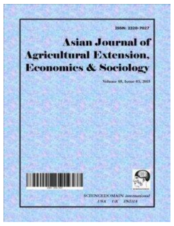

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# Computational Economic Analysis of Duck Production at the Farm Household Level in the Context of Highly Pathogenic Avian Influenza Subtype H5N1 in the Red River Delta, Vietnam

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***Authors' contributions***

*Both the authors contributed to this study are as follows: Author CCT designed, carried out the analysis, interpreted the results and wrote this manuscript. Author JFY supervised the work and contributed to the design and revision of the article. Both the authors read and approved the final manuscript.*

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## ABSTRACT

Smallholder duck producers are considered to be more susceptible to contracting the HPAI H5N1 infection. Occurrence of the Highly Pathogenic Avian Influenza subtype H5N1 (HPAI H5N1) usually results in the complete loss of the producer's entire flock due to high mortality rate and stamping out conducted to contain the virus. The extent of the economic loss from culling of the flock (stamping out) depends on the time of the disease occurrence during the production cycle.
This study aims to explore the expected economic impacts of HPAI H5N1 on smallholder duck producers in the Red River Delta of Vietnam. A conceptual model is developed to describe how a producer responds at each week of duck production to maximize profit and evaluate expected

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profits/losses of the producer in light of HPAI H5N1.
The results suggest that in the case of no disease occurrence, the optimal time to sell ducks is at week 10 of the production cycle when ducks reach the age of 8 weeks. Maximum profit gained is US$ 805.10 for a producer with an average flock size of 794 ducks. However, the producer would suffer serious losses once the disease occurs. The expected investment loss is far higher than the maximum profit received at each production cycle and is estimated to be 3 times higher (US$ 2665.19 expected loss vs. US$ 805.10 maximum profit). The sensitivity analysis results also show that with 95% confidence, the producer gains profit ranging from US$ 803.95 to US$ 821.25 in case of no HPAI H5N1 disease, but suffers expected losses ranging from US$ 2659.23 to US$ 2670.60 in case of the disease occurrence. This severe loss can have long term consequences and producers may face severe difficulties to recover without financial assistance.

*Keywords: HPAI H5N1; outbreaks; conceptual model; duck producer; revenue function; cost function.*

## 1. INTRODUCTION

The first outbreaks of HPAI H5N1 in Vietnam were reported in the late 2003, since then, there have been five epidemic waves and sporadic outbreaks recorded over the years. The disease was mainly confirmed in unvaccinated ducks [1,2]. The presence of the HPAI H5N1 virus has been found mostly in live ducks and geese, and it was suggested that the free range duck farming system was most vulnerable and/or susceptible to HPAI H5N1 [3]. If several flocks of ducks enter the rice-field at once, this may create favorable conditions for the disease to spread. The free range system is considered to be a typical Asian production method which has the potential of contracting and spreading the HPAI H5N1 virus to other neighboring farms [4,5]. Poultry sectors 3 and 4 (as classified by [5]) include smallholder or backyard producers which are characterized by the free range production system. While producing 80 percent of the poultry products in Vietnam, these producers are considered to be more susceptible to contracting the HPAI H5N1 infection [6].

Economic losses to Vietnam's poultry sector caused by HPAI H5N1 were serious and estimated to be about 3000 billion VND (US$ 187.15 million at an exchange rate of 16,030 VND per US dollar as of 12/31/2007 by the State Bank of Vietnam)[1] [7,8]. However, it is not clear how the disease affects duck producers at the farm level. Although the disease has been repeatedly reported over the years across the country, the frequency of occurrence at any given location is low, based on the spatial distribution data provided by the Department of Animal Health of Vietnam. Farmers are often not aware how dangerous the disease is because outbreaks may be occurring in other locations and thus fail to take precautions during the production cycle.

Occurrence of the disease usually results in the complete loss of the producer's entire flock due to high mortality rate and compulsory stamping out by culling birds from contaminated farms to contain the virus [9]. The extent of the economic loss from culling of the flock (stamping out) depends on the time of the disease occurrence during the production cycle. If the disease occurs early during the production cycle, the loss will be lower since investment in production is lower at this point. If the disease occurs at the end of the production cycle when the ducks are nearly ready for sale, the producer will suffer serious economic losses.

If there is no HPAI H5N1 occurrence, then the producer continues production as usual. Profit earned depends on the producer's decisions – continue production, sell in the market or cull flock because of disease – at each period of production. The objective is to maximize profit. In any case, the decision to cull is always not desired since it results in complete loss of production. In most cases, the decision to sell yields profit. However, the farmer should determine the optimal time to sell the ducks in order to maximize profit. The situation is made more complex given the probability of HPAI H5N1 occurrence or detection. It is also unclear what the magnitude of economic impacts from HPAI H5N1 occurrence will be on duck producers.

