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Livestock Disease Indemnity Design under Common Uncertainty: A Multi-agent Problem

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Abstract

For most of the contagious livestock diseases, the disease prevalence rates among farms are interrelated. This article develops a principal multi-agent model to study the optimal livestock indemnity design in face of common uncertainties. Our results indicate that the indemnity scheme taking multiple farms into account is most applicable in two cases: 1) the farmers' disease prevalence rates are highly correlated and 2) the effectiveness of biosecurity effort proves to be low.

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1. Introduction

In the face of highly contagious zoonotic diseases, mass destruction of animals is often necessary to return a country to disease free status. According to the Fifth Amendment of the US Constitution, indemnities will be paid to livestock owners to compensate them for the destruction of their animals. In terms of the compensation amount, two guiding principles established by Animal Health Protection Act (AHPA) are *i*) fair market value and *ii*) payment reduction for compensation received from any other sources (Ott 2006).

While indemnity has been playing an important role in garnering farmer's support for disease eradication historically (Kuchler and Hamm 2000, Olmstead and Rhode 2004), it may trigger a moral hazard problem (Muhammad and Jones 2008). That is, it could give farmers a reason to cut back the biosecurity measure which includes the ex-ante prevention measures in susceptible herds and the ex-post control measures of the infected ones (Chi et al. 2002). Therefore in designing an optimal indemnity payment scheme it is important for the government to take farmers' ex-ante biosecurity choice into account (Jin and McCarl 2006). Meanwhile, as biosecurity efforts are typically hard to observe, it is important to give incentives for farmers to comply voluntarily (Gramig, Horan and Wolf 2005, 2009).

To avoid the moral hazard problem, Hennessy (2007) and Gramig, Horan and Wolf (2009) took incentive compatibility (IC) into account when designing the optimal indemnity payment. For example, Gramig, Horan and Wolf (2009) has applied the principal agent model and depicted the indemnity payment as a function of the disease prevalence rate of a single representative farmer. However, while doing so they assumed that all farms face independent risks. This is hardly the case when it comes to the highly contagious diseases, for which the disease prevalence rates faced by the farms are most likely interrelated. For example, when Foot and Mouth Disease (FMD) breaks out in a region, typically a large number of farms will be infected by this disease, even if adequate biosecurity measures are taken (Ekboir 1999). Therefore it is vital to take the interactions among farmers into account in the face of interdependent risks.

To capture farmers' strategic behavior in taking biosecurity measures as described by Kobayashi and Melkonyan (2011), we apply the principal multi-agent model to study the optimal indemnity scheme. In this setup, the optimal government indemnity scheme is presented in the relative performance evaluation (RPE) form, which has been proved as an effective method to improve contract efficiency (Hölmstrom 1979, Mookherjee 1984 and Luporini 2006). Under the RPE, the agents are evaluated on their performance relative to a comparison group, rather than an absolute standard. Fleckinger (2012) studies the robustness of RPE when correlation between the outcomes is not fixed but varies with effort. Using first order approach (FOA), that is substituting the constraints with their first order conditions (FOC), Luporini (2006) proved that affiliation of the random variables affecting the agents' outputs is both necessary and sufficient for one agent's compensation to be non-increasing in the other agent's output. While FOA is mathematically more tractable, it is generally invalid. In order to prove the validity of FOA, the monotone likelihood ratio condition (MLRC) and convexity of distribution function condition (CDFC) need to be satisfied (Rogerson 1985). This article extends the RPE literature by proving the result of Luporini (2006) using the original constraints instead of the FOC, thus renders the MLRC and CDFC assumptions unnecessary. We also provide a numerical example to identify the structure of the optimal indemnity schemes under different scenarios and to investigate the situations where use of RPE is more justified.

2. Model

To model interdependent disease risks, we present a one-principal, two-agent model which resembles the model in Mookherjee (1984). Here the principal stands for the government, and the agents stand for two farmers whose livestock face a positive probability of contracting a certain contagious disease.

