternative government policy designs
Price reduction factor when diseases outbreak	0.63	The price reduction is 37%, so the price when disease outbreak occurs -price declines by 37%.

With the intention of observing the influence of each variable, sensitivity analysis has been conducted by keeping other variables constant while changing the value of the indemnity penalty and comparing the different bio-secure farms' number required to maximize the certainty equivalent. Results are shown in Table.

Table 5.6

Sensitivity analysis of indemnity penalty (Mu)

Value of variable Mu	Number of bio-secure farms for Max CE	Net Revenue
0	900	437.23
0.1	900	437.70
0.2	850	436.54
0.3	800	435.85
0.4	750	435.63
0.5	700	435.87
0.6	650	436.59
0.7	600	437.78
0.8	600	439.66
0.9	550	441.55
1	500	443.91

The value of the indemnity penalty changes from 0 to 1 in increments of 0.1. Accordingly, the number of bio-secure farms is influenced by the change of indemnity penalty level, which has a decreasing trend. So, this result suggests that the indemnity penalty can affect the integrator's choice of bio-secure farms, which is negatively related to the number of bio-secure farms.

Before doing the sensitivity analysis for deductible coefficient, there is an assumption that the larger deductible coefficient value will lead to more bio-secure farms, as the integrator will prefer more bio-secure farms to insure less disease outbreak. This is because the higher deductible coefficient value will cause the integrator to receive a lower indemnity payment in the event of a disease outbreak.

Table 5.7

Sensitivity analysis of deductible coefficient (d)

Value of variable d	Number of bio-secure farm for Max CE	Net Revenue
0	400	451.90
0.1	450	447.64
0.2	500	443.91
0.3	550	440.72
0.4	500	437.49
0.5	650	435.94
0.6	700	434.34
0.7	750	433.28
0.8	800	432.75
0.9	800	431.14
1	850	431.41

In Table, results show a positive relationship between the deductible value and the number of bio-secure farms. When the deductible level is 0 (100 percent indemnity for loss) the integrator picks 400 bio-secure farms. When the deductible level is 1 (no indemnity at all) the integrator chooses 850 bio-secure farms. So, if government wants to induce integrators to choose more bio-secure farms, one approach might be to increase the deductible coefficient. It gives government a hint that the higher level of compensation will lead integrator's lower level of bio-secure farms. So, if government wants integrator to choose more bio-secure farms, they could decrease the compensation level, on the other words to increase deductible level.

The share of output not lost in an outbreak should have a negative relationship with the number of bio-secure farms. If more (less) output is lost from an outbreak, the more (less) incentive integrators have to contract with bio-secure farms as a means of reducing the probability of an outbreak.

Table 5.8

Sensitivity analysis of share of output which does not lost in outbreak (alpha)

Value of variable alpha	Number of bio-secure farms for Max CE	Net Revenue
0	600	433.93
0.1	550	438.68
0.2	500	443.91
0.3	350	450.62
0.4	150	459.51
0.5	0	469.37
0.6	0	477.03
0.7	0	484.69
0.8	0	492.36
0.9	0	500.02
1	0	507.68

The simulation result in Table shows the less output that is lost in an outbreak, the lower the number of bio-secure farms chosen by the . If the share of output not lost in the outbreak is zero, in other words, the loss rate is 100%; the integrator will contract with 600 bio-secure farms. When the loss rate is 50%, the integrator only contracts with 150 bio-secure farms. If there is no loss, the bio-secure farm number is 0.

The risk aversion coefficient reflects the risk aversion level of integrator. A smaller value corresponds to lower risk aversion. For the sensitivity analysis of risk aversion coefficient, the assumption is that a more risk averse integrator will choose more bio-secure farms. Because they prefer more stable production to less stable production, they will be willing to trade lower output for more consistency in that output.

Table 5.9

Sensitivity analysis of risk aversion coefficient (R_av)

Value of variable R_av	Number of bio-secure farms for Max CE	Net Revenue
1	400	444.41
2	500	443.91
3	500	443.91
4	500	443.91

The result in table illustrates the positive relationship between an integrator's risk aversion coefficient and the number of bio-secure farms the integrator will choose. It shows that more risk averse integrators will choose more bio-secure farms, which is consistent with the assumption. And the risk averse integrators is willing to trade more stable production by less output.

