GEOSPATIAL AND COMPUTATIONAL ECONOMIC ANALYSES FOR THE OCCURRENCE PREDICTION, ECONOMIC IMPACTS AND PREVENTION OF HIGHLY PATHOGENIC AVIAN INFLUENZA SUBTYPE H5N1: CASE STUDIES IN THE RED RIVER DELTA OF VIETNAM

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Abstract

Highly Pathogenic Avian Influenza (HPAI) subtype H5N1 poses severe threats to both animals and humans. This dissertation seeks to improve disease detection and prevention and evaluate the potential economic consequences to smallholder producers in the Red River Delta of Vietnam through a series of 3 essays.

The first essay takes into account spatial and temporal occurrences of HPAI H5N1 by using a two-stage procedure: logistic regression modeling followed by Bayesian Kriging. The results demonstrated that higher average monthly temperatures and poultry density in combination with lower average monthly precipitation and humidity in low elevation areas, roughly from November to January and April to June, contribute to the higher occurrence of HPAI H5N1. Provinces near the Gulf of Tonkin, including Hai Phong, Hai Duong, Thai Binh, Nam Dinh and Ninh Binh are areas with higher probability of HPAI H5N1 occurrence.

The second essay explores the expected economic impacts of HPAI H5N1 on smallholder duck producers. A conceptual model is developed to optimize the producer profit maximization decision and evaluate expected profits/losses of the producer in light of HPAI H5N1. The results suggest that in the case of no disease occurrence, the optimal length of a production cycle is 10 weeks when ducks reach the age of 8 weeks which yields an estimated maximum profit of US$805. However, if the disease occurs, the resulting economic losses could reach a level three times higher than the maximum profit.

The third essay addresses the tradeoff between the current policy which implements an annual two-round vaccination program for the entire area of the Delta and an alternative policy which focuses more frequent vaccinations in high probability areas within the Delta. The study applies an ex-ante analysis framework for identifying focus areas for the alternative vaccination program and efficacy and cost analyses for the tradeoff between current and alternative policies. The ex-ante analysis identifies 1137 communes for the alternative vaccination program. The efficacy and cost analysis suggests that the alternative policy would be more successful in reducing the occurrence rate and vaccination costs as compared to the current policy.
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CHAPTER 1. INTRODUCTION

1.1. Introduction

1.1.1. Background

Highly Pathogenic Avian Influenza (HPAI) subtype H5N1 is one of the most dangerously infectious animal diseases as defined in Terrestrial Animal Health Code – 2011 (Article 1.2.3) of the Office International des Epizooties (OIE), also known as the World Organization for Animal Health. The disease has the potential to cause serious global outbreaks for many species of domestic and wild birds as well as to infect humans because of its high degree of virulence (OIE, 2014a). Several countries across Europe, Africa and Asia have reported being infected by the disease.

Vietnam has been among the most adversely affected countries since the first infection reported on 27 December 2003 (OIE, 2004). Presently, there have been 5 large epidemic waves of HPAI H5N1 and sporadic outbreaks recorded until present (Minh et al., 2009; OIE, 2014a; Pfeiffer, Minh, Martin, Epprecht, & Otte, 2007a, 2007b). Since the first reported disease occurrence, other occurrences have quickly spread nationwide, causing unpredictable epidemics over the years. By April 2004, HPAI H5N1 affected 57 of the 64 provinces in Vietnam, resulting in 44 million poultry culled, corresponding to approximately 17 percent of the total poultry population in the country (World Bank, 2007). The disease decreased average poultry population growth rate to -3.8% in the period 2003 – 2006 (during HPAI H5N1 disease occurrence) as compared to 7.6% in the period 2000 – 2003 (before disease occurrence) (Desvaux et al. 2008). Economic losses to the poultry sector were estimated at 3000 billion VND (approximately US$ 187.15 million) nationwide. (Peyre et al., 2008; Phan, Dusquesne, Lebailly, & Vu, 2010). The disease also caused serious human illness. It was reported that a total of 119 human cases were infected by HPAI H5N1 virus, resulting in 59 deaths by 19 November 2010 (CAP, 2011).

Ducks as hosts for the HPAI H5N1 virus have been discussed earlier in studies (Gilbert et al., 2006; Gilbert, Xiao, et al., 2008; Minh et al., 2009; Pfeiffer, 2007; Smith et al., 2006; Songserm et al., 2006; Webster et al., 2007). The number of outbreaks recorded in ducks increased steadily and reached a peak of 78% in both the Red River Delta and Mekong Delta of Vietnam in 2006-2007 (Minh et al., 2009). The disease was mainly confirmed in unvaccinated ducks (Gilbert, Xiao, et al., 2008; Minh et al., 2009). (Edan & Bourgeois, 2006) found the
presence of the HPAI H5N1 virus was mostly in live ducks and geese which suggested that the free range duck farming system was most vulnerable (at risk) to the disease. While the number of duck producers account for 74% of households in the two Deltas, they are also characterized as employing a low bio-security duck production system with free range duck farming and highly susceptible to HPAI H5N1 virus (Phan et al. 2010b; Ton et al. 2008).

This dissertation aims to improve the disease detection, contain the disease and evaluate potential economic consequences for duck producers through a series of 3 essays. This dissertation focuses on the Red River Delta in Vietnam, which was identified as a high-risk area for the disease (Minh et al., 2009; Pfeiffer et al., 2007b). The Delta has been severely affected by the three large epidemic waves of HPAI H5N1 outbreaks and other sporadic outbreaks over the period from December 2003 until the present with the recently reported outbreaks in Bac Ninh and Nam Dinh provinces in January and February 2014 (OIE, 2014b). The three large epidemic waves of HPAI H5N1 outbreaks occurred in this region i.e., the first wave occurred from January – February 2004, the third wave and the fifth wave took place from October – December 2005 and May – September 2007, respectively (FAO, 2008; Pfeiffer et al., 2007a, 2007b).

The 3 essays to be studied are entitled:

i. Spatio-temporal occurrence modeling of Highly Pathogenic Avian Influenza subtype H5N1: A case study in the Red River Delta, Vietnam

ii. Economic analysis of duck production household farm level in the context of Highly Pathogenic Avian Influenza subtype H5N1 in the Red River Delta, Vietnam

iii. Policy implications for prevention, control and eradication of Highly Pathogenic Avian Influenza subtype H5N1 in conjunction with risk factors in the Red River Delta, Vietnam.

The first essay seeks to identify factors affecting the occurrence of HPAI H5N1, predict probabilities and map the spatio-temporal distribution of the disease in the Red River Delta. Investigating where, when and why the disease occurs is important to help animal health authorities develop effective control policies.

Studies by Wilcox and Gubler (2005) and Wilcox and Colwell (2005) argued that weather variability across space and time, and agricultural intensification, industrialization and urbanization, likely promoted the survival and spread of pathogens in the environment. These unpredictable changes may have directly caused circulation of the avian influenza virus through
water birds (Gilbert, Slingenbergh, & Xiao, 2008). Although increased minimum temperature in January and decreased lower annual precipitation were respectively found to be associated with HPAI H5N1 in Europe and China (Fang et al., 2008; Si et al., 2010), the mechanism of how space-time dynamics of these factors affected disease occurrence were not investigated. It is noted that space-time dynamics provide a viable picture of when, where and why a phenomenon occurs as well as its consequences (Cressie & Wikle, 2011).

This essay explores the variability of weather across space and time, as measured in terms of average monthly temperature, precipitation and humidity, and other anthropogenic and physical environmental factors, such as poultry density and elevation in relation with the occurrence of the HPAI H5N1 virus. A two-stage procedure was used: (1) logistic regression modeling to identify factors influencing the occurrence of HPAI H5N1 and to predict probabilities of the disease occurrence; and (2) a geostatistical approach to develop monthly predictive maps.

The second essay aims to evaluate the optimal decision to maximize profit and estimate the expected economic impacts of HPAI H5N1 on smallholder duck producers in the Red River Delta.

Given the high degree of virulence, the HPAI H5N1 virus causes severe economic losses to duck producers. Occurrence of the disease 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 (OIE, 2014a). 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 kill (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 when is the optimal time to sell the ducks in order to maximize profit. The situation is made more complicated 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.

To address the problems, this essay (i) develops a conceptual model using a dynamic optimization process by constructing the Bellman equation to optimize the producer's decision of maximizing profit; (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.

The third essay focuses on policy implications for prevention of HPAI H5N1 in conjunction with risk factors in the Red River Delta, Vietnam.

Although the current vaccination campaign covered all geographical areas of the Red River Delta, the campaign was carried out only twice a year in April – May and October – November. However, poultry production occurs all year round. A later study (see Tran et al. 2013) confirmed that November to January and April to June were the periods most vulnerable for disease occurrence. A sizeable portion of poultry production remained unvaccinated at different times of the year. The vaccination program has shown to be a viable means of protection against the HPAI H5N1 virus (Henning et al. 2009). Unvaccinated poultry remained at high risk of contracting the virus.

This study explores implications of an alternative policy, which is likely to be more successful in containing and preventing the disease from recurrence in the Red River Delta, Vietnam and reducing vaccination costs. Specifically, the alternative policy involves shifting vaccination for HPAI H5N1 from the entire Delta to specific areas identified as higher probability areas for the disease occurrence within the Delta. This modification would involve more frequent vaccination campaigns throughout the year. Two key questions emerge with this proposal: (i) Where are the high probability areas (focus areas) for the alternative policy?; (ii) Is it beneficial for the Government to switch to the alternative policy in terms of the efficacy and the costs of vaccination program? To answer the questions and fulfill the objective, this study (i) identifies the focus areas for the alternative policy to be implemented in the Red River Delta and (ii) processes the tradeoff between the current policy and the alternative policy based on the evaluation of vaccination efficacy and the vaccination costs.

The overall and specific objectives and the structure of this dissertation are stated in the following section.
1.1.2. Objectives

The fundamental objective of this dissertation is to provide policy implications and production options which assist policy makers and smallholder poultry producers in their decision to prevent, control and eradicate HPAI H5N1.

To address this central theme, it is essential to understand the mechanisms affecting the emergence and spread of HPAI H5N1 across space and time scales and predict the probability and spatio-temporal distribution of the disease. Provision of where, when and why the H5N1 virus occurs and disseminates assists animal authorities to focus resources for the prevention, control and eradication of the disease. It is also critical to increase duck producers' awareness of disease severity by investigating the expected economic losses they would suffer under the context of the HPAI H5N1 occurrence as compared to the maximum profit gained in case of being disease free. The application of a powerful framework of geospatial technology for geostatistics and visualization using integration of geographical information system (GIS) and remote sensing techniques is designed in the way that multi-dimensional data such as measurements of socio-economic factors and remotely sensed data can be incorporated, analyzed and visualized for effective decision making for control and prevention of the HPAI H5N1 disease in the Red River Delta. More specifically, the dissertation focuses on three specific objectives:

(i) Identify how weather variability, as measured in terms of monthly temperature, precipitation and humidity together with poultry density and elevation factors is related to the emergence of HPAI H5N1 and predict the probability and spatio-temporal distribution of the disease.