The overall objective of this study is to quantify the expected economic impacts of HPAI H5N1 on smallholder duck producers in the Red River Delta of Vietnam. More specifically, the study (i)

[1]*Exchange rate at 1USD = 16,030 VND as of 12/31/2007 by the State Bank of Vietnam*

develops a conceptual model using a dynamic optimization process by constructing the Bellman equation to optimize the producer's decision of profit maximization; (ii) uses the conceptual model's results to evaluate expected profits/losses of the producer in light of HPAI H5N1 and (iii) conducts sensitivity analysis to determine changes of expected profits/losses under given changes in the model's parameters.

## 2. METHODOLOGY

### 2.1 Conceptual Model

Consider a smallholder producer who raises ducks for meat and assume that the producer's income is derived solely from the sale of the ducks. In other word, the producer focuses all resources for the production of ducks. The producer has a free range duck farming system which is considered at risk of contracting HPAI H5N1. Given this farming system, the disease may occur at any point during the production cycle. To study its economic consequences, a dynamic economic model was developed based on production characteristics. Following the optimality principle in dynamic programming developed by Richard E. Bellman [10], the model was expressed as the Bellman equation, which addressed the fundamental problem regarding the need to optimally balance present rewards versus expected future rewards [11]. The framework for the Bellman equation for duck production is shown in Fig. 1.

The objective function of the Bellman equation is to maximize profit from duck production. The equation involves several components, including state variables, action space, state transition and reward function, to be dynamically observed over time. To develop the dynamic model, several assumptions are made: (i) all ducks are either bought, sold or culled simultaneously; (ii) there is no own-consumption of ducks produced on the farm; (iii) production activities and market prices for adult ducks are stable; (iv) no ducks are either sick or have died from other diseases (other than HPAI H5N1); all ducks must be culled when the disease occurs; (vi) ducklings are purchased at the first day of age and raised up to 12 weeks old at which point the flock starts to experience significant reductions in their rate of growth; (vii) vaccination for the prevention of HPAI H5N1 is not available; and (viii) the first two week of a production cycle is a cleaning period to remove viruses and contaminated materials within the farm before the new flock of ducklings arrive.

This is an infinite horizon $T = \infty$ with time t measured in weeks. State variables are the week of the production cycle and the detection of HPAI H5N1. The week of the production cycle is denoted by a, ranging from 1 to 14 or $\mathrm{a} \in \{1,2,...,14\}$, where $\mathrm{a} = \{1, 2\}$ represents the cleaning period, implying that there are no ducks on the farm in this period. Ducklings enter the farm from week 3. The maximum length of a production cycle is 14 weeks at which the maximum age of the duck is 12 weeks old. The detection of HPAI H5N1 is represented by $\mathrm{d} \in \{0,1\}$, where $\mathrm{d} = 1$ implies that the disease is detected and d = 0 if the disease is not present or undetected. State variables are given as:

$$\begin{cases} \mathrm{a} \in \{1,2,..,14\} & \text{Week of production} \\ \mathrm{d} \in \{0,1\} & \text{Detection of HPAI H5N1} \end{cases} \tag{1}$$

At the beginning of each week, the producer observes the farm situation and disease status to decide whether to continue to feed, sell, or cull the flock of ducks. These decisions are components of an action space.

Let x = {CO, SE, CU} denote the producer's actions where CO, SE and CU respectively represent actions "continue", "sell", and "cull". The action space can be introduced by an equation system:

$$\mathrm{x} = \begin{cases} \{\mathrm{CO}\} & \text{if } \mathrm{a} \le 2 \,\&\, \forall \mathrm{d} \\ \{\mathrm{CU}\} & \text{if } 2 < a < 14 \,\&\, \mathrm{d} = 1 \\ \{\mathrm{CO}, \mathrm{SE}, \mathrm{CU}\} & \text{if } 2 < a < 14 \,\&\, \mathrm{d} = 0 \\ \{\mathrm{SE}\} & \text{if } a = 14 \,\&\, \mathrm{d} = 0 \\ \{\mathrm{CU}\} & \text{if } \mathrm{a} = 14 \,\&\, \mathrm{d} = 1 \end{cases} \tag{2}$$

The system equation (2) indicates that a new production cycle starts with a 2 week cleaning period before a new flock of duckling arrives. When the length of the production cycle is less than or equal to 2 weeks, the producer has only the option to continue. From weeks 3 to 14, two cases are possible: (i) if HPAI H5N1 occurs, which means state d = 1, the producer has to cull all the ducks in the flock, a mandatory requirement to prevent the spread of the disease;

(ii) if there is no disease, d= 0, then all options – continue, sell, cull – are available. At the week a = 14, the producer has to sell if there is no disease occurrence, but if the HPAI H5N1 virus is detected within the farm, the producer must cull all ducks immediately. Subsequently, another production cycle begins starting with the cleaning period, after all ducks are sold or culled.