Let $B=\{b_i \mid b_i \geq 0, i=1,2\}$ denote the possible biosecurity practices for both agents. A random variable $\theta_i \in [0,1]$ stands for an environmental risk factor that is beyond farmers' control. The disease is more prevalent in the area when θ_i takes a high value. The joint probability density function for θ_1 and θ_2 is $g(\theta_1,\theta_2)$.

Assume that all the farms are identical in scale and that the output produced by farmer i is $q_i(b_i,\theta_i) \in [\underline{q},\bar{q}]$. Note that the output here is used as an indicator for the seriousness of the disease, where a low farm output is regarded as a result of high within-herd disease prevalence. For example, the lowest possible output $\underline{q}$ stands for the output where all the livestock contract the disease, while $\bar{q}$ denotes the output where all livestock are healthy. The output of farmer i depends both on his own biosecurity effort and on the ambient disease prevalence rate such that $\partial q_i(b_i,\theta_i)/\partial b_i \geq 0$ and $\partial q_i(b_i,\theta_i)/\partial \theta_i \leq 0$. Without loss of generality, assume the output price is 1.

Indemnity to agent i is denoted by $I_i(q_i,q_j)$. Here (q_i,q_j) stands for a combination of outputs by farmers i and j, where $i,j=1,2$ and $i \neq j$. Denote farmer i's utility function as $V(\cdot)$, where $V'(\cdot) \geq 0$ and $V''(\cdot) \leq 0$. Thus farmer i's gross utility takes the value of $V(q_i + I_i(q_i,q_j))$ when the combination of outputs by farmers i and j is (q_i,q_j). For simplicity purposes, we assume the unit cost of biosecurity measure as w. Thus the corresponding net utility is $V(q_i + I_i(q_i,q_j)) - b_i w$. Compared to the linear cost function, a more realistic convex cost function implies that the biosecurity effectiveness will not improve as much with the same amount of increase in biosecurity cost (Hennessy 2013). We will investigate the impact of biosecurity effectiveness on government indemnity scheme in the numerical example section, where lower biosecurity effectiveness can also be interpreted as a more convex cost function.

Denote the agents' reservation net utility as $\underline{U}$. Here $\underline{U}$ could be understood as the maximum utility a farmer can obtain while not participating in the program. For example, a farmer may obtain a discounted sales value by selling the diseased livestock to some illegal traders instead. Following Mirrlees (1974), we set up the optimal contracting problem by suppressing θ_i and consider output levels as random variables parameterized by the biosecurity input b_i. The joint probability density that the output level (q_1,q_2) is realized given the biosecurity input level (b_1,b_2) is $f(q_1,q_2;b_1,b_2)$, where $f(\cdot)$ is continuous w.r.t. q_1,q_2. The distribution function corresponding to $f(\cdot)$ is $F(\cdot)$. Here $F(q_1,q_2;b_1,b_2) = Prob(q_1(b_1,\theta_1) \leq q_1; q_2(b_2,\theta_2) \leq q_2)$.

2.1 Second-best Situation

The second best (SB) situation here stands for the case where farmers' biosecurity inputs are their own private information and could not be observed by the government. Take Bovine TB as an example. While some relevant biosecurity practices such as buying animals from an accredited TB-free herd and vaccinations are observable, many other practices such as movement restrictions and quarantines may not be observable (Coble 2010; Wolf 2005).

Assume that the optimal biosecurity level $(\hat{b}_1, \hat{b}_2)$ is determined exogenously, e.g., by the most recent scientific breakthroughs and epidemiological evidence. Due to its own budget constraint, the government is to find the most efficient indemnity scheme, i.e., to minimize its total indemnity payments to farmers, while ensuring that the optimal biosecurity measures are taken. In the optimal contracting problem (OCP), the objective of the government can be expressed in:

$$\min_{\mathbf{I}_1,\mathbf{I}_2} \int_{\underline{q}}^{\overline{q}}\int_{\underline{q}}^{\overline{q}} I_1(q_1,q_2)+I_2(q_1,q_2)\, f(q_1,q_2;\hat{b}_1,\hat{b}_2)dq_1dq_2 \tag{1}$$