(ii) Analyze economic impacts of HPAI H5N1 to smallholder duck producers by estimating the expected economic losses under the context of the disease as compared to the maximum profit gained under the disease free situation.

(iii) Explore implications of an alternative policy, which is likely to be more successful in containing and preventing the disease from recurrence in the Red River Delta, Vietnam and reducing vaccination costs as compared to the current policy.

1.1.3. Dissertation structure

The dissertation is structured as follows: Chapter 1 is an introduction to the research. This is followed by a discussion of the space-time dynamics of weather variability related to the
emergence of HPAI H5N1 and the prediction probability and spatio-temporal distribution of the disease in the Chapter 2. Using information on the probability of HPAI H5N1, Chapter 3 develops a dynamic conceptual model that optimizes smallholder duck producers' decision during a production cycle and calculate the expected economic losses under the context of HPAI H5N1 as well as maximum profit gained under the disease free situation. Chapter 4 applies the ex-ante analysis framework to identify the location and spatial distribution of higher probability areas of disease occurrence in the Red River Delta for the alternative policy and evaluate the accuracy of the analysis and the cost analysis to process the tradeoff between two vaccination policies. Chapter 5 summarizes the conclusion from this research, discusses policy implications and suggests areas for further research.

1.2. Overview of HPAI H5N1 situation

1.2.1. Overview of HPAI H5N1 situation

The initial occurrences of the HPAI H5N1 disease were officially reported on 27 December 2003 by the Department of Animal Health of Vietnam (DAH). An estimate of 70,000 poultry was found infected with HPAI H5N1 virus in Long An and Tieng Giang provinces, Vietnam (OIE, 2004). It marked the beginning of the first large epidemic wave of HPAI H5N1 which was followed by 4 other epidemic waves reported in later years. Table 1-1 presents a summary of the epidemic waves of the HPAI H5N1 outbreaks in Vietnam since December 2003.

After the initial outbreaks of HPAI H5N1, the disease quickly spread nationwide, affecting 57 out of 64 provinces of Vietnam (World Bank, 2007). The disease left behind devastating damages to both human health and economy. Twenty of the twenty nine cases of human infestation from the HPAI H5N1 virus resulted in death in 2004 and an estimate of 38.8 million poultry was culled to prevent further spread of the HPAI H5N1 virus. On January 24, 2004, the Ministry of Finance announced the indemnity payment level at 5000 VND/head (0.32 US$/head)\(^1\) for poultry culled.

The second epidemic wave occurred from November 2004 – March 2005, involving 1511 outbreaks reported in 35 provinces, mostly in the Mekong Delta. It was estimated that 2.17 million poultry were culled during this wave. A high number (61) of human cases were reported which led to 19 deaths in the country.

\(^1\) Exchange rate at 1USD = 15,600 VND
Table 1-1: Overview major epidemic waves of HPAI H5N1 disease in Vietnam

<table>
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<th>Events</th>
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<th>Statistics</th>
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Total provinces affected: 57  
Total poultry culled: 38.83 million  
Human cases: 29 (20 fatal) |
Total provinces affected: 35  
Total poultry culled: 2.17 million  
Human cases: 61 (19 fatal) |
Total provinces affected: 24  
Total poultry culled: 0.89 million  
Human cases: 0 |
Total provinces affected: 12  
Total poultry culled: 0.99 million  
Human cases: 8 (5 fatal) |
| Fifth wave | May – September 2007                              | Total outbreaks: 149  
Total provinces affected: 22/64  
Total poultry culled: 0.17 million  
Human cases: 8 (5 fatal) |

Source: (WHO, 2014), Pfeiffer et al. (2007b) and FAO Representation in Vietnam

The third epidemic wave, September – December 2005, affected 24 provinces, mainly in the Red River Delta. It recorded 457 outbreaks and an estimate of 0.89 million poultry culled. There was no human cases reported in this period.

The fourth epidemic wave occurred from December 2006 to March 2007, causing five human deaths out of eight infected cases with the HPAI H5N1 virus. There were 135 outbreaks confirmed in 12 provinces in the Mekong Delta and about 0.99 million poultry were culled.

It was noticeable that the first 4 epidemic waves occurred around the Tet holiday (the national lunar new year celebration) in Vietnam when demand for poultry is substantially higher. While the first, second and fourth epidemic waves happened before and lasted through Tet, the third epidemic wave occurred and ended before the Tet holiday. It is noted that the occurrence and spread of HPAI H5N1 were thought to be associated with either increases in poultry production, trade and movement of live poultry before, during and after Tet (Pfeiffer et al., 2007b).

Unlike the previous epidemic waves, the fifth wave, however, was not associated with Tet. It was reported from May – September 2007, affecting 22 provinces in the north, mostly in
Sporadic outbreaks have continued to occur in between the epidemic waves and since the fifth wave. The latest outbreak was detected recently in January and February 2014 in Bac Lieu, Soc Trang, Vinh Long, Ca Mau, Long An and Tra Vinh provinces in the Mekong Delta and Bac Ninh and Nam Dinh provinces in the Red River Delta as well as a few more provinces. Six human cases of HPAI H5N1 virus have been reported (5 deaths) in 2008, 5 cases (5 deaths) in 2009, 7 cases (2 deaths) in 2010, 4 cases (2 deaths) in 2012, 2 cases (1 death) in 2013, and 1 case (1 death) in 2014. A total of 62 human deaths out of 125 cases infected with the HPAI H5N1 virus have been reported so far (WHO, 2014).

1.2.2. Overview of national policies on HPAI H5N1 control measures

In response to the occurrence and rapid spread of HPAI H5N1 in the end of 2003 and early 2004, a National Steering Committee for disease prevention and combat was established through the Decision No 13/2004/QD-TTg dated 18 January 2004. The Committee was in charge of planning and coordinating activities among government organization for the prevention and control of the disease, supervising the implementation of emergency prevention and control measures. Several control measures such as poultry culling (stamping out), vaccination, live poultry movement restriction, closure of live poultry markets, etc., have been applied.

To deal with the rapid spread of the disease during the first epidemic wave of outbreak, orders of culling of all birds within a radius of 3km around infected farms were implemented. The compensation for a bird culled was announced at 5000VND (0.32 US$/head)² by the Ministry of Finance in the Decision No 396/2004/QD-TTg dated 20 April 2004 using the emergency disease control and the recovery of the poultry sector budget of 245,316 billion VND (15.7 million US$). The main guidelines for compensation were (i) direct subsidy of 5000 VND/head (0.32 US$) culled and (ii) subsidy of 2000 VND/head (0.13 US$) for recovery of poultry production.

² Exchange rate at 1USD = 15,600 VND
The average amount of compensation was increased to 15,000VND (0.96 US$) per bird culled by Decision No 574/QD-TTg dated 24 June 2005. This decision was then replaced on by Decision No 309/2005/QD-TTg dated 26 November 2005, which provides a subsidy of 10,000 VND/head (0.64 US$) for a bird culled voluntarily along with 15,000VND/bird forcibly culled. This policy aims at preventing a public health threat from HPAI H5N1, as well as reducing the economic losses at the national level associated with the outbreak by encouraging poultry producers to disclose the disease status early and to cull their birds instead of selling them illegally on the market. The average amount of compensation continued to increase to 23,000VND (1.24 US$/head) per bird culled, regulated by Decision No 719/QD-TTg dated 5 June 2008.

At the same time, The National Steering Committee issued several technical guidelines for culling birds. However, the mass culling of birds (up to 44 million heads country-wide) during the first wave period (World Bank, 2007) was implemented without specific technical guidelines for the prevention and control of the epidemic. The official guidelines were not released until 18 May 2004, over a month after the end of the first wave (guidelines No 536 TY/DT by the Department of Animal Health). The official procedures called for the dispersing of powdered lime after birds were culled. This culling strategy caused a dramatic decrease in the poultry population at that time, approximately 17% of total poultry raised in 2004 (World Bank, 2007). This strategy, however, could not prevent and stop the virus. Other control measures were also applied. Circular No. 155/TTg-NN dated 3 February 2005 promulgated by the Prime Minister and Decision No. 321/BNN-NN dated 4 February 2005 from the Ministry of Agriculture and Rural Development (MARD) imposed a temporary ban from raising ducks, quails and geese. This temporary ban on the incubation and hatching of waterfowl, Muscovy ducks, quails and geese covered the entire country. However, it was too late to deal with the seasonal increase in bird rearing for Tet. The temporary ban was in effect until February 2007.

Because of the severity of the situation, an alternative vaccination campaign was planned after the end of the second epidemic wave of HPAI H5N1 outbreaks. Directive No. 25/2005/CT-TTg dated 12 July 2005 by the Prime Minister called for the vaccination of all poultry in order to prevent H5N1 outbreaks throughout the country. Following this directive, MARD publicized Decision 1715/QĐ/BNN-TY dated 14 July 2005 on the use of HPAI H5N1 vaccines and

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3 Exchange rate at 1USD = 18,500 VND

The first vaccination campaign began in August 2005, with two pilot vaccination campaigns in Tien Giang and Nam Dinh provinces. A mass vaccination campaign was then conducted nationally from late September to the beginning of November 2005. The campaign mainly focused on high risk areas in the Mekong and Red River deltas at that time. The goal of the vaccination campaign was to reduce the spread of the HPAI H5N1 virus. Since then, the vaccination campaign consisted of two rounds of vaccination each year until 2010. Three phases of vaccination were implemented: 2005 – 2006, 2007 – 2008 and 2009 – 2010 with financial support from international organizations such as FAO, USAID etc...

Together with the eradication program and mass vaccination campaign, other control measures have been applied over the last few years. Circular No 69/2005/TT–BNN dated 7 October 2005 from MARD provided guidelines for urgent responses when the HPAI H5N1 disease occurs at the local level with focus on 5 major issues including:

(i) No free-ranging poultry when the disease occurs;
(ii) No trading of infected poultry;
(iii) No use of infected poultry or poultry of unknown origin;
(iv) No hiding of the disease; and
(v) No uncontrolled disposal of poultry carcasses.

The methods applied to deal with the disease vary depending on each situation. Each year, MARD and concerned ministries monitor each disease situation and make decisions on how, where and when to implement prevention and eradication programs.