The evolution of state variables over time with respect to the producer's actions is represented via a state transition. The change in the week of the production cycle is characterized by deterministic systems based on the actions in equation (3).

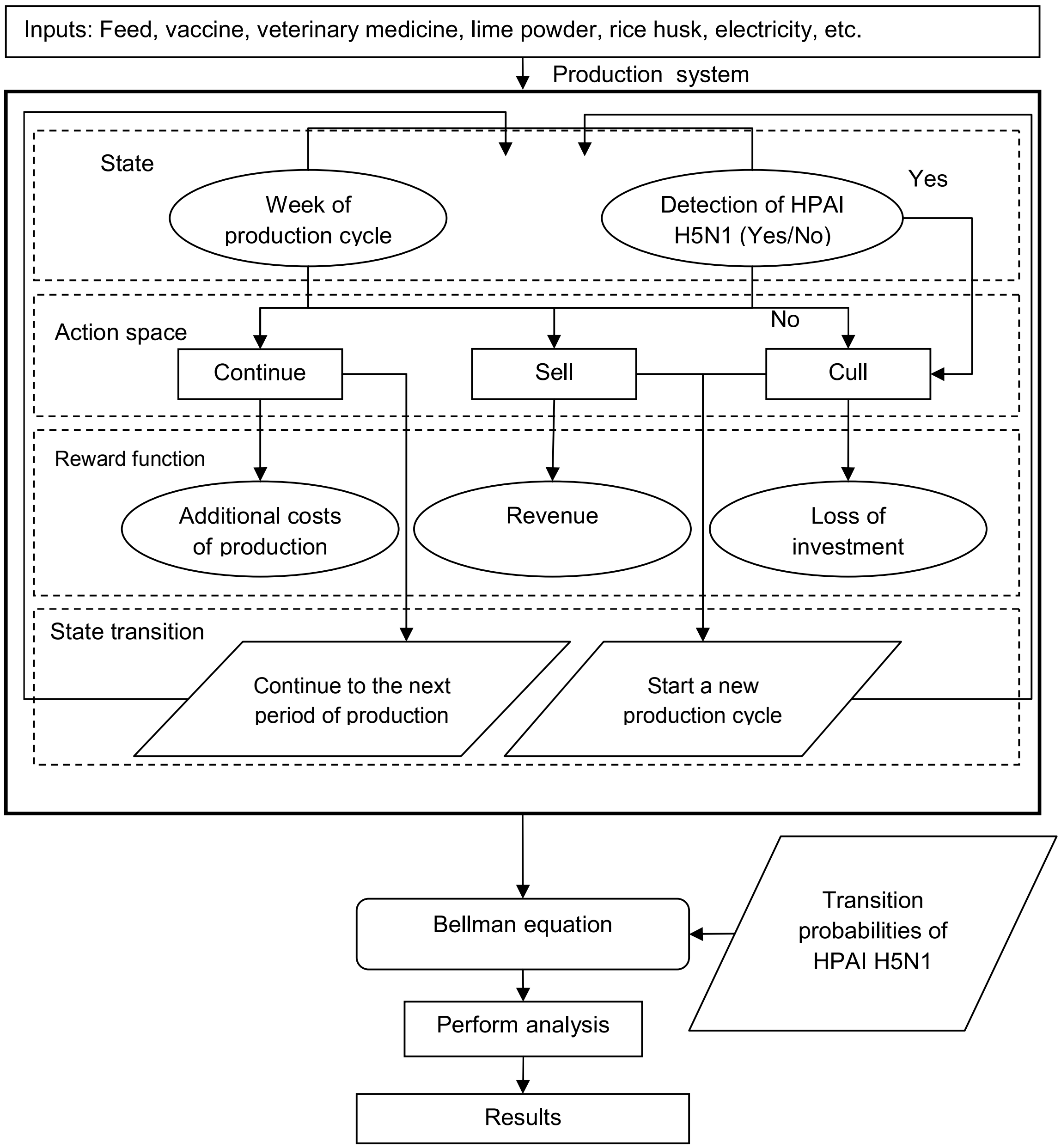


**Fig. 1. A framework for the conceptual model**

$$a_{t+1} = \begin{cases} 1 & \text{if } x_t = \{SE, CU\} \\ a_t + 1 & \text{if } x_t = CO \end{cases} \quad (3)$$

where $a_{t+1}$ is the week of the production cycle at time t+1. Equation (3) indicates that if the producer elects to sell or cull all ducks at time t, a new production cycle is started, meaning that the week of production is $a_{t+1} = 1$. If the producer chooses to continue to feed ducks, then at the next period, the week of production is $a_{t+1} = a_t + 1$