Meanwhile, to guarantee a successful program the government should give farmers financial incentives to be a part of the program. The participation constraints (PC) ensure the farmers’ net utilities from being a part of the indemnity program is greater than the maximum utility the farmers can obtain without participating in the program:

$$\int_{\underline{q}}^{\overline{q}}\int_{\underline{q}}^{\overline{q}} V(q_i + I_i(q_1,q_2))\, f(q_1,q_2;\hat{b}_i,\hat{b}_j)dq_1dq_2 - \hat{b}_i w \geq \underline{U}, \quad \forall i, j = 1,2; i \neq j. \tag{2}$$

Considering the interdependent risks faced by the farmers, a Nash incentive compatibility constraints (NIC) is also required, which ensures that the optimal strategy pair $(\hat{b}_1, \hat{b}_2)$ constitutes a Nash equilibrium (NE) under optimal indemnity scheme $\mathbf{I}_i = \{I_i(q_1,q_2), \forall q_1,q_2\},\ i=1,2$:

$$\begin{aligned}&\int_{\underline{q}}^{\overline{q}}\int_{\underline{q}}^{\overline{q}} V(q_i + I_i(q_1,q_2))\, f(q_1,q_2;\hat{b}_i,\hat{b}_j)dq_1dq_2 - \hat{b}_i w \\ \geq &\int_{\underline{q}}^{\overline{q}}\int_{\underline{q}}^{\overline{q}} V(q_i + I_i(q_1,q_2))\, f(q_1,q_2;b_i,\hat{b}_j)dq_1dq_2 - b_i w; \quad \forall b_i \in B.\end{aligned} \tag{3}$$

Following the analysis in Grossman and Hart (1983) and Mookherjee (1984), it is convenient to transform the constraints into a linear form with regard to the control variables. Defining $V(q_i + I_i(q_i,q_j)) \equiv v_i(q_i,q_j)$, we have $I_i(q_i,q_j) = h(v_i(q_i,q_j)) - q_i$, where $h(\cdot) = V^{-1}(\cdot)$. The OCP defined by (1) to (3) will now become the transformed optimal contracting problem (TOCP) as specified by (4):

$$\min_{v_1,v_2} \int_{\underline{q}}^{\overline{q}}\int_{\underline{q}}^{\overline{q}} [h(v_1(q_1,q_2)) + h(v_2(q_1,q_2)) - q_1 - q_2]\, f(q_1,q_2;\hat{b}_1,\hat{b}_2)dq_1dq_2$$

$$\int_{\underline{q}}^{\overline{q}}\int_{\underline{q}}^{\overline{q}} v_i(q_1,q_2)\, f(q_1,q_2;\hat{b}_1,\hat{b}_2)dq_1dq_2 - \hat{b}_i w \geq \underline{U}; \tag{4}$$

$$\int_{\underline{q}}^{\bar{q}}\int_{\underline{q}}^{\bar{q}} v_i(q_1,q_2)\, f(q_1,q_2;\hat{b}_i,\hat{b}_j)dq_1dq_2 - \hat{b}_i w$$
$$\geq \int_{\underline{q}}^{\bar{q}}\int_{\underline{q}}^{\bar{q}} v_1(q_1,q_2)\, f(q_1,q_2,b_i;\hat{b}_j)dq_1dq_2 - b_i w; \forall b_1 \in B.$$

From TOCP we could obtain:

$$h'(v_i(q_1,q_2)) = \lambda_i + \sum_{b_i \in B}\gamma_i(b_i)(1-\frac{f(q_1,q_2;b_i,\hat{b}_j)}{f(q_1,q_2;\hat{b}_i,\hat{b}_j)})\ \ \forall i, j=1,2; i\neq j. \tag{5}$$

Equation (5) is a standard result in principal agent literature (See e.g. Hölmstrom 1979 and Mookherjee 1984). Given that farmer j takes the optimal biosecurity practice $\hat{b}_j$, the government can update its prior on b_i based the observation of disease prevalence levels from farm i and j, inferred from q_i and q_j.