References


WHO. (2014). *WHO | Cumulative number of confirmed human cases of avian influenza A(H5N1) reported to WHO*. Retrieved from http://www.who.int/influenza/human_animal_interface/EN_GIP_20140124CumulativeNumberH5N1cases.pdf?ua=1


Appendix: List of policies

Decision No 13/2004/QD-TTg dated 18 January 2004 of the Prime Minister on the establishment of a National Steering Committee for bird flu prevention and combat
Decision No 396/QD-TTg dated 20 April 2004 of the Prime Minister on the provision of financial support for prevention, control of HPAI and recovery of the poultry production sector.
Directive No. 22/2004/CT-TTg dated 15 June 2004 of the Prime Minister, on continuing prevention and control of HPAI and quick restoration and development of poultry production and farming
Directive No. 47/2004/CT-BNN dated 5 October 2004 of the MARD on further enhancing bird flu prevention and control
Decision No. 574/QD-TTg dated 24 June 2005 of the Prime Minister on the provision of financial supports for control of HPAI
Decision No. 309/2005/QD-TTg dated 26 November 2005 of the Prime Minister on the provision of financial support for bird flu prevention and control. The Decision replaces Decision No. 574/QD-TTg dated 24 June 2005
Decision No 719/QD-TTg dated 05 June 2008 of the Prime Minister on the provision of financial support for the prevention, control and eradication of diseases in domestic cattle and poultry
Guidelines No 536 TY/DT dated 18 May 2004 of the Department of Animal Health for prevention and control of avian influenza epidemic from recurring
Circular No. 155/TTg-NN dated 03 February 2005 of the Prime Minister on continuing to steer the prevention and control of Bird Flu
Decision No. 321/BNN-NN dated 04 February 2005 of MARD on imposing a temporary ban on raising ducks, quails and geese.
Directive No. 25/2005/CT-TTg dated 12 July 2005 of the Prime Minister on vaccination against avian influenza
Decision 1715/QĐ/BNN-TY dated 14 July 2005 of MARD on temporary regulations on the use of avian influenza vaccines
Decision 1716/QĐ/BNN-TY dated 15 July 2005 of MARD on detailed plan for vaccination campaign
Circular No 69/2005 / TT–BNN dated 07 October 2005 of MARD on guidelines on urgent measures to be carried out against H5N1
Directive No. 53-CT/TW dated 28 October 2005 on urgent measures for prevention of HPAI H5N1
Resolution No. 15/2005/NQ-CP dated 04 November 2005 of the Government on urgent measures for prevention of H5N1 human influenza pandemic
Circular No. 69/2005/TT-BNN dated 07 November 2005 of the MARD, guiding the application of a number of urgent measures for prevention and control of Bird Flu
Decision No. 12/2005/QD-BTNMT dated 09 November 2005 of the Ministry of Natural Resources and Environment on an urgent plan of action for avian influenza epidemic and human influenza pandemic prevention and control
Document No. 239/TTg-NN dated 10 February 2006 of the Prime Minister on continuous instruction of avian influenza prevention and control
Decision No. 525/QD/BNN-TY dated 23 February 2006 of MARD on the approval of 2006 vaccination plan against HPAI
Decision No 645/TTg-NN dated 24 May 2007 of the Prime Minister on continuous instruction of avian influenza prevention and control.
Decision 3541/QD-BNN-TY dated 12 November 2007 of MARD on the approval of 2008 vaccination plan against HPAI.
Document No. 2281/TTg-KTN dated 23 December 2008 of the Prime Minister on the use of vaccines against avian influenza for phase III (2009-2010)
Decision No 47/QD-BNN-TY dated 07 January 2009 of MARD on the approval of vaccination plan against HPAI, phase III (2009-2010)
Decision No 23/QD-BNN-TY dated 07 January 2010 of MARD on the approval of 2010 vaccination plan against HPAI.
CHAPTER 2. SPATIO-TEMPORAL OCCURRENCE MODELING OF HIGHLY PATHOGENIC AVIAN INFLUENZA SUBTYPE H5N1: A CASE STUDY IN THE RED RIVER DELTA OF VIETNAM

2.1. Introduction

Highly Pathogenic Avian Influenza (HPAI) subtype H5N1 has posed a global threat to both animal and human populations (Si et al., 2010). The HPAI H5N1 virus has caused unpredictable epidemics over the years. Understanding the mechanism affecting the occurrence of HPAI H5N1 plays a vital role in the prevention, control and eradication of the disease. However, this mechanism has not been fully understood in a scientific sense (Wilcox & Colwell, 2005; Wilcox & Gubler, 2005). In Vietnam, the occurrence and spread of HPAI H5N1 were thought to be associated with either increases in poultry production, trade and movement of live poultry before, during and after Tet (the national lunar new year celebration), or the expansion of free-range duck farming where domestic ducks came into contact with rice paddy fields during the rice crop harvest season (Desvaux et al., 2011; Pfeiffer et al., 2007). However, temporal distribution of the disease in Thailand showed this same trend, even though movement of poultry in high-risk areas was restricted (Gilbert, Xiao, et al., 2008; Paul et al., 2010). In addition, the US Centers for Disease Control and Prevention (CDC) found the HPAI H5N1 virus in live, healthy ducks and geese in Hanoi in 2001, two years prior to the disease occurrence (Edan & Bourgeois, 2006). Although presently, the virus was classified as inactive, mechanisms that activated the H5N1 virus and caused disease occurrence are still not clear.

Studies by Wilcox and Gubler (2005) and Wilcox and Colwell (2005) argued that weather variability across space and time, and agricultural intensification, industrialization and urbanization, likely promoted the survival and spread of pathogens in the environment. These unpredictable changes may directly cause circulation of the avian influenza virus through water birds (Gilbert, Slingenbergh, & Xiao, 2008). Although increased minimum temperature in January and decreased lower annual precipitation were respectively found to be associated with HPAI H5N1 in Europe and China (Fang et al., 2008; Si et al., 2010), the mechanism of how space-time dynamics of these factors affected disease occurrence were not investigated. In other words, the variability of weather across space and time in relation with the occurrence of HPAI H5N1 has been overlooked.
This study seeks to understand the relationship between weather variability, as measured in terms of average monthly temperature, precipitation and humidity, and other anthropogenic and physical environmental factors, such as poultry density and elevation in association with the occurrence of the HPAI H5N1 virus. Records of past occurrences are incorporated with environmental and anthropogenic factors to predict probabilities and map the spatio-temporal distribution of HPAI H5N1. The study focuses on the Red River Delta in Vietnam, which was previously defined as a high-risk area for the disease (Minh et al., 2009; Pfeiffer et al., 2007).

2.2. Methods

2.2.1. Study area and data sources

Figure 2-1: The study area – The Red River Delta of Vietnam

The Red River Delta (RRD) (Figure 2-1) is one of the two largest flood plains in Vietnam with dense population, including the capital city of Hanoi and the main port of Hai Phong. Agriculture and livestock are among the main economic activities, including primary crops –
rice, corn, beans and rapeseed crops and poultry, pigs and cows husbandry. Three large waves of HPAI H5N1 outbreaks occurred in the region over the period December 2003 to March 2010, corresponding to the first, the third and the fifth waves as defined at the national level, which happened in 2003-2004, 2004-2005 and 2007, respectively. These waves had high degrees of virulence which caused severe damages. By April 2004, HPAI H5N1 affected 57 of the 64 provinces in Vietnam, resulting in 44 million poultry culled which corresponds to approximately 17 percent of the total poultry population in the country (World Bank, 2007). Economic losses to poultry producers were extensive and estimated at about 3000 billion VND (Peyre et al., 2008; Phan, Dusquesne, Lebailly, & Vu, 2010). The disease mainly impacted a large number of the poor households. Both decreases in demand for poultry products and significant declines in market prices due to the disease caused heavy losses to poultry producers (World Bank, 2007). Human health also suffered. Several human cases of HPAI H5N1 were reported. By November 19, 2010, a total of 119 human cases were linked to HPAI H5N1, resulting in 59 deaths (CAP, 2011).

Data on the occurrences of HPAI H5N1 collected and reported by the Vietnam Department of Animal Health (DAH). Each HPAI H5N1 occurrence was confirmed either by the National Centre for Veterinary Diagnostics or Regional Animal Health Offices by performing haemagglutination inhibition, real-time polymerase chain reaction (PCR), or real-time reverse transcriptase/polymerase chain reaction (RRT-PCR) tests (OIE, 2012). Although disease occurrences were first officially reported in the region at the end of 2003 by DAH, the dates and locations of occurrences were formally reported from the end of March, 2004 (Pfeiffer et al., 2007). Therefore, this study focused on the period from the end of March, 2004 to the end of February, 2009 which included 333 confirmed HPAI H5N1 occurrences in the RRD.

All occurrence data were grouped accordingly to the start month and location at the commune level. Duplicate reports of the disease for the same month and location were discarded, resulting in 277 affected communes. The other 1967 unaffected communes in the Delta were also considered as statistical units for the analysis. Therefore, the data included 2244 infected and uninfected communes. Record of disease occurrences was derived for each commune on monthly basis from January to December and coded as 1 if the disease was reported within a month or 0 if there was no disease reported. The data file also included commune codes used for
merging with other data of other factors to be analyzed. This step was done using Stata software version 12 (StataCorp LP., College Station, Texas, USA).

Weather data on precipitation, humidity and temperature, measured daily from 2003 to 2006 at 30 weather stations throughout the Red River Delta and surrounding areas, were provided by the Hydro-Meteorological Data Center of Vietnam. Ordinary kriging within ArcMap version 10.1 (ESRI, Redlands, CA, USA) with a spherical semi-variogram model which was considered as one of the best approaches for climate data interpolation (Earls & Dixon, 2007). This technique was performed to interpolate weather data for each month of the year in the Red River Delta and then converted to raster layers, resulting in 36 raster layers representing average monthly precipitation, humidity and temperature. The weather data consist of both spatial and temporal aspects since they vary across location and time.

Other factors included in the study were poultry density at the commune level and elevation, respectively, obtained from the 2006 Vietnam Agricultural Census provided by East West Center – National Science Foundation project and from the Shuttle Radar Topography Mission (SRTM) 90-m resolution Digital Elevation Model (DEM). These two factors contain the spatial aspect only. Figure 2-2 represents the spatial distribution of poultry density and elevation in the Red River Delta of Vietnam. Poultry density of each commune was divided into 4 groups and coded as 1 for no poultry, 2 for a group of 1 to 25 poultry/ha, 3 for a group of 26 to 100 poultry/ha and 4 for a group of more than 100 poultry/ha. Most of communes were categorized as poultry density group 3 and located inside the delta. The areas with no poultry were in the city center of Hanoi and other provinces such as Hai Duong, Hai Phong and Nam Dinh. Communes in poultry density group 2 were mainly distributed around big cities, mountain and coastline area by the east sea of Vietnam.
Following the idea of Le and Rambo on topographic classification (Le & Rambo, 2001), we categorized the Red River Delta topography into 4 groups of elevation less than 5m, from 5m to 15m, from 15m to 200m, and above 200m, respectively, coded from 1 to 4, representing coastal, lowland, midland and upland areas. The Red River Delta was characterized as a flat plain area with low elevation, mostly less than 15m (Figure 2-2). The coastal area is located near the east sea of Vietnam, consisting of Hai Duong, Hai Phong, Thai Binh, Nam Dinh and an eastern part of Ninh Binh provinces.