The probability of HPAI H5N1 contamination is assumed to follow a Markov process and can be represented by transition probabilities:

$$P(d'|\, d, x) = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} \quad (4)$$

where $p_{11} + p_{12} = 1$ and $p_{21} + p_{22} = 1$. Following each action – continue, sell, or cull – in the action space, the producer receives a reward, represented via a Reward function. The producer's objective is to maximize the expected production profits over the infinite time horizon. The per-period reward function is specified below:

$$f(a) = \begin{cases} -C(a) & \text{if } x = CO \\ R(a) - C(a) - F & \text{if } x = SE \\ -C(a) - F & \text{if } x = CU \end{cases} \quad (5)$$

where $C(a)$ is a cost function of production at week a. The cost of production varies depending on the specific period of production and often includes feed costs, duckling price, veterinary costs, and other costs. The producer's benefit is the net farm income. The term $R(a)$ represents a revenue function at week a. This function characterizes the relationship between the market value of ducks and their weight. The term F represents a fixed cost associated with the cleaning period, such as the cost of lime powder and other sterile powders.

The immediate reward depends on the producer's action. The reward equation above states that if the producer chooses to keep raising ducks, the immediate benefit is the negative costs because of the feed costs, $f(a) = -C(a)$. By selling ducks, the immediate reward is equal to the revenue function minus the cost function, $f(a) = R(a) - C(a) - F$. Culling ducks due to HPAI H5N1 would result in the sum of the negative cost function $C(a)$ plus a negative fixed cost F, $f(a) = -C(a) - F$.

From equations (4) and (5), a Bellman equation for the dynamic optimal decision making process is formulated:

$$V(a) = \text{Max } \{f(a) + \delta \sum p(d'|\, d) V(a')\} \quad (6)$$

where $V(a)$ is the value function that represents the sum of current reward and $V(a')$ is the expected future rewards, given the transition probability $p(d'|\, d)$ and the discount factor $\delta$. The formulation of the discount factor is given:

$$\delta = 1/(1+r)^t \quad (7)$$

where r is the discount rate and t is the compounded period. Each decision directly affects future benefits. Intuitively, if the producer chooses to keep ducks, it means that he/she believes that future rewards are greater than rewards from immediate sales. A "sell" action benefits the producer as they earn income from this activity. A "cull" action is always the worst option as it causes serious losses for the producer. Consequently, the occurrence of HPAI H5N1 would cause complete loss of the investment as the producer must exterminate the entire flock. The Bellman equation derives an optimal expected profit following optimal action in regard to HPAI H5N1.

## 2.2 Statistical Analysis

The conceptual model consists of several parameters, including (i) discount factor used to translate expected benefits or costs in any given future time period into present value terms; (ii) probabilities of HPAI H5N1; (iii) fixed costs of exterminating infected ducks and cleaning after sale; and (iv) cost and revenue functions of duck production.

The cost and revenue functions are important components of the producer's rewards. They are estimated with a quadratic functional form. This functional form accurately captures the underlying relationships between revenue/cost and their explanatory variables and has been widely used in several studies such as the relationship between revenue and price of the commodity, water used in production of the commodity and composite input factor as shown in the research [12–15]. Let C and R respectively represent the cost and revenue functions. The quadratic functional forms are given in the equations 8 and 9:

$$C = \alpha_0 + \alpha_1 * a + \alpha_2 * a^2 + \varepsilon \quad (8)$$

$$R = \beta_1 * a + \beta_2 * a^2 + \gamma \quad (9)$$

where $a$ and $a^2$ are explanatory variables representing the week of production and its square; and $\varepsilon$ and $\gamma$ are normally distributed error terms reflecting the determinants of the outcome. In the cost function (equation 8), $\alpha_0, \alpha_1 \text{ and } \alpha_2$ are unknown parameters to be estimated, where $\alpha_0$ is a constant denoting fixed costs, $\alpha_1$ indicates the change in variable costs over time (week of production) and $\alpha_2$ denotes increasing or diminishing costs over time.

Assuming that the producer only receives revenue from selling ducks. This implies that the producer's revenue R = 0 if there is no duck sale. As a result, the constant is taken out from the revenue function (equation 9). The estimation of the function provides the values of the parameters $\beta_1 \text{ and } \beta_2$, where $\beta_1$ presents the change in revenue over time (week of production) and $\beta_2$ denotes increasing or diminishing revenue over time.

In estimating of the econometric model, there may exist problems that lead to unreliable results. Heteroskedasticity which implies that the error terms in the model are no longer independently and identically distributed is one of the major problems. Heteroskedasticity results in incorrect test statistics such as t and F tests and confidence intervals. Therefore, it is critical to test for heteroskedasticity problem by performing the Breusch-Pagan and White tests. These tests are commonly used for detecting heteroskedasticity [16,17].