The final sensitivity analysis addresses the trigger value of probability of outbreak for other diseases, whose change may also have effects on integrator's choices. The trigger value is an outbreak standard, which means when the probability of other diseases outbreak is greater than this threshold value, an outbreak is assumed to occur; otherwise, no outbreak is assumed. The higher the trigger value, the lower the outbreak probability. It is assumed, then, that as the trigger value increases, the integrator will choose fewer bio-secure farms.

Table 5.10

Sensitivity analysis of trigger value of outbreak probability for other diseases

Trigger Value of prob OT	Ns Number for Max CE	Net Revenue
0.25	700	369.14
0.40	500	443.91
0.65	0	472.18

The result in table shows the negative relationship between the trigger value of outbreak probability and bio-secure farm numbers, which supports the assumption that a higher outbreak probability will lead to fewer bio-secure farms. In summary, the sensitivity analysis gives proof of the intuitive assumption discussed earlier. In the next chapter, the meaning and application of these research results is discussed.

CHAPTER VI

CONCLUSION

The goal of this work is to investigate the relationship between the bio-security choices of poultry growers and their production performance for integrators with whom they have contracted. The conceptual framework underlying this work is the maximization of integrator expected utility under different disease outbreak scenarios for bio-secure and bio-insecure farms, with scenarios differing in terms of the probabilities of outbreak for avian influenza and other diseases.

The simulation model was calibrated to reflect that the integrator would choose an equal proportion of bio-secure and bio-insecure farms if they do not know the influence of secure and insecure farms on economic outcomes or if they do not care about that influence. Key variables such as price reduction when an outbreak occurs, the risk aversion level of integrator, share of output lost in the event of an outbreak, probability of other disease outbreak, deductible level and indemnity penalty are evaluated for their influence on the optimal combination of bio-secure and bio-insecure farms for integrators. The results imply that a higher indemnity level will lead to less bio-secure farms being chosen by integrators. A more risk averse integrator will choose more bio-secure farms to maximize expected utility. It is found that if disease outbreaks do not lead

to large reductions in broiler production and/or price, the integrator prefers more bio-insecure farms. In contrast, if disease outbreaks cause high mortality, integrators would select a larger proportion of bio-secure farms. The sensitivity analysis result shows that the probability of other disease outbreaks has an effect on the integrators' bio-security decisions. A higher probability of outbreak for other disease will lead an integrator to select a larger proportion of bio-secure farms. So if the diseases are widespread and severe, the integrators favor to more bio-secure farms.

This research originally focused on investigating the ways which government can incite integrators to apply better bio-security measures in the poultry industry to avoid avian influenza and contain the spread of the disease. Potential measures include an ex post indemnification program, a prior insurance or indemnification program, and tiered indemnification program. After talking with experts from the poultry industry, we found the decision is much more complicated and that previous models fail to accurately reflect the context in which AI bio-security decisions are made. The primary focus of the work was thus changed to examine the integrators' bio-security choice under different diseases outbreak probability scenarios. The research path allows the examination of whether alternative USDA/APHIS indemnification rules can influence integrators willingness to improve bio-security measures. The final result shows the deductible level of government indemnification can change the integrators decision and, specifically, that lower indemnification will lead to a greater proportion of bio-secure farms. The indemnity penalty is taken into consideration in the model; however, simulation results suggest that this factor does not have a significant influence on the integrator's choice between bio-

secure and bio-insecure farms. If USDA/APHIS wants to reform current policy, they may consider changing different deductible level to induce integrators making more bio-secure efforts.

The inadequacy of this paper is that no primary data from poultry industry exist that would permit further empirical verification of the conceptual issues that have been raised. So in the further, researcher could use the first hand side to verify this paper's conclusion.