2.2 Indemnity Payment Based on RPE

In this section we relax Luporini (2006)'s FOA assumptions and study how RPE could be utilized in optimal indemnity payment. First we will present an equivalent condition to the affiliation condition provided in Luporini (2006).

Lemma 1: The following two conditions are equivalent: 1) $\frac{g(\theta_1^+,\theta_2^-)}{g(\theta_1^-,\theta_2^-)} - \frac{g(\theta_1^+,\theta_2^+)}{g(\theta_1^-,\theta_2^+)} \leq 0$;

2) $\frac{f(q_i,q_j;b_i^-,b_j)}{f(q_i,q_j;b_i^+,b_j)}$ is non-decreasing in q_j for $b_i^- < b_i^+$, $i, j=1,2$ and $i\neq j$.

Proof. See supplementary material. □

Condition 1) in Lemma 1, proposed by Luporini (2006), captures the affiliation relationship between the environmental shocks received by two farmers. Introduced by Milgrom and Weber (1982) in auction theory, affiliation in our context it means that when the environmental shock turns out to be favorable for one farmer, we are likely to observe an equally favorable condition for the other. Condition 2) conforms to the commonly used contracting problem setup after Mirrlees (1974). It means that ceteris paribus a higher output q_j signals a lower level of b_i.

Proposition 1: Under conditions specified in Lemma 1, Farm i 's indemnity $I_i(q_i,q_j)$ is a non-increasing function of farm j 's output level q_j.

Proof. The result follows readily from equation (5) and Condition 2) of Lemma 1. □

Proposition 1 shows that when the environmental shocks received by farmers are interrelated, one farmer's indemnity payment is a non-decreasing function of the other farm's disease prevalence rate. When there are more than two farms in the region, we could regard all the other farms as a unit and use the average regional disease prevalence rate as the benchmark.

2.3 First-best Situation

The first-best (FB) situation refers to the case where the biosecurity efforts are fully observable. In this case there is no moral hazard problem, thus NIC conditions defined under the previous SB section is no longer necessary. Now the counterpart for equation (5), which implicitly determines the indemnity scheme, becomes $h'(v_i(q_1,q_2)) = \lambda_i$, $\forall i = 1,2$. When the optimal biosecurity measure $\hat{b}_i$ is taken, the optimal indemnity level can be solved as $I_i^*(q_1,q_2) = h(\hat{b}_i w + \underline{U}) - q_i$. Otherwise the indemnity payment will be arbitrarily small. Therefore in the FB case the indemnity payment to farmer *i* will increase when the disease prevalence rate on farm *i* increases. Perfect risk sharing is guaranteed, which implies that the indemnity payment to one farm is only contingent on its own disease prevalence rate, no disease information from other farms is needed.

Note that under the current government indemnification practice, the consequential losses such as loss from business downtime and loss of consumers and markets is not likely to be compensated (Umber, Miller, and Hueston 2010). As these losses could be substantial (Grannis and Bruch 2006), the perfect risk sharing under the first-best is not realized.

3. An Example

To shed some insights on the structures of indemnity scheme, in this section we provide a numerical example to illustrate indemnity payments under different scenarios.

Suppose there are two possible output levels $q_i^H = 10$ and $q_i^L = 0$. The unit biosecurity investment cost is $w = 1$ and the two biosecurity options available are $b_i^H = 1$ and $b_i^L = 0.3$. Non-participant farmers can obtain a reservation utility $\underline{U} = 1$. A constant relative risk aversion (CRRA) function will be used as the utility function, where $v(a) = ln(a)$ and its inverse function is $h(v) = e^v$. Given the biosecurity action b, let $p(b)$ denote the probability that the output level is q^H and $1 - p(b)$ stand for the probability that output level is q^L. Assume $p(b^H) = 3/4$ and $p(b^L) = 1/2$. Finally, we use variable $\rho \geq 0$ to denote the correlation between the two farmers' output levels.