For the purpose of data analysis, Geographical Information System (GIS) technology was used to generate centroids from each commune polygon in the Delta, resulting in 2244 points. The resulting commune centroid-based map was the basis for conducting temporal and spatial analysis (Figure 2-3).
Figure 2-3: Commune administrative polygon and commune centroids

All layers detailing environmental characteristics (average monthly precipitation, average monthly humidity, average monthly temperature and elevation) were then extracted to the commune centroids and then exported to Stata software version 12 to be merged with poultry density data and disease occurrence records using commune codes. Details on variable description and sources were described in Table 2-1.
Table 2-1: Description and data sources of variables in the study

<table>
<thead>
<tr>
<th>Variables</th>
<th>Unit</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPAI H5N1 occurrences</td>
<td></td>
<td>Locations and dates of occurrences</td>
<td>Vietnam Department of Animal Health</td>
</tr>
<tr>
<td>Weather data</td>
<td></td>
<td>Measurements at 30 weather stations</td>
<td>Hydro</td>
</tr>
<tr>
<td>Precipitation</td>
<td>mm</td>
<td>Located broadly in the Red River Delta and surrounding areas. Data contain both spatial and temporal aspects</td>
<td>Meteorological Data Center of Vietnam (HMDC)</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poultry density</td>
<td>Heads/ha</td>
<td>Derived from 2006 Vietnam agricultural census. Data contain the spatial aspect</td>
<td>The 2006 Vietnam Rural, Agricultural and Fishery Census</td>
</tr>
<tr>
<td>Group 1: 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 2: 1-25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 3: 26-100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 4: &gt;100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevation</td>
<td>m</td>
<td>Derived from SRTM 90-m resolution Digital Elevation Model (DEM). Data contain the spatial aspect</td>
<td>SRTM 90-m resolution DEM: <a href="http://srtm.csi.cgiar.org/">http://srtm.csi.cgiar.org/</a></td>
</tr>
<tr>
<td>Group 1: &lt;5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 2: &gt;5-15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 3: &gt;15-200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 4: &gt;200</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A multilevel analysis technique was applied by performing a two-stage procedure: (1) logistic regression modeling followed by (2) a geostatistical analysis approach to interpolate results.

Overall structure and analytical procedures of the study is shown in Figure 2-4 below:
Ordinary Kriging was run for each month of the year. There was a total of 36 raster files generated corresponding to average monthly precipitation, humidity and temperature data.

**Legend:**
- Data file in ArcMap 10.1
- Data file in Stata 12
- Geo-processing tool in ArcMap 10.1
- Command tool in Stata 12

**First stage:**
Bayesian Kriging was run for each month to create monthly predictive maps from January to December.

**Second stage:**
Bayesian Kriging was run for each month to create monthly predictive maps from January to December.

**Data preparation and analytical procedures of the study**
2.2.2. Statistical analysis

In the first stage, logistic regression models were fitted to the values obtained at the commune centroids to investigate critical factors affecting the occurrence of HPAI H5N1. The advantage of the logistic regression model is that it can explain the effects of the explanatory variables on the binary response. The logistic regression results provide odds ratios (ORs), standard errors, p-values and 95% confidence intervals. An OR equal to 1 indicates no relationship between the explanatory variable and the response variable, while an OR greater than 1 indicates a positive relationship while an OR less than 1 represents a negative relationship (Verbeek, 2008).

Computation of variance inflation factors (VIFs) for each explanatory variable in the model indicates the presence of multicollinearity. The critical threshold value of a VIF is 10. A VIF greater than 10 suggests severe collinearity and should be excluded from the model (Verbeek, 2008). Goodness-of-fit tests were also performed, reporting Akaike’s information criterion (AIC) for each model. The AIC value helps select the optimal statistical model. A smaller AIC value implies a better fit model. The best fit model is indicated by the lowest AIC value (Akaike, 1974). This model was then used to estimate predicted probabilities of HPAI H5N1 which were used in the geostatistical analysis performed in the second stage. All statistical analyses were performed by using the Stata software version 12 (StataCorp LP., College Station, Texas, USA).

2.2.3. Geostatistical analysis

The second stage in the analysis examined the spatio-temporal patterns of HPAI H5N1. The fundamental goal was to interpolate monthly-based probability predictions for the occurrence of the disease. The predicted probabilities of HPAI H5N1 obtained in the first stage of the analysis were fitted into the commune centroid-based map. A geostatistical analysis approach considers the physical location of each individual observation in a dataset and its value with respect to one another to interpolate values at unsampled locations. Given that HPAI H5N1 is a contagious infectious disease that is easily transmitted to surrounding areas over time, significant spatial autocorrelation may influence the estimates of the disease risk. The idea suggests that values of points located close together are more similar than those far away. This relationship was calculated through a variogram model which is the core of geostatistical kriging interpolation techniques (Goovaerts, 2000; Webster & Oliver, 2007).
Bayesian kriging is a useful tool for spatial interpolation in the context of epidemiology (Biggeri et al., 2006). Different from other kriging methods such as simple kriging or ordinary kriging which exclude uncertainty in the variogram model by using a fixed variogram parameter, Bayesian kriging considers variogram parameters as random variables and estimates the variogram model directly from data using restricted maximum likelihood (REML). Therefore, uncertainty in the variogram parameters is included in the final estimation (Diggle & Ribeiro Jr, 2002). The use of a large number of simulations following Markov chain Monte Carlo techniques required in the Bayesian prediction approach yields more accurate predictions (Diggle & Ribeiro Jr, 2002; Krivoruchko, 2011). The outcomes were monthly prediction maps of the occurrence of HPAI H5N1 in the Red River Delta.

The accuracy of Bayesian kriging was validated using the commonly accepted 10-fold cross validation technique (Harrell, 1998). The original data were randomly divided into a training subset and a test subset at the proportion of 90-10%, respectively. Bayesian kriging was performed using the training subset, then was cross-validated using the test subset. Level of prediction errors were then measured by mean absolute percentage error (MAPE):

\[
MAPE = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{P_t - A_t}{A_t} \right| \times 100
\]  

where \( P_t \) and \( A_t \) are respectively the predicted and actual values at point \( t \). The accuracy of the prediction is the converse of MAPE.

\[
Accuracy = 100 - MAPE = (1 - \frac{1}{n} \sum_{t=1}^{n} \left| \frac{P_t - A_t}{A_t} \right|) \times 100
\]

2.3. Results and Discussion

2.3.1. Results

Logistic regression models provided important information about what factors critically affect the occurrence of HPAI H5N1 in the Red River Delta. Based on calculation of the Akaike’s information criterion (AIC), it appeared that a model with all factors - average monthly temperature, humidity and precipitation, poultry density and elevation - was the best fitting model in terms of the lowest AIC value. The logistic regression results are shown in Table 2-2. The variance inflation factor (VIF) values indicated no problem with collinearity in the model.
Table 2-2. Logistic regression model of HPAI H5N1 in the Red River Delta, Vietnam

<table>
<thead>
<tr>
<th>Variable</th>
<th>OR</th>
<th>SE</th>
<th>P</th>
<th>95% CI</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average monthly temperature</td>
<td>1.518***</td>
<td>0.066</td>
<td>0</td>
<td>1.394</td>
<td>1.653</td>
</tr>
<tr>
<td>Average monthly humidity</td>
<td>0.949***</td>
<td>0.006</td>
<td>0</td>
<td>0.936</td>
<td>0.962</td>
</tr>
<tr>
<td>Average monthly precipitation</td>
<td>0.975***</td>
<td>0.002</td>
<td>0</td>
<td>0.971</td>
<td>0.980</td>
</tr>
<tr>
<td>Poultry density</td>
<td>1.368**</td>
<td>0.153</td>
<td>0.006</td>
<td>1.0912</td>
<td>1.696</td>
</tr>
<tr>
<td>Elevation</td>
<td>0.716**</td>
<td>0.076</td>
<td>0.002</td>
<td>0.582</td>
<td>0.881</td>
</tr>
</tbody>
</table>

1/ OR – odds ratio, SE – standard error, P – probability, 95% CI – 95% confidence interval, VIF – variance inflation factor
* Significant at the 0.05 level; and *** significant at the 0.01 level, two-tailed test.

The results revealed that all five factors tested had statistically significant effects on the occurrence of HPAI H5N1 in the Red River Delta. Positive associations with odds ratios of 1.518 and 1.368 were found between the disease occurrence and average monthly temperature and poultry density, while other factors - average humidity, precipitation and elevation had negative relationships with odds ratios of 0.949, 0.975 and 0.716 respectively. The results suggested that higher average monthly temperature and poultry density would likely increase the probability of HPAI H5N1 while lower average monthly humidity, precipitation and elevation would likely increase the probability of occurrence of the disease.

Table 2-3. Monthly estimated probability of HPAI H5N1 in the Red River Delta.

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0.0216</td>
<td>0.0066</td>
<td>0.0047</td>
<td>0.0471</td>
</tr>
<tr>
<td>February</td>
<td>0.0055</td>
<td>0.0016</td>
<td>0.0013</td>
<td>0.0110</td>
</tr>
<tr>
<td>March</td>
<td>0.0065</td>
<td>0.0020</td>
<td>0.0013</td>
<td>0.0151</td>
</tr>
<tr>
<td>April</td>
<td>0.0226</td>
<td>0.0096</td>
<td>0.0026</td>
<td>0.0467</td>
</tr>
<tr>
<td>May</td>
<td>0.0073</td>
<td>0.0032</td>
<td>0.0013</td>
<td>0.0155</td>
</tr>
<tr>
<td>June</td>
<td>0.0089</td>
<td>0.0072</td>
<td>0.0005</td>
<td>0.0317</td>
</tr>
<tr>
<td>July</td>
<td>0.0037</td>
<td>0.0024</td>
<td>0.0000</td>
<td>0.0107</td>
</tr>
<tr>
<td>August</td>
<td>0.0004</td>
<td>0.0002</td>
<td>0.0000</td>
<td>0.0013</td>
</tr>
<tr>
<td>September</td>
<td>0.0030</td>
<td>0.0029</td>
<td>0.0001</td>
<td>0.0164</td>
</tr>
<tr>
<td>October</td>
<td>0.0078</td>
<td>0.0059</td>
<td>0.0005</td>
<td>0.0352</td>
</tr>
<tr>
<td>November</td>
<td>0.0254</td>
<td>0.0115</td>
<td>0.0038</td>
<td>0.0663</td>
</tr>
<tr>
<td>December</td>
<td>0.0106</td>
<td>0.0038</td>
<td>0.0021</td>
<td>0.0217</td>
</tr>
<tr>
<td>Year average</td>
<td>0.0102</td>
<td>0.0098</td>
<td>0.000012</td>
<td>0.0663</td>
</tr>
</tbody>
</table>

The predicted probabilities of HPAI H5N1 occurrence (Table 2-3) were estimated from the logistic model. The results suggested that periods from October to January and April to June,
contribute to the higher probability of HPAI H5N1. Of which, November, April and January are most vulnerable to disease occurrence (with high predicted probabilities of 0.0663, 0.0467 and 0.0471, respectively as compared to other months. A year average probability is estimated at 0.0102.