If there is no heteroskedasticity problem, then OLS is the best method for the estimation of the cost and revenue functions. If heteroskedasticity exists, a Weighted Least Squares (WLS) method is used to correct for the problem of heteroskedasticity by transforming the error term. In the case of heteroskedasticity, the use of weights implies that observations are expected to have error terms such that higher variances are given a smaller weight in the estimation process. Feasible Generalized Least Squares (FGLS) is a technique that yields BLUE estimators when heteroskedasticity exists by minimizing a weighted sum of squared residuals [16].

### 2.3 Data

This study focuses on smallholder duck producers in the Red River Delta, Vietnam. A two round survey procedure was designed. The baseline survey in the first round was followed by a follow-up survey in the second round. The baseline survey collected basic information about producer household characteristics and economic activities. The follow-up survey focused on duck production. The sample size is determined based on the formula for estimating a population proportion $\pi$ by the sample proportion:

$$n = \pi(1-\pi)\left(\frac{z}{M}\right)^2 \quad (10)$$

where n is the sample size that has margin of error M and z is z-score. In calculation of the sample size, a 95% confidence level which has z = 1.96 is desired. The population proportion π is set at 0.5 as a safe approach and the desired margin of error is 0.1. Then, the sample size is:

$$n = \pi(1-\pi)\left(\frac{z}{M}\right)^2 = (0.5)(1-0.5)\left(\frac{1.96}{0.1}\right)^2 = 96$$

Prior to the survey, a pilot investigation was conducted with the support of the local office of agricultural extension to better understand the duck production system in the area and to contact duck producers for the survey. A total of 98 duck producers in two provinces, Hai Duong and Bac Ninh, were invited to participate in the study. Data were collected on a weekly basis for the entire production cycle, from the beginning of a new production cycle until sale. All production information, including costs of production and growth rate of ducks, was gathered on a weekly basis to estimate cost and revenue functions. Data were collected from August 2012 to February 2013. The survey results indicated that the average duck flock size and average duck weight for sale are respectively 794 heads and 2.49kg. Average market price for a kilogram of duck meat was US$ 1.94. Details on the descriptive statistics of duck production are shown in Table 1.

Other parameters used in the conceptual model include:

(i) A discount rate of 9% per year or 0.173% per week as of December 31, 2012 for Vietnam was obtained from the World Fact Book 2012 by the Central Intelligence Agency [18]. The weekly discount factor is computed as: $\delta = \dfrac{1}{1+0.00173} = 0.9982$;
(ii) An average annual probability of 0.0102 for HPAI H5N1 occurrence was estimated by [19];
(iii) Average fixed costs for exterminating infected ducks and duck farm cleaning after sale was calculated as US$22.41 per farm from the data collected.

## 3. RESULTS AND DISCUSSION

### 3.1 Econometric Estimations

The Breusch-Pagan and White tests were performed under hypothesis of homoskedasticity against unrestricted heteroskedasticity. The results shown in the Table 2 strongly indicate the existence of heteroskedasticity in both the cost and revenue functions.

To correct for heteroskedasticity, Feasible Generalized Least Squares (FGLS) was applied. Table 3 reports the results of the FGLS estimation applied to the quadratic functional forms of the revenue and cost functions.

The terms a and $a^2$ respectively represent the week of duck production and its square. The results reveal that all parameters for both the quadratic cost and revenue functions have statistically significant effects on costs and revenues for duck production. The functional forms are summarized in equations below.

$$C = 327.37 - 45.15{*}a + 11.67{*}a^2 \qquad (11)$$

$$R = 110.45{*}a + 49.84{*}a^2 \qquad (12)$$

where C denotes the cost function and R is the revenue function. These functions together with the discount factor, probabilities of HPAI H5N1occurrence and fixed costs of cleaning were used in the conceptual model. A dynamic optimization process was then employed to define the producer's optimal decision at each period of production. Results from this process were then used to calculate expected losses under the context of risk from contracting the HPAI H5N1 disease.

**Table 1. Descriptive statistics of duck production**

| Variable | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| Flock size per farm (head) | 794 | 495 | 50 | 2500 |
| Average market price ($US/kg) | 1.94 | 0.14 | 1.67 | 2.15 |
| Average weight per duck sold (kg) | 2.49 | 0.37 | 2 | 3.7 |
| Total costs of production per farm ($US) | 2870.95 | 1734.49 | 294.56 | 7255.00 |
| Revenue per farm ($US) | 3592.79 | 2345.21 | 235.86 | 9883.03 |
| Profit per farm ($US) | 721.84 | 760.29 | -2238.13 | 2629.41 |

**Table 2. Breusch-Pagan and white tests for heteroskedasticity**

| Functional forms | Breusch-Pagan | White |
|---|---|---|
| Quadratic cost function | Chi-square = 142.42<br>Probability > chi-square = 0.00 | Chi-square = 179.53<br>Probability > chi-square = 0.00 |
| Quadratic revenue function | Chi-square = 617.92<br>Probability > chi-square = 0.00 | Chi-square = 348.95<br>Probability > chi-square = 0.00 |