3.1 Problem Setup

We provide three contract problem setups, which are the contract for individual farmers in the SB case, contract for farmers jointly in the SB case and the contract in the FB case. Note that joint contract will generate the same result as individual contract in FB case due to perfect risk sharing, so individual contract suffices.

(i) Individual Contract in SB Case.

The contract between the government and one single farmer is modeled in the SB case. This model is similar to TOCP specified in (4), except that only one participation constraint and one incentive constraint are required. To render the notations simple, we will use (x_H, x_L) to denote $(v(q^H), v(q^L))$. With $\hat{b} = b^H$ as the optimal biosecurity level, the optimal SC can be written as:

$$\min_{\mathbf{x_H},\mathbf{x_L}} \frac{3}{4}(e^{x_H} - q^H) + \frac{1}{4}(e^{x_L} - q^L) \tag{6}$$

$$\text{s.t.} \quad \begin{aligned} &\frac{3}{4}x_H + \frac{1}{4}x_L - 1 \geq 1 \\ &\frac{3}{4}x_H + \frac{1}{4}x_L - 1 \geq \frac{1}{2}x_H + \frac{1}{2}x_L - 0.3 \end{aligned}$$

(ii) Joint Contract in SB Case.

Here we specify the contract between the government and two farmers. Following Dasgupta and Maskin (1987), we first derive the probabilities of combination $(q^H,q^H),(q^H,q^L),\ (q^L,q^H)$ and (q^L,q^L) as specified in Table 1. Based on the bounds on ρ for different biosecurity inputs specified in Table 2, we specify that ρ takes the values between 0 and 0.5 at 0.1 increments. Detailed derivation for Table 1 and 2 can be found in Supplemental Materials. Here we will only list problem setup at $\rho = 0$. The probabilities of (q_1,q_2) when ρ takes different values can also be calculated from Table 1. To simplify the notation, let:

$$\begin{aligned} &(v_1(q_1^H,q_2^H), v_1(q_1^H,q_2^L), v_1(q_1^L,q_2^H), v_1(q_1^L,q_2^L)) = (x_1,x_2,x_3,x_4) \\ &(v_2(q_1^H,q_2^H), v_2(q_1^H,q_2^L), v_2(q_1^L,q_2^H), v_2(q_1^L,q_2^L)) = (y_1,y_2,y_3,y_4) \end{aligned} \tag{7}$$

Following our general TOCP setup in (6), with $(\hat{b}_1,\hat{b}_2) = (b_1^H, b_2^H)$, the optimal joint contract can be written as:

$$\begin{aligned} \min_{\mathbf{X},\mathbf{Y}} &\frac{9}{16}(e^{x_1} + e^{y_1} - q_1^H - q_2^H) + \frac{1}{16}(e^{x_2} + e^{y_2} - q_1^L - q_2^L) \\ &+ \frac{3}{16}(e^{x_3} + e^{y_3} - q_1^H - q_2^L) + \frac{3}{16}(e^{x_4} + e^{y_4} - q_1^L - q_2^H) \end{aligned} \tag{8}$$

$$\text{s.t.} \quad \begin{aligned} &\frac{9}{16}x_1 + \frac{1}{16}x_2 + \frac{3}{16}x_3 + \frac{3}{16}x_4 - 1 \geq 1 \\ &\frac{9}{16}y_1 + \frac{1}{16}y_2 + \frac{3}{16}y_3 + \frac{3}{16}y_4 - 1 \geq 1 \\ &\frac{9}{16}x_1 + \frac{1}{16}x_2 + \frac{3}{16}x_3 + \frac{3}{16}x_4 - 1 \geq \frac{3}{8}x_1 + \frac{1}{8}x_2 + \frac{1}{8}x_3 + \frac{3}{8}x_4 - 0.3 \\ &\frac{9}{16}y_1 + \frac{1}{16}y_2 + \frac{3}{16}y_3 + \frac{3}{16}y_4 - 1 \geq \frac{3}{8}y_1 + \frac{1}{8}y_2 + \frac{3}{8}y_3 + \frac{1}{8}y_4 - 0.3 \end{aligned}$$

(iii) Contract in FB Case.