All predicted probabilities were fitted to the commune centroid-based map to interpolate predictive spatio-temporal distribution of HPAI H5N1 in the Red River Delta using Bayesian kriging. The monthly prediction maps provided visual insight on the times and locations in which the disease would likely occur across the Delta. Empirical evaluation of mean absolute percentage error and accuracy based on a 10-fold cross-validation technique indicated the performance level of the prediction. Figure 2-5 representing the results of MAPE and accuracy of the prediction suggested a consistent trend across various months of the year. The cross-validation of the predictive maps showed accuracy around 85% which were considered as high values of the predictive models (Si et al., 2010).

![Figure 2-5. Cross-validation for accuracy of Bayesian kriging.](image)

**2.3.2. Discussion**

This study presented a method for combining statistical and spatial analyses to identify significant factors affecting the occurrence of HPAI H5N1 and to produce maps of the monthly
probabilities of HPAI H5N1 occurrence in the Red River Delta, Vietnam. The goal was to better understand the factors associated with the disease by addressing questions regarding why, when and where HPAI H5N1 would likely occur.

The logistic regression results suggested that HPAI H5N1 occurrences were significantly related to consistent and predictable circumstances. The key factors increasing the probability of the occurrence for HPAI H5N1 were lower average monthly precipitation, humidity and elevation and higher average monthly temperature and poultry density. These results were consistent with previous studies conducted separately in other regions or countries such as Europe, China, Thailand, and Vietnam, but at different scales. Increased minimum temperature and decreased precipitation in January were associated with a higher incidence of HPAI H5N1 in wild birds in Europe (Si et al., 2010), while lower annual precipitation was related to the disease occurrence in mainland China (Fang et al., 2008). Lower elevation areas were more vulnerable to increased risk of contracting the disease in Europe and Thailand (Gilbert, Xiao, et al., 2008; Si et al., 2010). Increased duck and chicken density were thought to increase the incidence of the disease in Thailand and Vietnam (Desvaux et al., 2011; Gilbert, Xiao, et al., 2008; Minh et al., 2009; Pfeiffer et al., 2007).

The occurrence of HPAI H5N1 could not be explained separately by a single factor, but rather by combinations of the key factors. As noted by Pfeiffer et al. (2007), a single factor, low temperature, would unlikely be associated with the first two waves of HPAI H5N1 which occurred around the Tet holiday, as temperature patterns vary substantially from the North with colder conditions to the South with warmer weather in Vietnam (Pfeiffer et al., 2007). However, the combination of all weather factors poultry density and elevation might explain the situation. Although the temperature in December and January are low (averaging around 16 degree Celsius), these months are characterized by low humidity, low precipitation (Figure 2-7) and high poultry density (Pfeiffer et al., 2007) to meet high demand for poultry for Tet holiday which favor the occurrence of the disease. November and April which were predicted as months with the highest probability of HPAI H5N1 occurrence have the same temperature patterns as in the south. These months are characterized by warmer conditions, lower precipitation and less humidity which appear to be associated with favorable conditions for the virus spread.
Figure 2-6. Monthly probability prediction of HPAI H5N1 occurrence
The temporal pattern together with geographical location provide interesting insights into the epidemic. Although the temporal aspect of poultry density and elevation was not recorded in the study, their combination with variable weather contributed the varying spatio-temporal distribution of the disease in the Red River Delta. The direct as well as indirect links between weather variability and the occurrence of HPAI H5N1 has been documented (Fang et al., 2008; Gilbert, Slingenbergh, et al., 2008; Si et al., 2010). Given the dynamic changes in the key factors over space and time, the probability of HPAI H5N1 occurrence changed accordingly.

The monthly prediction maps in Figure 2-6 show that the presence of factors contributing to the spread of HPAI H5N1 vary in terms of timing and location. It is noticeable that the region of highest probability, as identified in red, mostly occurs in coastal and lowland provinces throughout all months of the year. However, regions of highest probability and change across the months. As identified in the logistic regression model, weather factors significantly affected the occurrence of HPAI H5N1. Weather patterns in the Red River Delta vary and can be characterized as distinct seasons with Spring, Summer, Autumn and Winter. Figure 2-7 presents the range of weather patterns by month in the Red River Delta in the period from 2003-2006. The variable weather between months contributed to the spatial distribution of the disease.

In January, the predicted probability was high compared to other months with mean probability at 0.0216 (Table 2-3). The higher probability areas were predicted in provinces to the east and south of Hanoi capital such as Ha Nam, Hung Yen, Bac Ninh and Hai Duong and part of Hai Phong. Although temperature is lower than other months, precipitation and especially, humidity are also low which would likely favor the occurrence of HPAI H5N1. In addition, increased production, movement and trade of live poultry prior to the Tet holiday to meet the high demand for poultry, as noted by Pfeiffer et al. (2007), may be associated with the spread of the H5N1 virus. The predicted spatial distribution is consistent with the first and the second waves of HPAI H5N1 which mostly occurred in Bac Ninh, Hung Yen, Hai Duong and Hai Phong in January.

These provinces still remain at higher risk for HPAI H5N1 occurrence as compared to other areas in the Red River Delta in February and March. However, the probability of HPAI H5N1 appears to decrease when the number of poultry significantly declines after the Tet holiday and humidity is exceptionally high (close to 100%).
Figure 2-7. Weather patterns by months in the Red River Delta from 2003 - 2006

The situation starts to change in April, May, June and July with higher probability recorded in April but lower in the months after. The area with higher probability expands east and south into lower elevation provinces near the Gulf of Tonkin. The area in red includes Thai Binh, Nam Dinh and a part of Ha Nam and Ninh Binh provinces where rice farming and poultry production are the main agricultural activities. Hai Duong and Hai Phong are still vulnerable to the disease. The predictive spatial pattern is also consistent with the observed spatial distribution of the fifth wave reported in May and June, 2007 which occurred mostly in Ninh Binh, Nam Dinh, Ha Nam and Hai Phong provinces. The fifth wave was concentrated in areas where rice was harvested and free-grazing ducks were raised to meet the high demand for duck meat during the summer. These factors are in addition to those associated with weather and represent factors consistent with other studies (Desvaux et al., 2011; Fang et al., 2008; Gilbert, Xiao, et al., 2008; Minh et al., 2009; Paul et al., 2010; Pfeiffer et al., 2007) explaining the occurrence of HPAI H5N1.
The predicted spatial distribution of HPAI H5N1 shifts in the period from July to October. Starting from the southern areas of the Red River Delta, including Nam Dinh and Thai Binh provinces in July, a zone of high probability moves up North to Hung Yen, Hai Duong and Bac Ninh in August, then expands to the capital of Hanoi and Vinh Phuc province in September. The zone extends to Hai Phong province in October. The probability of HPAI H5N1 occurrence between July and September appears to be lower compared to other months. This period falls in the summer rice cropping which starts in June and ends with harvests in October and November. Hot, humid and rainy weather is typical for the Red River Delta during this time. This type of weather does not support the occurrence and circulation of the H5N1 virus as suggested by the logistic analysis in the previous section. In addition, farmers focus more on harvesting and selling popular summer fruits such as litchi and longan.

The highest probability of HPAI H5N1 occurrence occurs in November and remain high in December, mainly concentrating on coastal provinces to the east and south east of Hanoi, including Hai Phong, Hai Duong, Thai Binh and Nam Dinh. This result is consistent with the third wave of HPAI H5N1 which occurred in November and December 2005. This period is characterized by increased poultry numbers, movement and trade of live young poultry as well as mature poultry to prepare for increased sales occurring before the Tet holiday. The weather patterns also favor the disease occurrence with warm temperatures, low precipitation and low humidity.

2.4. Conclusions

The study results suggested that average monthly temperature, average monthly precipitation, average monthly humidity, poultry density and elevation were critical factors explaining the probability of HPAI H5N1 occurrences and spread in the Red River Delta region of Vietnam. Higher average monthly temperatures and poultry density in combination with lower average monthly precipitation, humidity in low elevation areas, roughly from November to January and April to June, contribute to the higher occurrence of HPAI H5N1. The monthly predictive maps identify areas that have a higher probability of HPAI H5N1 occurrence. The areas more vulnerable to the disease are lower elevation provinces to the east and south of Hanoi, near the Gulf of Tonkin, including Hai Duong, Hai Phong, Ninh Binh, Thai Binh and Nam Dinh. The cross-validation results indicated high accuracy of the predictive maps with accuracy levels around 85%.
The analysis examining the predicted temporal and spatial distribution of HPAI H5N1 provides insights into factors affecting the HPAI H5N1 occurrences. The study’s results would provide the Vietnam Department of Animal Health (DAH) as well as other international organizations such as Food and Agriculture Organization (FAO) and World Health Organization (WHO), etc., with important information on when, where and why the disease would likely occur. Such predictive maps may be useful in developing effective control strategies.

References


CHAPTER 3: ECONOMIC ANALYSIS OF DUCK PRODUCTION AT HOUSEHOLD FARM LEVEL IN THE CONTEXT OF HIGHLY PATHOGENIC AVIAN INFLUENZA SUBTYPE H5N1 IN THE RED RIVER DELTA OF VIETNAM

3.1. Introduction

The first outbreaks of HPAI H5N1 in Vietnam were reported in late 2003, since then, there have been five waves and sporadic outbreaks recorded over the years. The disease was mainly confirmed in unvaccinated ducks (Gilbert et al., 2008; Minh et al., 2009). Edan & Bourgeois (2006) found the presence of the HPAI H5N1 virus mostly in live ducks and geese. It was suggested that the free range duck farming system is most vulnerable (at risk) to HPAI H5N1 (Edan & Bourgeois, 2006). 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 (Alhaji & Odetokun, 2011; FAO, 2008). Poultry sectors 3 and 4 as classified by (FAO, 2008) include smallholder or backyard producers which are characterized by this 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 (Thieme, 2007).

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) (Peyre et al., 2008; Phan, Dusquesne, Lebailly, & Vu, 2010). 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 stamping out conducted to contain the virus (OIE, 2014). 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 when is the optimal time to sell the ducks in order to maximize profit. The situation is made more complicated 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 explore the expected economic impacts of HPAI H5N1 on smallholder duck producers in the Red River Delta of Vietnam. More specifically, the study (i) develops a conceptual model using a dynamic optimization process by constructing the Bellman equation to optimize the producer's decision of maximizing profit; (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.