**Table 3. FGLS estimation results**

| Functions | | Coefficient | 95% Confidence Interval | |
|---|---|---|---|---|
| Cost function | Intercept | 327.37***<br>(46.66) | 235.75 | 418.98 |
| | a | -45.15**<br>(21.18) | -86.74 | -3.57 |
| | $a^2$ | 11.67***<br>(2.27) | 6.21 | 15.14 |
| Revenue function | a | 110.45**<br>(37.28) | 37.16 | 183.72 |
| | $a^2$ | 49.84***<br>(7.23) | 35.63 | 64.05 |

***Significant at the 0.01 level; and *** significant at the 0.001 level, two-tailed test*

## 3.2 Simulation Results

The computational analysis using dynamic optimization suggests that the optimal duration for a production cycle is 10 weeks, including the cleaning period in the first 2 weeks and 8 weeks for raising ducks in the case of disease free status. Fig. 2 presents the optimal action at each period of the production cycle. The "cull" decision is not applied in any period of production except when the disease occurs since this is a mandatory requirement to eradicate and prevent the spread of the HPAI H5N1 virus. In case of no disease occurrence (d=0), it is suggested that the optimal action is to continue production from week 1 to 9 and sell all flocks of ducks in week 10 when they reach the age of 8 weeks.

The profit level estimated for a producer with an average of 794 ducks (Table 1) at each week of production is presented in Fig. 3. Negative profit is found for the first 3 weeks of production. This cost largely represents the producer's initial investment. It includes the costs of lime powder and disinfectants to disinfect duck production premises for cleaning period during the first 2 weeks and the purchase of ducklings at week 3. Positive profit is gained beginning from week 4 and continues increasing until it reaches the maximum at the optimal time for sale at week 10. The producer receives a maximum profit of US$ 805.10 (Fig. 3). Profit gradually decreases if the producer sells ducks after the 10th week since the growth rate of costs (primarily additional feed costs) exceeds the growth of revenues and become negative after week 13.

The producer can earn profit only if there is no HPAI H5N1 occurrence. However, it is possible that the disease may occur at any time during production, given the existence of the HPAI H5N1 virus. Once it happens, the producer suffers complete loss of production since all ducks are culled in order to eradicate the disease. Hence, the loss in this situation is measured by the costs of production. The severity of the loss depends on the time of disease occurrence. If the disease occurs in the early state of production, for example week 3 when ducklings enter the farm, the loss is measured at US$ 874.59 (Table 4). The major loss comes from the purchase of ducklings for this period (week 3). At this time, feed cost together with other costs such as electricity and rice husk is only a small part of the total cost.

If the disease occurs in weeks 4 or 5 of production, the losses imposed on the producer are estimated at US$ 1208.08 and US$ 1601.45, respectively. Vaccination against common diseases in ducks is scheduled during this period. The common diseases in ducks are duck virus hepatitis, duck plague or duck virus enteritis, riemerella anatipestifer infection, avian cholera, colibacillosis and aspergillosis. The costs of vaccines and labor for vaccination constitute a major proportion of total cost. During the first 3 weeks of age, ducks are mainly kept in a closed house and fed with industrial feed because they are weak and vulnerable in the outside environment.

Starting from week 6 of production, when ducks reach the age of 4 weeks, they have access to neighboring rice fields, ditches, rivers or channels during the day time. Although the free grazing duck system is still being used, duck producers tend to shift their production to a closed house system with access to limited areas such as ponds or lakes within the farm. Integrating duck-fish production is becoming a common system in Hai Duong and Bac Ninh provinces where the survey was conducted. This production system is also found in Ha Tay, Ha

Nam, Nam Dinh and Hung Yen provinces [20]. A typical duck farm is often located in areas near rivers or channels and close to rice fields. This type of farming primarily uses industrial or semi-industrial feed derived principally from unhusked rice and corn. Rice paddy fields contribute only a small portion of duck feed, based on the survey data. Later in the production process, feed cost becomes the largest cost component. The extent of economic loss from disease occurrence increases substantially later in the production period due to increasing costs such as feed.

Table 4 indicates that the estimated loss increases substantially from US$ 2078.04 in week 6 to US$ 2661.19, US$ 3374.4 and US$ 4240.53 in week 7, 8 and 9, respectively, if the disease occurs during these periods. The most serious loss is measured at week 10 of production when ducks are optimally ready for sale in the market to gain maximum profit. The loss is the estimated at US$ 5283.40. This includes all investment costs for the entire production cycle.

Assuming that the producer behaves optimally i.e., using 10 weeks for production, including the first 2 weeks for cleaning the farm, the actual time for a typical flock of ducks to be on the farm is 8 weeks. Therefore, the probability of disease occurrence at any time is 0.125. Let E(x) represent the expected loss of the duck producer per cycle. The formulation of the expected loss is given: $E(x) = \sum x * P(x)$, where x represents the total loss at any week of the production cycle if the disease occurs during that week and p(x) is the probability of each possible loss value. The expected loss of production is then estimated at $US 2665.19 when the disease occurs (see Table 4).