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APPENDIX

SAS CODE

```
libname sd2 'c:\saswork\units\data\';
options nocenter;


%macro analysis;

/* do loop to randomly drawn shape parms, number of units, and correlations */

%do I = 50 %to 50 %by 50;

data adat;

*ivar = I;
/*    PREISM Simulation  Firm search for right mix of secure and unsecure farms

     Random var1= prob of AI secure,     var2 = prob of AI unsecure
          var3= prob of other disease secure, var4 = prob of other disease unsecure
          var5 =poultry price    */

proc iml;
/* defines  the correlation matrix  */
*use adat;  *read all into ccp_corr;
cor = j(5,5,0); /* creates a 5x5 matrix of zeros  */

cor[1,1]=1; cor[2,2]=1; cor[3,3]=1;  cor[4,4]=1; cor[5,5]=1;
cor[1,2]= 0.15; cor[2,1]=0.15;
cor[1,3]= 0.0; cor[3,1]= 0.0;
cor[1,4]= 0.0; cor[4,1]= 0.0;
cor[1,5]=-0.15; cor[5,1]=-0.15;

cor[2,3]= 0.0; cor[3,2]= 0.0;
cor[2,4]= 0.0; cor[4,2]= 0.0;
cor[2,5]=-0.15; cor[5,2]=-0.15;

cor[3,4]= 0.2; cor[4,3]= 0.2;
cor[3,5]=-0.2; cor[5,3]=-0.2;

cor[4,5]=-0.2; cor[5,4]=-0.2;

*PRINT Cor;
*TITLE 'CORR DATA';
*print I;  *title 'I variable';
/* convert rank correlation to product/moment equivalent correlations */
a=3.14159265/6*cor;
```

```
b=sin(a);  c=2*b;

/*********************************************  Phoon Quek and Wang
**************************/
call eigen(eval_ccp, evec_ccp, c);
/* eigen decomposition of correlation matrix */
if eval_ccp[2,1]< 0 then eval_ccp[2,1]=0;

n=100000;
*print eval_ccp;
*print evec_ccp;
*print c;

/* square root of eigenvalues */
sq_val=sqrt(eval_ccp);

/* independent random standard normal deviates each column will represents a separate
set of correlated variables */
z=normal(repeat(0,5,n));

/* elementwise pre-multiplication of iid standard normals and eigenvalues */
z_val=z#sq_val;

/* multiplication by eigenvector matrix */
z_val_vec=evec_ccp*z_val;

*print sq_val; *print z_val; *print z_val_vec;

/* conversion of correlated standard normals into correlated uniform(0,1) */
p=probnorm(z_val_vec);
*print p;
/* transpose of probability matrix so that each row is a set of corrlated
        U(0,1) variables (probabilities) */
tp=t(p);

/* separating columns of the probability matrix */
AIs_1=tp[,1];
AIu_2=tp[,2];
OTs_1=tp[,3];
OTu_2=tp[,4];
prc_1=tp[,5];

*print cr_y1; *title 'cr_y1';
/* generating correlated standard normals through inverse transormation
```

```
   using correlated U(0,1) deviates */
*crp_z=probit(cr_p);


/**** Alternative  Fixed Parameters for the beta distribution ****/
a_AIs= 2; b_AIs= 15;
a_AIu= 4; b_AIu= 15;
a_OTs= 2; b_OTs= 12;
a_OTu= 2; b_OTu= 10;
ub=1;