The FB contract resembles that in (8), except that there is no NIC, therefore the last two constraints are removed.

3.2 Solution and Discussion

To solve the problem we will use the SAS/IML (SAS 9.2) nonlinear optimization subroutine NLPNRR, which implements a ridge-stabilized Newton-Raphson method and computes Gradient and Hessian using analytic formulas. Values of $v_i(\cdot)$ could be obtained from the program output directly, and the indemnity payments could be derived using our previous definition $I_i(\cdot) = h(v_i(\cdot)) - q_i$. Due to our symmetric problem setup we only list government indemnity payment to farmer 1. Note that the negative solutions could be understood as a tax imposed by government.

Table 3 displays government indemnity payments for different realized disease status under the joint contract. For the individual contract, the expected indemnity payment is fixed at 3.89 in SB case, which is equal to the expected indemnity payment in joint contract when $\rho = 0$. The government is expected to pay less indemnity when correlation increases. For example, when the correlation increases from 0 to 0.5, we can see from Table 3 that the indemnity payment in joint contract decreases from 3.89 to 2.15. This occurs because government can better utilize the information conveyed by the other farmer's output (Hölmstrom 1979). Table 3 also shows that the government pays the lowest indemnity value in FB case.

Figure 1 demonstrates farmer 1's utilities at different realizations of disease status. We can see that under the joint contract, farm 1’s utility is a non-decreasing function of its own output (Gramig, Horan and Wolf, 2009) and a non-increasing function of farm 2’s output (Proposition 1). Moreover, only at the point where $\rho = 0$, farm 1’s optimal indemnity payment does not depend on that of farm 2's disease status. In this case the individual contract design is still optimal, as shown in Mookherjee (1984). When correlation between the two farm’s disease statues increases, the disease prevalence rate of farm 2 plays an increasing role in farm 1’s indemnity payment. On the contrary, farm 2's disease status plays a minor role in farm 1's indemnity payment if the correlation in disease shocks is small.

In this example if probability of high output contingent on the optimal biosecurity measure increases, then we say the optimal biosecurity measure is more effective. Next we adjust the effectiveness for optimal biosecurity measure by increasing $p(b^H)$ from 0.6 to 0.9 at increments of 0.05. Without loss of generality, assume $\rho = 0.3$.

Farm utility levels under different biosecurity effectiveness are depicted in Figure 2. It shows that farmers need a larger incentive, or larger utility variability, to adopt less effective biosecurity measures. As a result greater indemnity payment will be incurred. From Table 4 we also observe that $I_1(q_1, q^L) - I_1(q_1, q^H)$ decreases when the optimal biosecurity measure becomes more effective. It indicates that a RPE indemnity scheme will be more justified when effectiveness of biosecurity measure is lower. This is because farmer's performance will be more dependent on the common environmental factors rather than his own biosecurity investment.

Therefore both increased correlation between farms’ disease statues and decreased effectiveness of optimal biosecurity measure suggest an increased information value of the other farms' disease status. It suggests that for those highly contagious diseases where disease statues are highly correlated and the biosecurity measure not very effective, joint contract design is indispensable.

4. Conclusion

This article has studied the optimal design of a government indemnity program taking both moral hazard and common uncertainty into account. Our results suggest that RPE indemnity scheme is most justified under the following two scenarios. One is the case where the disease prevalence rates among farms are highly correlated, the other being that the optimal biosecurity investment is relatively ineffective in curtailing the disease. The design of indemnity payment in reality should take many other factors into account as well. Such factors may include nature of disease (endemic, exotic or novel), farmer's risk category, biosecurity effectiveness and auditing cost, etc.