3.2 Analytical methods

3.2.1 Conceptual model

Consider a smallholder producer who raises ducks for meat. Assume that the producer’s income is derived solely from the sale of 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 characteristics of production. Following the optimality principle in dynamic programming developed by Richard E. (Bellman, 1957), 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 (Fackler, 2002). The framework for the Bellman equation for duck production is shown in Figure 3-1.
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 assumption 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 (than possibly HPAI H5N1); all ducks must be culled when the disease occurs; (vi) ducklings are purchased at the first day of age and raised till 12 weeks old at which point the flock starts to experience significant reductions in their rate of growth; (vii) vaccination for 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 $a \in \{1,2,\ldots,14\}$, where $a = \{1,2\}$ represents the cleaning period, implying that there is 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 $d \in \{0,1\}$, where $d = 1$ implies that the disease is detected and $d = 0$ if the disease is not present or undetected. State variables are given as:

$$
\begin{align*}
  a & \in \{1,2,\ldots,14\} & \text{Week of production} \\
  d & \in \{0,1\} & \text{The detection of HPAI H5N1}
\end{align*}
$$

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.
Inputs: Feed, vaccine, veterinary medicine, lime powder, rice husk, electricity...etc.,

Production system

State variables
- Week of production cycle
- Detection of HPAI H5N1

Action space
- Continue
- Sell
- Cull

Reward function
- Additional costs of production
- Revenue
- Loss of investment

State transition
- Continue to the next period of production
- Start a new production cycle

Bellman equation (maximize profit)

Perform analysis

Results

Transition probabilities of HPAI H5N1

Figure 3-1: A framework for the conceptual model.
Let \( x = \{\text{continue, sell, cull}\} \) denote the producer’s action. The action space can be introduced by an equation system:

\[
x = \begin{cases}
\{\text{continue}\} & \text{if } a \leq 2 & \forall d \\
\{\text{cull}\} & \text{if } 2 < a < 14 & d = 1 \\
\{\text{continue, sell, cull}\} & \text{if } 2 < a < 14 & d = 0 \\
\{\text{cull, sell}\} & \text{if } a = 14 & d = 0 \\
\{\text{cull}\} & \text{if } a = 14 & d = 1
\end{cases}
\] (2)

The system equation (2) indicates that a new production cycle starts with 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 2 to 13, 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 production cycle is characterized by deterministic systems based on the actions in (3).

\[
a_{t+1} = \begin{cases}
1 & \text{if } x_t = \{\text{sell, cull}\} \\
a_t + 1 & \text{if } x_t = \text{continue}
\end{cases}
\] (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 age of ducks 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:

\[
P(d'|d, x) = \begin{bmatrix}
p_{11} & p_{12} \\
p_{21} & p_{22}
\end{bmatrix}
\] (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:

\[
f(a) = \begin{cases} 
- C(a) & \text{if } x = \text{continue} \\
R(a) - C(a) - F & \text{if } x = \text{sell} \\
-C(a) - F & \text{if } x = \text{cull}
\end{cases}
\] (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 would result in the sum of the negative cost function \( C(a) \) plus a negative fixed cost \( F \), \( f(a) = -C(a) - F \).

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

\[
V(a) = \max \left\{ \begin{array}{ll}
-C(a) + \delta \sum p(d' = p_{d_i}|d)V(a') & \text{if } x = \text{continue} \\
R(a) - C(a) - F + \delta \sum p(d' = p_{d_i}|d)V(a') & \text{if } x = \text{sell} \\
-C(a) - F + \delta \sum p(d' = p_{d_i}|d)V(a') & \text{if } x = \text{kill}
\end{array} \right.
\] (6)

where \( V(a) \) is the value function that represents the sum of current and expected future rewards \( V(a') \), given the transition probability \( p(d' = p_{d_i}|d) \) and the discount factor \( \delta \). The formulation of the discount factor is given: \( \delta = 1/(1+r)^i \) where \( r \) is the discount rate and \( i \) 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 illustrates an optimal expected profit following an optimal action in the context of HPAI H5N1.

3.2.2 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 (Huffman, 1988; Moolman, Blignaut, & Van Eyden, 2006; Moore, 1999; Moore & Dinar, 1995). Let C and R respectively represent the cost and revenue functions. The quadratic functional forms are given in the equations 7 and 8:

\[
C = \alpha_0 + \alpha_1 a + \alpha_2 a^2 + \epsilon 
\]

(7)

\[
R = \beta_1 a + \beta_2 a^2 + \gamma 
\]

(8)

where \(a\) and \(a^2\) are independent variables representing weeks of production and its square; and \(\epsilon\) and \(\gamma\) are error terms reflecting the determinants of the outcome. In the cost function (equation 7), \(\alpha_0, \alpha_1\) and \(\alpha_2\) are unknown parameters to be estimated, where \(\alpha_0\) is a constant denoting fixed costs and \(\alpha_1\) and \(\alpha_2\) indicate variable costs.

Assuming that the producer only receives revenue from selling ducks. It 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 8). The estimation of the function provides the values of the parameters \(\beta_1\) and \(\beta_2\).
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 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 (Verbeek, 2008).

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 (Verbeek, 2008).

### 3.2.3 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:

\[
 n = \pi(1 - \pi)(\frac{Z}{M})^2,
\]

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

\[
 n = \pi(1 - \pi)(\frac{Z}{M})^2 = (0.5)(0.5)(\frac{1.96}{0.1})^2 = 96
\]

Prior to the survey, a pilot investigation was conducted with the support of the local office of agricultural extension to understand duck production systems 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, were gather on a weekly
basis to estimate cost and revenue functions. Data were collected from September 2012 to January 2013. The survey results indicate 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 1.94$US in the period from August 2012 to January 2013. Details on the descriptive statistics of duck production are shown in Table 3-1.

**Table 3-1: Descriptive statistics of duck production**

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

Other parameters used in the conceptual model, including:

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 (CIA, 2013). The weekly discount factor is computed as: \( \delta = \frac{1}{1 + 0.00173} = 0.9982 \);

ii. An average annual probability of 0.0102 for HPAI H5N1 occurrence was estimated by Tran et al. (2013);

iii. Average fixed costs for exterminating of infected ducks and duck farm cleaning after sale was calculated as US$22.41 from the data collected.

### 3.3 Results and discussion

#### 3.3.1 Econometric estimations

The Breusch-Pagan and White tests were performed under hypothesis of homoskedasticity against unrestricted heteroskedasticity. The results shown in the Table 3-2 strongly indicate the existence of heteroskedasticity in both the cost and revenue functions.
Table 3-2: Breusch-Pagan and White tests for Heteroskedasticity

<table>
<thead>
<tr>
<th>Functional forms</th>
<th>Breusch-Pagan</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadratic cost function</td>
<td>Chi2 = 142.42</td>
<td>Chi2 = 179.53</td>
</tr>
<tr>
<td></td>
<td>Prob &gt; chi2 = 0.0000</td>
<td>Prob &gt; chi2 = 0.0000</td>
</tr>
<tr>
<td>Quadratic revenue function</td>
<td>Chi2 = 617.92</td>
<td>Chi2 = 348.95</td>
</tr>
<tr>
<td></td>
<td>Prob &gt; chi2 = 0.0000</td>
<td>Prob &gt; chi2 = 0.0000</td>
</tr>
</tbody>
</table>

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

Table 3-3: FGLS estimation results

<table>
<thead>
<tr>
<th>Functions</th>
<th>Coeff.</th>
<th>Std. Err.</th>
<th>p-value</th>
<th>95% Conf. Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost function</td>
<td>Intercept</td>
<td>327.37***</td>
<td>46.66</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>a</td>
<td>-45.15**</td>
<td>21.18</td>
<td>0.033</td>
</tr>
<tr>
<td></td>
<td>a²</td>
<td>10.67***</td>
<td>2.27</td>
<td>0.000</td>
</tr>
<tr>
<td>Revenue function</td>
<td>a</td>
<td>110.45**</td>
<td>37.28</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>a²</td>
<td>49.84***</td>
<td>7.23</td>
<td>0.000</td>
</tr>
</tbody>
</table>

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

The terms a and a² respectively represent the week of duck production and its square in weeks. 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.

\[
C = 327.37 - 45.15a + 10.67a^2 \\
R = 110.45a + 49.84a^2
\]

where C denotes the cost function and R is the revenue function. These functions together with the discount factor, probabilities of HPAI H5N1 occurrence 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.

3.3.2 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. Figure 3-2 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 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.

Figure 3-2: Optimal action at each period of the production cycle

The profit level estimated for a producer with an average of 794 ducks (Table 3-1) at each week of production is presented in Figure 3-3. Negative profit is found at the first 3 weeks of production. It is the producer's initial investment. It includes the costs of lime powder and disinfectants to disinfect duck production premises for cleaning period at 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 (Figure 3-3). Profit gradually decreases if the producer sells ducks late since the growth rate of costs is faster than the growth of revenues and become negative after week 13.
Figure 3-3: Estimated profit obtained at each week of the production cycle

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 3-4). The major loss comes from the purchase of ducklings for this period. 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 or 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 system is also found in Ha Tay, Ha Nam, Nam Dinh and Hung Yen provinces (Desvaux, Ton, Phan Dang, & Hoa, 2008). The duck farm is often located in the area 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 become 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 3-4: Expected Loss of production in case of disease occurrence at each period

<table>
<thead>
<tr>
<th>Week</th>
<th>Loss ($US)</th>
<th>Probability</th>
<th>Expected loss (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>874.59</td>
<td>0.125</td>
<td>109.32</td>
</tr>
<tr>
<td>4</td>
<td>1208.08</td>
<td>0.125</td>
<td>151.01</td>
</tr>
<tr>
<td>5</td>
<td>1601.45</td>
<td>0.125</td>
<td>200.18</td>
</tr>
<tr>
<td>6</td>
<td>2078.04</td>
<td>0.125</td>
<td>259.76</td>
</tr>
<tr>
<td>7</td>
<td>2661.19</td>
<td>0.125</td>
<td>332.65</td>
</tr>
<tr>
<td>8</td>
<td>3374.24</td>
<td>0.125</td>
<td>421.78</td>
</tr>
<tr>
<td>9</td>
<td>4240.53</td>
<td>0.125</td>
<td>530.07</td>
</tr>
<tr>
<td>10</td>
<td>5283.40</td>
<td>0.125</td>
<td>660.43</td>
</tr>
</tbody>
</table>

**Expected loss per production cycle** 2665.19

Table 3-4 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 duck producer per cycle. The formulation of the expected loss is given $E(x) = \sum x \cdot p(x)$, 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 $\$US\ 2665.19$ (Table 3-4) when the disease occurs.