/* generating correlated yield observations using inverse
   transformation of beta distribution upper bound = ub */

ub2_dat= j(n,1,1);
ub2_dat=ub*ub2_dat;
prob_AIs=betainv(AIs_1,a_AIs,b_AIs)*ub;
prob_AIu=betainv(AIu_2,a_AIu,b_AIu)*ub;
prob_OTs=betainv(OTs_1,a_OTs,b_OTs)*ub;
prob_OTu=betainv(OTu_2,a_OTu,b_OTu)*ub;


/* generating correlated standard normals through inverse transormation
   using correlated U(0,1) deviates */
price1=probit(prc_1);

/* retreiving means and standard deviations of prices to convert
   correlated standard normals into lognormal price series */
price_mn1= -0.57;
price_std1=0.12;
sim_price1=exp((price1*price_std1)+price_mn1);
/* building single matrix w/ all prices and yields for conversion
   into SAS data set */
*print ub2_dat;


data_set=prob_AIs||prob_AIu||prob_OTs||prob_OTu||sim_price1;

*parm_set = a_cr1||b_cr1||a_cr2||b_cr2||I ;
*print data_set; *title 'data set';
create sim_data from data_set;
append from data_set;
close sim_data;
```

```
*print parm_set; title 'parm set';
*create parm_data from parm_set;
*append from parm_set;
*close parm_data;
quit;


/********************  Analaysis of sim_data  ************/
data rev0; set sim_data;
probAIs=col1;  probAIu=col2; probOTs=col3; probOTu=col4; price=col5;
if probAIs > 0.4 then outbreak_AIs = 1; else outbreak_AIs = 0;
if probAIu > 0.4 then outbreak_AIu = 1; else outbreak_AIu = 0;
if probOTs > 0.4 then outbreak_OTs = 1; else outbreak_OTs = 0;
if probOTu > 0.4 then outbreak_OTu = 1; else outbreak_OTu = 0;

cnt = &I;
/* risk aversion coef  */ r_av=2;
/* sample size = to n above  */ num=100000;
/*  intial wealth */ int_w=3000.000000;
/* output secure  no loss*/ Qs_nl=2.16;
/* output unsecure  no loss */ qu_nl= 2.200000;
/*  share of ouput not lost if an outbreak */ alpha= 0.2;
/*  Cost secure */   Cs =1.1;
/* cost unsecure  */ Cu =1.1;
/* number of biosecure farms */ NS = cnt;
/* number of biounsecure farms */ NU = 1000 - NS;
/* deductible  */  d=0.2;
/* indemnity penalty  */ mu = 1.0;
/* outbreak price reduction %  */ PR=0.63;

if outbreak_AIs = 1  and outbreak_AIu = 0 and outbreak_OTs = 0 and outbreak_OTu = 0
then
NRs = price * PR * alpha * Qs_nl - Cs + (1-alpha)*(1-d)*price*pr*Qs_nl;
if outbreak_AIs = 1  and outbreak_AIu = 0 and outbreak_OTs = 0 and outbreak_OTu = 0
then
NRu=price*PR*Qu_nl-Cu;

if outbreak_AIs = 1 and outbreak_AIu = 1 and outbreak_OTs = 0 and outbreak_OTu = 0
then
NRs = price * PR * alpha* Qs_nl - Cs + (1-alpha)*(1-d)*price*pr*Qs_nl ;
if outbreak_AIs = 1 and outbreak_AIu = 1 and outbreak_OTs = 0 and outbreak_OTu = 0
then
NRu = price * PR * alpha* Qu_nl - Cu + mu*(1-alpha)*(1-d)*price*pr*Qu_nl;
```