Our payment scheme could shed insights on potential livestock insurance designs. As noted by Green, Driscoll, and Bruch (2006), the adequacy of data is essential in determining the optimal indemnity payment. Our conceptual model suggests that development in data collection could be made in areas regarding disease prevalence correlation and biosecurity effectiveness in disease prevention. Experiences from other industries such as the Area Risk Protection Insurance by FCIC (2013) could also be useful when designing and implementing the optimal indemnity scheme in practice.

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Table 1. Joint Probability Distribution Computation Formula

	q^H	q^L
q^H	α	$p(b_1)-\alpha$
q^L	$p(b_2)-\alpha$	$1-p(b_2)-p(b_1)+\alpha$

Note: $\alpha = p(b_1)p(b_2)+\rho\sqrt{p(b_1)(1-p(b_1))}\sqrt{p(b_2)(1-p(b_2))}$.

Table 2. Bounds on ρ

	b^H	b^L
b^H	$[-1/3,1]$	$\left[-\sqrt{1/3},\sqrt{1/3}\right]$
b^L	$\left[-\sqrt{1/3},\sqrt{1/3}\right]$	$[-1,1]$

Table 3. Joint Contract Indemnity Payments Varying with Correlations

Correlation	$I_1(q^H,q^H)$	$I_1(q^H,q^L)$	$I_1(q^L,q^H)$	$I_1(q^L,q^L)$	Mean
0	4.88	4.88	0.9	0.9	3.89
0.1	4.3	4.98	0.55	3.36	3.71
0.2	3.49	4.81	0.43	4.99	3.38
0.3	2.65	4.54	0.36	6.03	3
0.4	1.77	4.16	0.3	6.94	2.59
0.5	1	3.84	0.26	7.15	2.15
FB	-2.61	-2.61	7.39	7.39	-0.11

Table 4: Joint Contract Indemnity Payments Varying with Biosecurity Effectiveness

$p(b^H)$	$I_1(q^H,q^H)$	$I_1(q^H,q^L)$	$I_1(q^L,q^H)$	$I_1(q^L,q^L)$	Mean
0.6	48.47	61.93	0	20.49	36.1
0.65	15.27	20.37	0.03	9.66	12.58
0.7	6.46	9.34	0.15	6.97	6.03
0.75	2.65	4.54	0.36	6.03	3
0.8	0.58	1.89	0.62	5.74	1.18
0.85	-0.7	0.22	0.89	5.76	-0.09
0.9	-1.56	-0.93	1.17	5.98	-1.07