### 3.3.3 Sensitivity analysis

Sensitivity analysis is applied to reveal how the estimated profit in case of disease free status and expected loss in case of HPAI H5N1 vary given the changes in 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 3-3. The range of the parameters are shown in the Table 3-5.

**Table 3-5: Parameters of the revenue and the cost functions at the 95% confidence intervals**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Revenue function</th>
<th>Cost function</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>[37.16, 183.72]</td>
<td>[-86.74, -3.57]</td>
</tr>
<tr>
<td>$a^2$</td>
<td>[35.63, 64.05]</td>
<td>[6.21, 15.14]</td>
</tr>
<tr>
<td>Cons</td>
<td>[235.75, 418.98]</td>
<td></td>
</tr>
</tbody>
</table>

Ten uniformly distributed values of parameters were chosen from each parameter ranges. It resulted in five sets of parameters with ten uniformly distributed values. Different combinations of parameters were generated from these sets of parameters which produced one hundred thousand possible combinations and estimated using the same computational procedure as applied in the previous analysis.

**Table 3-6: Results of the comparative static analysis (units = $US$)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
<th>95% Conf. Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated profit in case of disease free status</td>
<td>812.6</td>
<td>1395.32</td>
<td>-3823.92</td>
<td>5449.12</td>
<td>803.95 - 821.25</td>
</tr>
<tr>
<td>Expected loss in case of HPAI H5N1</td>
<td>2664.91</td>
<td>917.64</td>
<td>274.64</td>
<td>5055.19</td>
<td>2659.23 - 2670.60</td>
</tr>
</tbody>
</table>

Table 3-6 above represents the results of the comparative static analysis. The table 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.

3.4 Conclusion

This study develops a conceptual model using a dynamic optimization process to optimize the producer's decision at each period of the production cycle such that profits from production are maximized. The results are then used to evaluate the producer’s expected loss under the likelihood of contracting the HPAI H5N1 virus. The model results indicate 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 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's profit ranges from US$ 803.95 to US$ 821.25 if disease free, but suffers expected losses ranging from US$ 2659.23 to US$ 2670.60 if HPAI H5N1 occurs.

This study emphasizes the economic impact of HPAI H5N1 on a single producer at the farm level. The result suggests that a duck 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 expected maximum profit). If the disease is found in the flock and eradication is necessary, the economic loss can be devastating to the average duck producer. This shock can have long term consequences. Studies by Barnett et al. (2008); Carter & Barrett (2006); Carter et al. (2004) and Dercon (1996, 2005) have found that production may face severe difficulties to recover without financial assistance.

At the national level, each HPAI H5N1 event can have devastating economic losses as well as public health consequences. It not only impacts duck producers in the infected areas and human health in these areas but neighboring areas are also placed at risk. Dramatic decreases in duck meat demand and declines in market prices affect the entire production sector. The disease indirectly impacts other economic sectors of the country such as tourism. Therefore, it is crucial
for the government and policy makers to develop new disease prevention programs that are more successful in containing and preventing the HPAI H5N1 from recurrence.

References


BellmanDynamic programming1957.


Thieme, O. (2007). Trends, issues and options in applying long term biosecurity measures on production systems and sector structure. Presented at the Technical Meeting on HPAI and
% Preparing to run the program
clc
close all
clear all

% Optimal duck sale time schedule
fprintf('nOptimal profit under H5N1 context\n')

% Enter model parameters
delta = 0.9982;                % discount factor
F=22.41;                           % cost of killing ducks
K=9.73;                          % costs of duck farm cleaning

% Construct state space
s1 = (0:14)';                             % week of production
s2 = [0;1];                               % detection of H5N1
n1 = length(s1);
n2 = length(s2);
S1,S2] = gridmake(s1,s2);          % combined state grid

% Note that s1 enumerate all possible weeks, s2 enumerates all possible
% cleaning period, s3 enumerates detection of H5N1 and [S1,S2,S3] enumerates all conceivable
% combination of weeks, cleaning and detection of H5N1
n = n1*n2;                             % number of states
state=[S1,S2];

% Construct action space
X = ['S','K','G'];                        % sell, kill, or grow
% Construct reward function (actions sell=1, kill=2, grow=3)
age=S1-1; age(1)=0; % week of production
cost = 327.37-45.15*age+10.76*(age.*age); % per week cost function
revenue = 110.45*age+49.84*(age.*age); % revenue, if sold
f = [revenue-cost, -K*ones(size(age))-cost, -cost]; % period profit by action: Sell, cull and grow
% prohibited states/actions
   f(S1==0,1) = -inf; % No sales on an empty farm
   f(S1==0,2) = -inf; % No kill on an empty farm
   f(S1==1,1) = -inf; % No sales at week 1
   f(S1==0,3) = 0; % No cost on an empty farm
   f(S1==14,3) = -inf; % Can't keep birds week 14 or more
% Construct state transition probability matrix
P = zeros(3,n1,n2,n1,n2);
   for i=1:2 % no duck on a farm state
      for j=1:n2
            P(1,i,j,1,1)=1; % prohibited action
            P(2,i,j,1,1)=1;
            P(3,i,j,i+1,1)=1;
      end
   end
   for i=3 % duckling state
      for j=1:n2
            P(1,i,j,1,1)=1; % prohibited action
            P(2,i,j,1,1)=1;
            P(3,i,j,i+1,1,1)=1;
      end
   end
   for i=n1 % old duck state
      for j=1:n2
            P(1,i,j,1,1)=1;
            P(2,i,j,1,1)=1;
      end
   end
61
P(3,i,j,1,1)=1; % prohibited action
end
end
for i=3:n1-1
    for j=1
        P(1,i,j,1,1)=1;
P(2,i,j,1,1)=1;
P(3,i,j,i+1,1)=1-0.102;
P(3,i,j,i+1,2)=0.102;
    end
    for j=2
        P(1,i,j,1,1)=1;
P(2,i,j,1,1)=1;
P(3,i,j,i+1,2)=1;
    end
end
P = reshape(P,3,n,n);
% Patch model structure
clear model
model.reward = f;
model.transprob = P;
model.discount = delta;
% Solve infinite-horizon model using policy iteration
[v,x,pstar] = ddpsolve(model);
V=reshape(v,n1,n2);
X=reshape(x,n1,n2);
% Plot optimal value
V1=V(:,1);V2=V(:,2);
figure(1); plot(age(3:13), V1(3:13),age(3:13),V2(3:13))
xlabel('Week'); ylabel('Optimal Value');
legend('disease','no disease')
% Plot optimal action
X1=X(:,1); X2=X(:,2);
figure(2); plot(age(3:13), X1(3:13), age(3:13), X2(3:13))
xlabel('Week'); ylabel('Optimal Action');
legend('disease', 'no disease')
% Save Plots as EPS Files
prtfigs(mfilename)
CHAPTER 4: POLICY IMPLICATIONS FOR PREVENTION OF HIGHLY PATHOGENIC AVIAN INFLUENZA SUBTYPE H5N1 IN CONJUNCTION WITH RISK FACTORS IN THE RED RIVER DELTA OF VIETNAM

4.1. Introduction

The Highly Pathogenic Avian Influenza (HPAI) subtype H5N1 has had serious, detrimental effects on the economy and human health in Vietnam since the first reported outbreak on 27 December 2003 (OIE, 2004). Millions of poultry were culled due to the disease occurrences, causing an estimated economic loss of 3000 billion VND (approximately US$ 187.15 million) (Phan et al. 2010; Peyre et al. 2008). The average growth rate of poultry population was reduced from 7.6% for the period 2000 – 2003 (before HPAI H5N1 occurrence) to -3.8% for the period 2003 – 2006 (during HPAI H5N1 disease occurrence) (Desvaux et al. 2008). Market demand and price decreases further caused economic losses to poultry producers (Tran et al., 2013; World Bank, 2007). The disease also seriously affected human health. By 19 November 2010, a total of 119 human cases of HPAI H5N1 were reported, with 59 deaths (CAP, 2011).

Financial support from many international organizations, such as the Food and Agriculture Organization (FAO) of the United Nations, World Bank and others, helped to contain the disease through a mass vaccination campaign implemented nationally from late September to the beginning of November 2005. The goal of the vaccination program was to reduce the spread of the HPAI H5N1 virus as stated in the Directive No. 25/2005/CT-TTg dated 12 July 2005. Since then, the vaccination campaign had been applied in two rounds every year until 2010 (with the first round from April – May and the second round from October – November). The vaccination campaign covered most provinces in the country. The vaccination program continued in later years but on a smaller scale and primarily implemented in order to prevent the spread of the virus.

The Red River Delta has been identified as a high-risk area for the disease (Minh et al., 2009; Pfeiffer et al., 2007b). The Delta has been severely affected by the three large epidemic waves of HPAI H5N1 outbreaks and other sporadic outbreaks. The first wave occurred from

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4 Directive No. 25/2005/CT-TTg dated 12 July 2005 from the Prime Minister regarding vaccination against the avian influenza
January – February 2004, the third wave and the fifth wave took place from October – December 2005 and May – September 2007, respectively (FAO, 2008b; Pfeiffer et al., 2007a; Pfeiffer et al., 2007b). As a result, compulsory vaccination was implemented across all geographical areas for all provinces in the Delta. Although the launch of the vaccination campaign was thought to contribute to the reduction of the disease occurrence (Henning et al. 2009), it did not fully contain the disease. Sporadic outbreaks have been reported over the years and presently with the reported outbreaks in Bac Ninh and Nam Dinh provinces in January and February 2014 (OIE, 2014).

Although the vaccination program has shown to be a viable means of protection against the HPAI H5N1 virus (Henning et al. 2009) and it covered all geographical areas of the Red River Delta, the campaign was carried out only twice a year in April – May and October – November. However, poultry production occurs all year round. A later study (see Tran et al. 2013) confirmed that November to January and April to June were the periods most vulnerable for disease occurrence. A sizeable portion of poultry production remained unvaccinated at different times of the year. The circulation of HPAI H5N1 virus was found in unvaccinated waterfowl (Minh et al., 2009; Taylor & Do, 2007). Therefore, it is assumed that unvaccinated poultry between two rounds will be at risk of infection. Although mandatory vaccination occurs twice a year, farmers are encouraged to vaccinate whenever a new production period begins but are reluctant to vaccinate more frequently because of added costs. The cost of vaccination was estimated to be approximately US$10 million per round (Sims & Do, 2009). Therefore, it is critical for the animal health authorities to design a vaccination plan that effectively contains the disease in the Delta on a year round basis.