if outbreak_AIs = **1** and outbreak_AIu = **1** and outbreak_OTs = **1** and outbreak_OTu = **0** then
NRs = price * PR * alpha * Qs_nl - Cs + (**1**-alpha)*(**1**-d)*price*pr*Qs_nl ;
if outbreak_AIs = **1** and outbreak_AIu = **1** and outbreak_OTs = **1** and outbreak_OTu = **0** then
NRu = price * PR * alpha * Qu_nl - Cu + mu*(**1**-alpha)*(**1**-d)*price*pr*Qu_nl;

if outbreak_AIs = **1** and outbreak_AIu = **1** and outbreak_OTs = **1** and outbreak_OTu = **1** then
NRs = price * PR * alpha * Qs_nl - Cs + (**1**-alpha)*(**1**-d)*price*pr*Qs_nl ;
if outbreak_AIs = **1** and outbreak_AIu = **1** and outbreak_OTs = **1** and outbreak_OTu = **1** then
NRu = price * PR * alpha * Qu_nl - Cu + mu*(**1**-alpha)*(**1**-d)*price*pr*Qu_nl;

if outbreak_AIs = **1** and outbreak_AIu = **0** and outbreak_OTs = **1** and outbreak_OTu = **0** then
NRs = price * PR * alpha * Qs_nl - Cs + (**1**-alpha)*(**1**-d)*price*pr*Qs_nl;
if outbreak_AIs = **1** and outbreak_AIu = **0** and outbreak_OTs = **1** and outbreak_OTu = **0** then
NRu = price* PR * Qu_nl - Cu;

if outbreak_AIs = **1** and outbreak_AIu = **0** and outbreak_OTs = **0** and outbreak_OTu = **1** then
NRs = price * PR * alpha * Qs_nl - Cs + (**1**-alpha)*(**1**-d)*price*pr*Qs_nl ;
if outbreak_AIs = **1** and outbreak_AIu = **0** and outbreak_OTs = **0** and outbreak_OTu = **1** then
NRu = price * PR * Qu_nl - Cu;

if outbreak_AIs = **1** and outbreak_AIu = **0** and outbreak_OTs = **1** and outbreak_OTu = **1** then
NRs = price * PR * alpha * Qs_nl - Cs + (**1**-alpha)*(**1**-d)*price*pr*Qs_nl ;
if outbreak_AIs = **1** and outbreak_AIu = **0** and outbreak_OTs = **1** and outbreak_OTu = **1** then
NRu = NRu = price * PR * Qu_nl - Cu;

if outbreak_AIs = **1** and outbreak_AIu = **1** and outbreak_OTs = **0** and outbreak_OTu = **1** then
NRs = price * PR * alpha * Qs_nl - Cs + (**1**-alpha)*(**1**-d)*price*pr*Qs_nl ;
if outbreak_AIs = **1** and outbreak_AIu = **1** and outbreak_OTs = **0** and outbreak_OTu = **1** then
NRu = price * PR * alpha * Qu_nl - Cu + mu*(**1**-alpha)*(**1**-d)*price*pr*Qu_nl;

if outbreak_AIs = **0** and outbreak_AIu = **1** and outbreak_OTs = **1** and outbreak_OTu = **1** then
NRs = price * PR * Qs_nl - Cs ;
if outbreak_AIs = **0** and outbreak_AIu = **1** and outbreak_OTs = **1** and outbreak_OTu = **1** then
NRu = price * PR * alpha * Qu_nl - Cu + mu*(**1**-alpha)*(**1**-d)*price*pr*Qu_nl;

if outbreak_AIs = **0** and outbreak_AIu = **0** and outbreak_OTs = **1** and outbreak_OTu = **1** then
NRs = price * PR * alpha * Qs_nl - Cs ;
if outbreak_AIs = **0** and outbreak_AIu = **0** and outbreak_OTs = **1** and outbreak_OTu = **1** then
NRu = price * PR * alpha * Qu_nl - Cu;

if outbreak_AIs = **0** and outbreak_AIu = **0** and outbreak_OTs = **0** and outbreak_OTu = **1** then
NRs = price * PR * Qs_nl - Cs ;
if outbreak_AIs = **0** and outbreak_AIu = **0** and outbreak_OTs = **0** and outbreak_OTu = **1** then
NRu = price * PR * alpha * Qu_nl - Cu;

if outbreak_AIs = **0** and outbreak_AIu = **0** and outbreak_OTs = **0** and outbreak_OTu = **0** then
NRs = price * Qs_nl - Cs ;
if outbreak_AIs = **0** and outbreak_AIu = **0** and outbreak_OTs = **0** and outbreak_OTu = **0** then
NRu = price * Qu_nl - Cu;

if outbreak_AIs = **0** and outbreak_AIu = **1** and outbreak_OTs = **0** and outbreak_OTu = **1** then
NRs = price * PR * Qs_nl - Cs ;
if outbreak_AIs = **0** and outbreak_AIu = **1** and outbreak_OTs = **0** and outbreak_OTu = **1** then
NRu = price * PR * alpha * Qu_nl - Cu + (**1**-alpha)*(**1**-d)*price*pr*Qu_nl;