### 3.3. Sensitivity Analysis

Sensitivity analysis is applied to analyze how estimated profit (in case of disease free status) and expected loss (in case of HPAI H5N1) vary by changing parameters employed in the dynamic model. Parameters tested are the coefficient values given at the 95% confidence interval of the revenue and cost functions that were estimated using econometric analysis shown in Table 3. The range of the parameters is shown in the Table 5.

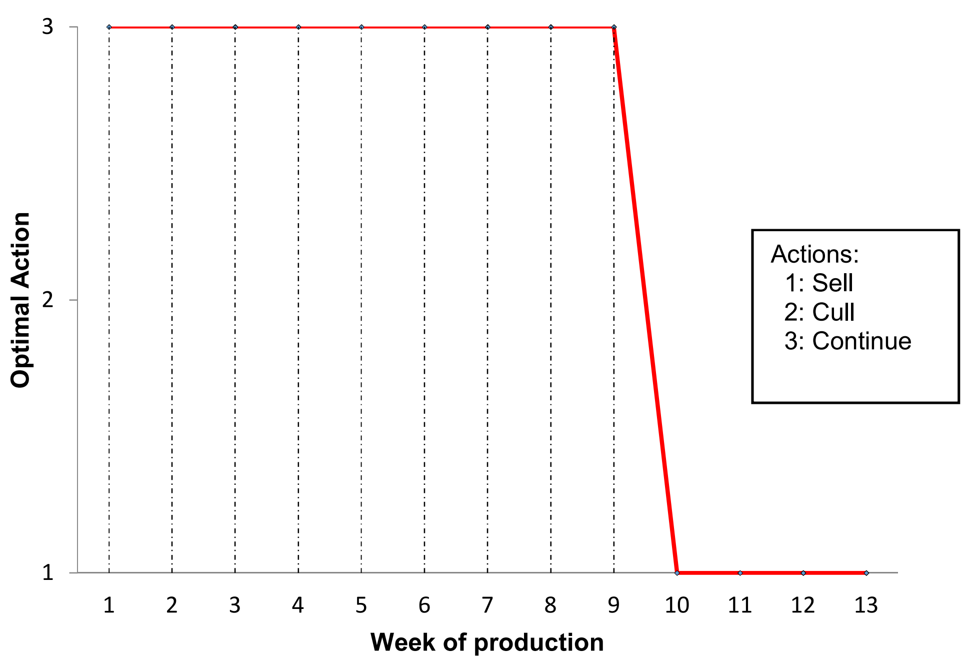


**Fig. 2. Optimal action at each period of the production cycle**

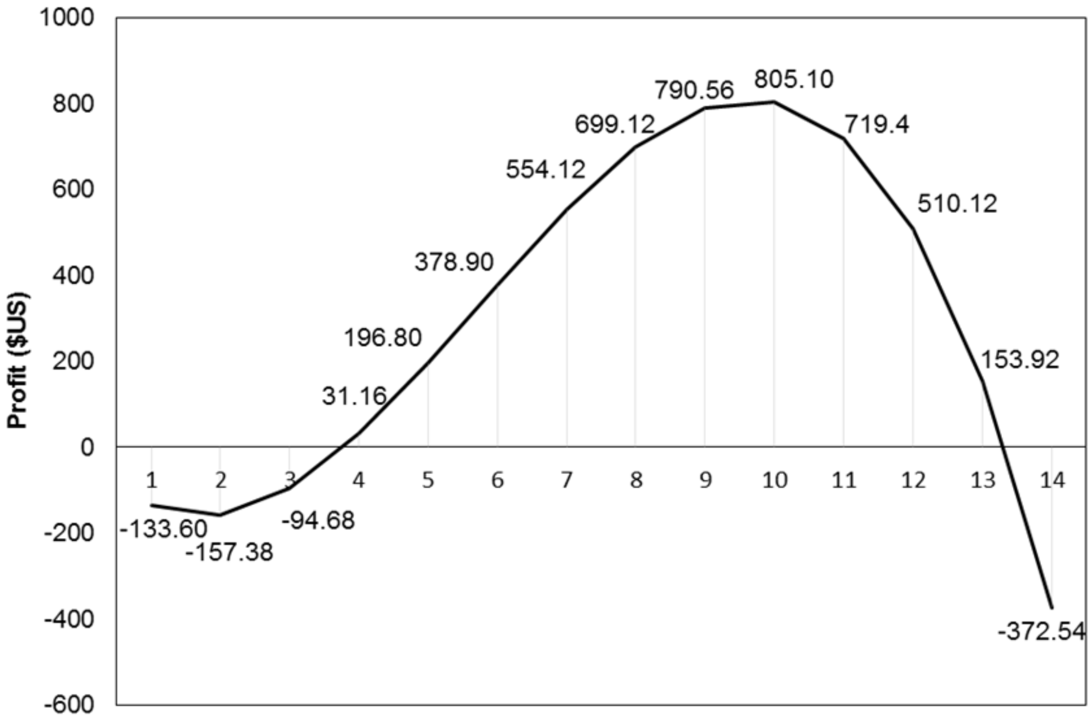


**Fig. 3. Estimated profit obtained at each week of the production cycle**

**Table 4. Expected loss of production in case of disease occurrence at each period**

| Week | Loss ($US) | Probability | Expected loss (US$ |
|---|---|---|---|
| 3 | 874.59 | 0.125 | 109.32 |
| 4 | 1208.08 | 0.125 | 151.01 |
| 5 | 1601.45 | 0.125 | 200.18 |
| 6 | 2078.04 | 0.125 | 259.76 |
| 7 | 2661.19 | 0.125 | 332.65 |
| 8 | 3374.24 | 0.125 | 421.78 |
| 9 | 4240.53 | 0.125 | 530.07 |
| 10 | 5283.40 | 0.125 | 660.43 |
| Expected loss per production cycle | | | 2665.19 |

**Table 5. Parameters of the revenue and the cost functions at the 95% confidence intervals**

| Parameters | Revenue function | Cost function |
|---|---|---|
| a | [37.16, 183.72] | [-86.74, -3.57] |
| $a^2$ | [35.63, 64.05] | [6.21, 15.14] |
| Constant | | [235.75, 418.98] |

Ten uniformly distributed values of parameters were chosen from each parameter ranges. It resulted in five sets of parameters with ten uniformly distributed values. All possible combinations of parameters were generated from these sets of parameters which produced 100,000 possible combinations and estimated using the same computational procedure as applied in the previous sections. Table 6 represents the results of the comparative static analysis. It shows that the producer expects to gain with 95% confidence between US$ 803.95 to US$ 821.25 per production cycle in the case of being HPAI H5N1 disease free. In the case of disease occurrence, however, the producer suffers expected losses ranging US$ 2659.23 to US$ 2670.60 per production cycle.

**Table 6. Results of the comparative static analysis (unit = $US)**

| Variable | Mean | Std. Dev. | Min | Max | 95% Conf. Interval | |
|---|---|---|---|---|---|---|
| Estimated profit in case of disease free status | 812.6 | 1395.32 | -3823.92 | 5449.12 | 803.95 | 821.25 |
| Expected loss in case of HPAI H5N1 | 2664.91 | 917.64 | 274.64 | 5055.19 | 2659.23 | 2670.60 |