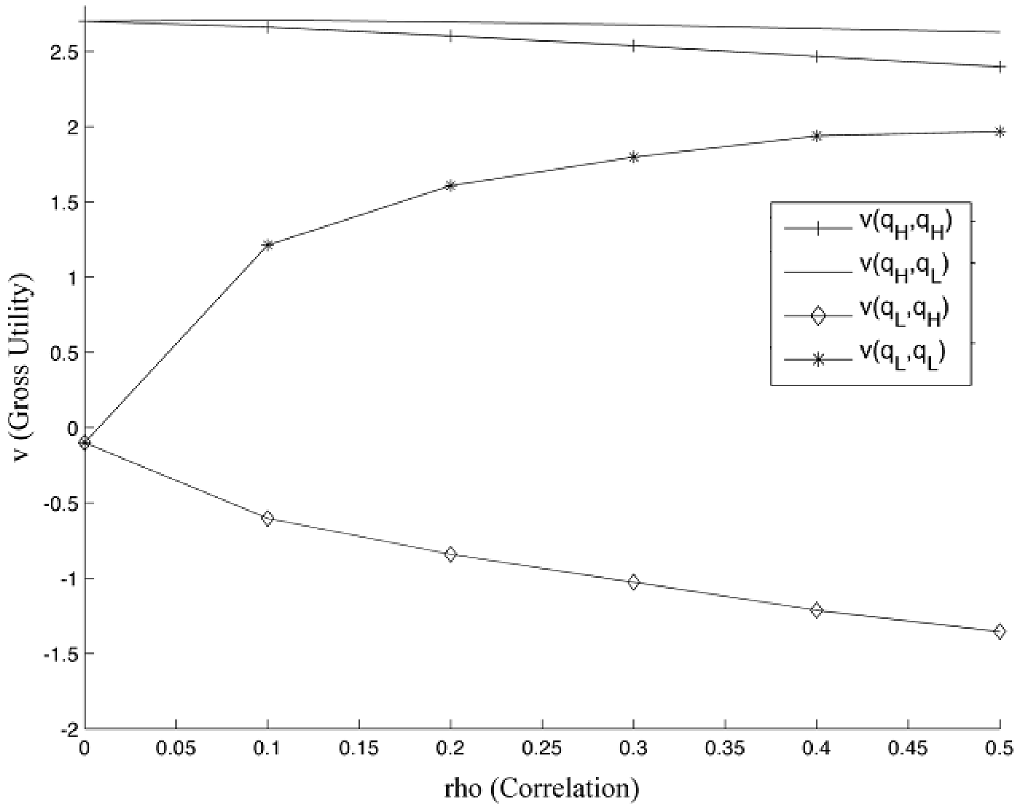

Figure 1. Utility Variability under Different Correlation Levels

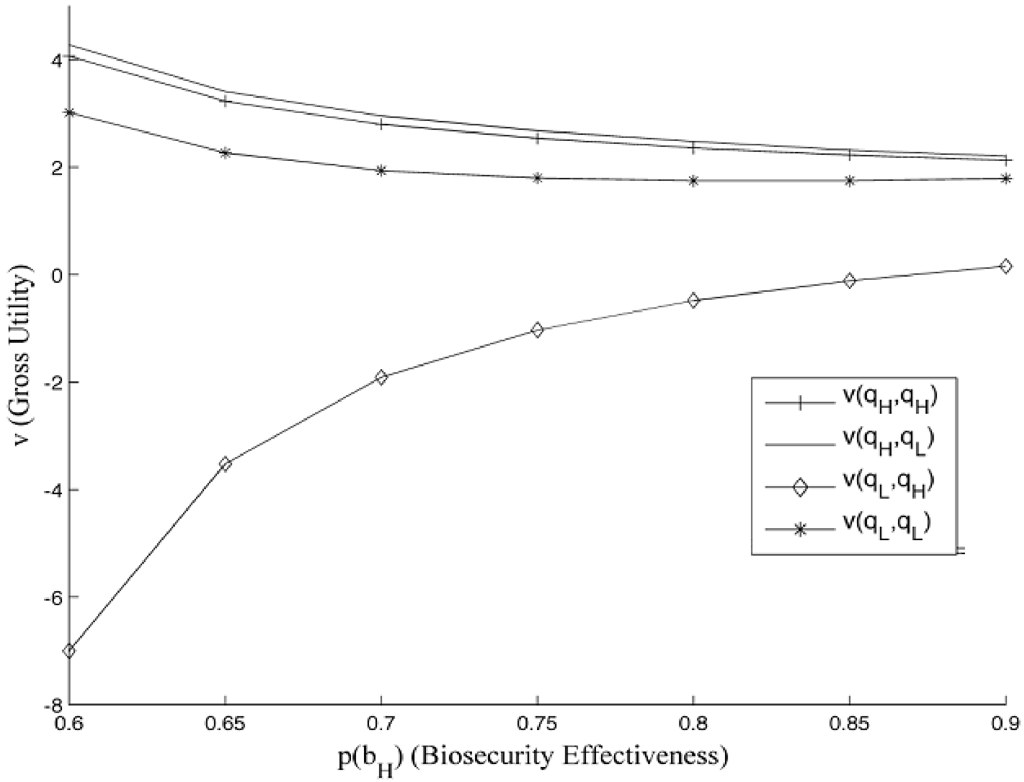

Figure 2. Utility Variability under Different Biosecurity Effectiveness Levels