if outbreak_AIs = **0** and outbreak_AIu = **1** and outbreak_OTs = **1** and outbreak_OTu = **0** then
NRs = price * PR * alpha * Qs_nl - Cs ;
if outbreak_AIs = **0** and outbreak_AIu = **1** and outbreak_OTs = **1** and outbreak_OTu = **0** then
NRu = price * PR * alpha * Qu_nl - Cu + (**1**-alpha)*(**1**-d)*price*pr*Qu_nl;

if outbreak_AIs = **0** and outbreak_AIu = **1** and outbreak_OTs = **0** and outbreak_OTu = **0** then

NRs = price * PR * Qs_nl - Cs ;
if outbreak_AIs = **0** and outbreak_AIu = **1** and outbreak_OTs = **0** and outbreak_OTu = **0** then
NRu = price * PR * alpha * Qu_nl - Cu + (**1**-alpha)*(**1**-d)*price*pr*Qu_nl;

if outbreak_AIs = **0** and outbreak_AIu = **0** and outbreak_OTs = **1** and outbreak_OTu = **0** then
NRs = price * PR * alpha * Qs_nl - Cs ;
if outbreak_AIs = **0** and outbreak_AIu = **0** and outbreak_OTs = **1** and outbreak_OTu = **0** then
NRu = price * PR * Qu_nl - Cu;

*net_comb = NS * NRs + NU * Nru;
net50 = **50** * NRs + **950** * Nru;
net100 = **100** * NRs + **900** * Nru;
net150 = **150** * NRs + **850** * Nru;
net200 = **200** * NRs + **800** * Nru;
net250 = **250** * NRs + **750** * Nru;
net300 = **300** * NRs + **700** * Nru;
net350 = **350** * NRs + **650** * Nru;
net400 = **400** * NRs + **600** * Nru;
net450 = **450** * NRs + **550** * Nru;
net500 = **500** * NRs + **500** * Nru;
net550 = **550** * NRs + **450** * Nru;
net600 = **600** * NRs + **400** * Nru;
net650 = **650** * NRs + **350** * Nru;
net700 = **700** * NRs + **300** * Nru;
net750 = **750** * NRs + **250** * Nru;
net800 = **800** * NRs + **200** * Nru;
net850 = **850** * NRs + **150** * Nru;
net900 = **900** * NRs + **100** * Nru;
net950 = **950** * NRs + **50** * Nru;
net1000 = **1000** * NRs + **0** * Nru;

/* utility */
*If r_av = 1 Then util = (Log(net_comb + int_w));
*Else util = (((net_comb + int_w) ** (1 - r_av)) / (1 - r_av));