## 4. CONCLUSION

This study provides information for smallholder duck producers as well as animal health authorities in dealing with duck production and the prevention and spread of HPAI H5N1. The study results showed that in the case of no disease occurrence, the optimal production cycle is 10 weeks with the first 2 weeks as the cleaning period. Ducks are sold when they are 8 weeks old. Maximum expected profit is US$ 805.10 for a producer with an average flock size of 794 ducks. If the disease occurs at any time during the production cycle, the result is a complete loss since all ducks are culled in order to eradicate the disease. The expected loss is estimated at US$ 2665.19. Sensitivity analysis further discovers substantial variability in expected profit under the disease free status and expected loss under disease occurrence. Given variability in the parameters of the revenue and cost functions, the results show that with 95% confidence, the producer gains profit ranging from US$ 803.95 to US$ 821.25 in case of no HPAI H5N1 disease, but suffers expected losses ranging from US$ 2659.23 to US$ 2670.60 in case of the disease occurrence.

The duck free range farming system is commonly found around large water bodies and rice paddy fields in low lying farm land near rivers in the Red River Delta where duck – rice production model is dominant [3]. Duck production is a main source of income in this model. If the disease is found in the flock and eradication is necessary, the economic loss can be devastating to duck producers in this area because of the production characteristics. The expected investment loss is far higher than the maximum profit received at each production cycle and is estimated to be 3 times higher (US$ 2665.19 expected loss vs. US$ 805.10 expected maximum profit). This severe loss can have long term consequences and producers may face severe difficulties to recover without financial assistance [21–24].

At the national level, each HPAI H5N1 event can have devastating economic losses as well as public health consequences. It does not only impact duck producers in the infected areas and human health in these areas but neighboring areas are also placed at risk. The disease indirectly impacts other economic sectors of the country such as tourism, animal feed industry, aquaculture and trade and commercial sector, etc. Therefore, it is crucial for the animal health authorities to work closely with duck producers in order to develop new disease prevention programs against HPAI H5N1. Discouraging use of the free range farming system could reduce the incidence and spread of the disease.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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