If r_av = **1** Then util50 = (Log(net50 + int_w)); Else util50 = (((net50 + int_w) ** (**1** - r_av)) / (**1** - r_av));
If r_av = **1** Then util100 = (Log(net100 + int_w)); Else util100 = (((net100 + int_w) ** (**1** - r_av)) / (**1** - r_av));

```
If r_av = 1 Then util150 = (Log(net150 + int_w)); Else util150 =  (((net150 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util200 = (Log(net200 + int_w)); Else util200 =  (((net200 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util250 = (Log(net250 + int_w)); Else util250 =  (((net250 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util300 = (Log(net300 + int_w)); Else util300 =  (((net300 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util350 = (Log(net350 + int_w)); Else util350 =  (((net350 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util400 = (Log(net400 + int_w)); Else util400 =  (((net400 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util450 = (Log(net450 + int_w)); Else util450 =  (((net450 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util500 = (Log(net500 + int_w)); Else util500 =  (((net500 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util550 = (Log(net550 + int_w)); Else util550 =  (((net550 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util600 = (Log(net600 + int_w)); Else util600 =  (((net600 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util650 = (Log(net650 + int_w)); Else util650 =  (((net650 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util700 = (Log(net700 + int_w)); Else util700 =  (((net700 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util750 = (Log(net750 + int_w)); Else util750 =  (((net750 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util800 = (Log(net800 + int_w)); Else util800 =  (((net800 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util850 = (Log(net850 + int_w)); Else util850 =  (((net850 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util900 = (Log(net900 + int_w)); Else util900 =  (((net900 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util950 = (Log(net950 + int_w)); Else util950 =  (((net950 + int_w) **
(1 - r_av)) / (1 - r_av));
If r_av = 1 Then util1000 = (Log(net1000 + int_w)); Else util1000 =  (((net1000 + int_w)
** (1 - r_av)) / (1 - r_av));


proc means; title 'raw data';
var NS NU NRs NRu r_av int_w outbreak_AIs outbreak_AIu outbreak_OTs
outbreak_OTu price
net50 net100 net150 net200 net250 net300 net350 net400 net450 net500
net550 net600 net650 net700 net750 net800 net850 net900 net950 net1000
```

```
UTIL50 UTIL100 UTIL150 UTIL200 UTIL250 UTIL300 UTIL350 UTIL400 UTIL450
UTIL500
UTIL550 UTIL600 UTIL650 UTIL700 UTIL750 UTIL800 UTIL850 UTIL900 UTIL950
UTIL1000;

proc means noprint ;
var                    NS  NU   r_av   int_w
UTIL50 UTIL100 UTIL150 UTIL200 UTIL250 UTIL300 UTIL350 UTIL400 UTIL450
UTIL500
UTIL550 UTIL600 UTIL650 UTIL700 UTIL750 UTIL800 UTIL850 UTIL900 UTIL950
UTIL1000;
output out=util_out mean= NSm NUm  r_avm int_wm
UTIL50M UTIL100M UTIL150M UTIL200M UTIL250M UTIL300M UTIL350M
UTIL400M UTIL450M UTIL500M
UTIL550M UTIL600M UTIL650M UTIL700M UTIL750M UTIL800M UTIL850M
UTIL900M UTIL950M UTIL1000M;


data ce_comp; set util_out;

/* calculates the certainty equivalent  */

If r_avm = 1 Then certeq50 = (Exp(util50M)) ; Else certeq50 = ((util50M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq100 = (Exp(util100M)) ; Else certeq100 = ((util100M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq150 = (Exp(util150M)) ; Else certeq150 = ((util150M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq200 = (Exp(util200M)) ; Else certeq200 = ((util200M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq250 = (Exp(util250M)) ; Else certeq250 = ((util250M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq300 = (Exp(util300M)) ; Else certeq300 = ((util300M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq350 = (Exp(util350M)) ; Else certeq350 = ((util350M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq400 = (Exp(util400M)) ; Else certeq400 = ((util400M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq450 = (Exp(util450M)) ; Else certeq450 = ((util450M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq500 = (Exp(util500M)) ; Else certeq500 = ((util500M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq550 = (Exp(util550M)) ; Else certeq550 = ((util550M * (1 -
r_avm))**(1 / (1 - r_avm)));
```

```
If r_avm = 1 Then certeq600 = (Exp(util600M)) ; Else certeq600 = ((util600M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq650 = (Exp(util650M)) ; Else certeq650 = ((util650M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq700 = (Exp(util700M)) ; Else certeq700 = ((util700M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq750 = (Exp(util750M)) ; Else certeq750 = ((util750M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq800 = (Exp(util800M)) ; Else certeq800 = ((util800M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq850 = (Exp(util850M)) ; Else certeq850 = ((util850M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq900 = (Exp(util900M)) ; Else certeq900 = ((util900M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq950 = (Exp(util950M)) ; Else certeq950 = ((util950M * (1 -
r_avm))**(1 / (1 - r_avm)));
If r_avm = 1 Then certeq1000 = (Exp(util1000M)) ; Else certeq1000 = ((util1000M * (1 -
r_avm))**(1 / (1 - r_avm)));

/*If r_avm = 1 Then certeq = (Exp(util_combm)) - int_wm;
        Else certeq = ((util_combm * (1 - r_avm)) ** (1 / (1 - r_avm))) - int_wm;
*/

proc print ;

%end;
%mend analysis;
%analysis; run;

quit;
```