A number of studies have identified factors affecting the occurrence and spread of the HPAI H5N1 virus in Vietnam in general and in the Red River Delta in particular. It was suggested that higher average monthly temperatures and poultry density in combination with lower average monthly precipitation and humidity and elevation significantly affected the occurrence of HPAI H5N1 in the Delta(Tran et al., 2013). Other factors linked with the disease at the national level were: (i) a higher proportion of land used for rice paddy fields and aquaculture, (ii) increases in production, trade and movement of live poultry and (iii) the expansion of free-grazing ducks (Desvaux et al., 2011; Gilbert, Chaitaweesub, et al., 2006; Gilbert et al., 2008; Pfeiffer et al., 2007b). Given these findings, it is not likely that all areas
within the Red River Delta are equally susceptible to the disease. Previous studies provided little information on spatial locations where efforts should be concentrated in order to prevent and control the spread of the disease in the Delta (Tran et al. 2013; Desvaux et al. 2011; Gilbert et al. 2008; Pfeiffer et al. 2007b).

This study explores implications of an alternative policy, which is likely to be more successful in containing and preventing the disease from recurrence in the Red River Delta, Vietnam and reducing vaccination costs. Specifically, the alternative policy involves shifting vaccination for HPAI H5N1 from the entire Delta to specific areas identified as high probability areas for the disease occurrence within the Delta. This modification would involve more frequent vaccination campaigns throughout the year. Two key questions emerge with this proposal: (i) Where are the high probability areas (focus areas) for the alternative policy?; (ii) Is it beneficial for the Government to switch to the alternative policy in terms of the efficacy and the costs of vaccination program? To answer the questions and fulfill the objective, this study (i) identifies the focus areas for the alternative policy to be implemented in the Red River Delta and (ii) processes the tradeoff between the current policy and the alternative policy based on the efficacy and cost analyses of vaccination programs.

4.2. Study area, data sources and data pre-processing.

This study focuses on the Red River Delta of Vietnam (Figure 4-1) which represents one of the two largest flood plains in Vietnam. The Delta includes two large river systems – the Red river and Thai Binh river systems that support agricultural and livestock activities. The Red River Delta includes 8 provinces and 2 municipalities, the capital city of Hanoi and the main port of Hai Phong. The Delta plays an important role and interacts with a wide range of environmental and socioeconomic sectors including industry, commerce, services, agriculture, tourism, etc. Livestock production is among the main activities in the Delta, including poultry, pig and cow husbandry. Poultry production has faced serious problems caused by the HPAI H5N1 disease.

The HPAI H5N1 outbreaks data were collected and reported by The Vietnam Department of Animal Health. The Red River Delta in Vietnam has been identified as a high-risk area for the disease (Minh et al., 2009; Pfeiffer et al., 2007b). The Delta has been severely affected by the three large epidemic waves of HPAI H5N1 outbreaks. The first wave occurred from January – February 2004, the third wave and the fifth wave took place from October – December 2005 and
May – September 2007, respectively (FAO, 2008b; Pfeiffer et al., 2007a, 2007b). A number of outbreaks in the second epidemic wave which was from November 2004 to March 2005 were also reported in the Red River Delta despite the main effects in the Mekong Delta. Other sporadic outbreaks over the period from December 2003 until the present with the recently reported outbreaks in Bac Ninh and Nam Dinh provinces in January and February 2014 (OIE, 2014). Although the disease occurred in the Delta from the end of 2003, the dates and locations of occurrences were not formally reported until the end of March 2004 (Pfeiffer et al., 2007b). This EWC study analyzed reported disease data for the period starting from the end of March, 2004 to the end of December, 2007 which included 267 confirmed HPAI H5N1 outbreaks in the Red River Delta. The data were reported at the commune level and coded as 1 if the disease was found or 0 if there was no disease reported.

![Figure 4-1: The study area – The Red River Delta, Vietnam](image)

Other data used for the analysis are identified based on earlier studies of HPAI H5N1 in Vietnam. They include factors which previously were found to have effects on the occurrence of
the disease such as the percentage of land used for rice paddy fields and aquaculture (Pfeiffer et al., 2007b), chicken and water bird density (Desvaux et al., 2011; Gilbert et al., 2008; Pfeiffer et al., 2007b) and elevation (Gilbert et al., 2008; Tran et al., 2013). Two other land use factors, characterizing built-up and forest/perennial trees features, are also included.

These variables, percentage of land used for rice paddy fields, aquaculture, built-up and forest/perennial trees, and chicken and water bird density, are measured at the commune level and obtained from The 2006 Vietnam Rural, Agricultural and Fishery Census provided by the East West Center—National Science Foundation project (EWC 2013). For this study, the weighted overlay technique is used whereby each factor is categorized into 4 groups by using the Jenks natural breaks classification method (Jenks 1967). This is a commonly used statistical method in ArcGIS to group data in categories. This procedure arranges variable values into different classes which reduces the variance within each class while increasing the variance between classes through an iterative process (Baz, Geymen, & Er, 2009). This method was found to be a suitable classification method for mapping epidemiological data (Brewer & Pickle, 2002; North, 2009). Details are presented in Table 4-1.

Elevation data are obtained from the Shuttle Radar Topography Mission (SRTM) 90-m resolution Digital Elevation Model (DEM) (CGIAR-CSI, n.d.). The Red River Delta topography is reclassified into 4 groups of elevation (above 200m, from 15 m to 200 m, from 5 m to 15 m and less than 5 m) and coded from 1 to 4 respectively to represent upland, midland, lowland and coastal areas (see (Tran et al., 2013). Of which, coastal areas were found to be most vulnerable to disease occurrence. These data are then retrieved for each commune at its centroid and merged with other data using commune codes for the statistical analysis.
Table 4-1: Data sources and classification descriptions of variables

<table>
<thead>
<tr>
<th>Data</th>
<th>Unit</th>
<th>Label</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPAI H5N1 occurrences</td>
<td>Unit</td>
<td></td>
<td>The Vietnam Department of Animal Health</td>
</tr>
<tr>
<td>Water bird density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1: 0 - 892</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 2: &gt; 892 - 2097</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 3: &gt; 2097 - 4299</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 4: &gt; 4299</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of heads/km²</td>
<td>1 = Low</td>
<td>The 2006 Vietnam Rural, Agricultural and Fishery Census</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 = Medium low</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 = Medium high</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 = High</td>
<td></td>
</tr>
<tr>
<td>Chicken density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1: 0 - 1738</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 2: &gt;1738 - 3992</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 3: &gt;3992 - 9472</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 4: &gt;9472</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Number of heads/km²</td>
<td>1 = Low</td>
<td>The 2006 Vietnam Rural, Agricultural and Fishery Census</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 = Medium low</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 = Medium high</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 = High</td>
<td></td>
</tr>
<tr>
<td>Elevation</td>
<td>m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1: ≤ 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 2: &gt; 5 - 15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 3: &gt; 15 - 200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 4: &gt; 200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Coastal areas</td>
<td>SRTM 90-m resolution DEM: <a href="http://srtm.csi.cgiar.org/">http://srtm.csi.cgiar.org/</a></td>
</tr>
<tr>
<td>Land use/land cover</td>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquaculture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Built-up</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest/perennial trees</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat TM/ETM+ Bands 1-5, 7</td>
<td></td>
<td></td>
<td>The 2006 Vietnam Rural, Agricultural and Fishery Census</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The USGS EROS Data Center (<a href="http://glovis.usgs.gov/">http://glovis.usgs.gov/</a>)</td>
</tr>
</tbody>
</table>

Remotely sensed Landsat TM/ETM+ Bands 1-5, 7 data that cover the study area were downloaded from the USGS EROS Data Center (USGS, 2013). The data provide critical information for identifying areas vulnerable to HPAI H5N1. The Red River Delta is covered by 4 Landsat tiles: P126R045, P126R046, P127R045 and P127R046 (Figure 4-2). This study uses the application of support vector machine (SVM) for land use/land cover classification. It is used to classify land use/land cover in the Red River Delta into four categories that represent built-up, agriculture, forest/perennial trees and water areas. This is a supervised learning algorithm based on statistical learning theory that determines a hyper plane for optimally separating two classes. The SVM method has been successfully applied in several studies on biophysical tasks, land cover land use including vegetation, agriculture, impervious surfaces such as urban areas, etc. (Castrence et al., 2014; Mountrakis, Im, & Ogole, 2011; Schneider, 2012).
Figure 4-2: Landsat tiles covering the Red River Delta of Vietnam

Prior to classification, the Red River Delta boundary polygon was divided into 4 polygon subsets respectively located within 4 tiles. Landsat scenes were then stacked into a single image per tile and cropped to the corresponding polygon subsets of the Red River Delta. The groundtruth point locations with defined built-up, agriculture, forest/fruit trees and water labels for each subset were identified and double checked by visualizing point locations in different map sources such as the Landsat scenes themselves, Google Earth images and Bing maps. These groundtruth point locations were used as training data for supervised classification.

The classification process was performed using ENVI version 4.8 (Exelis Visual Information Solutions, CO, USA) and ArcGIS version 10.1 (ESRI, Redlands, CA, USA). Outputs were the classification maps of land use/land cover for each subset and were mosaiced together to produce the final land use/land cover classification map for the Red River Delta. The map represented built-up, forest/fruit trees, water and agriculture areas as shown in red, yellow,
blue and green, respectively. They are coded from 1 to 4 respectively indicating the increasing contribution to the higher risk of the disease occurrence (Figure 4-3).

**Figure 4-3: Land use/land cover of the Red River Delta.**

The classification results suggested that agricultural activities are dominant in the Red River Delta as shown in green. Water for agricultural production is provided by large river systems with the main Red and Thai Binh rivers flowing through the Delta. Water is transported to the entire area through a complicated channel system and stored in ponds or lakes to form a large alluvial plain area. Other important information that the land use/land cover map conveys is the location of urban core areas of cities in different provinces. These are areas where the intense red pixels are concentrated. It is noticeable that the urban core area of Hanoi accounts for a large proportion of red areas in the Delta. Forest areas are mainly located in the outskirt of the Delta and a portion of the yellow pixels represents fruit tree areas in Hai Duong province.
4.3. Analytical methods

For the first objective to identify the focus areas for the alternative policy in the Red River Delta, this study adopts the framework of ex-ante analysis. The term "ex-ante" means "from before" in Latin (Wagner et al., 2007). The ex-ante analysis uses the outbreak data available at the time of the launch of the current vaccination program in 2005. For the second objective to process the tradeoff between the current and the alternative policy, the outbreak data after the launch of the vaccination program is used in addition to the outbreak data before the program. Outbreak data are divided into two datasets. The first dataset contains the data before the launch of the current vaccination program in 2005 which includes the second and the third epidemic waves with a total of 193 outbreaks. The second dataset consists of outbreak data that occurred after 2005 which comprises of the fifth epidemic wave with 74 outbreaks. The use of the first dataset is to identify the focus location for the alternative policy. The second dataset is to evaluate the efficacy and costs of the vaccination program for the tradeoff between the current and the alternative policies.

For ex-ante analysis, weighted overlay analysis is applied to identify the focus locations for the alternative vaccination program. This method has been considered as one of the most suitable techniques and frequently used for site selection and suitability models in spatial analysis (ESRI, 2014). It has been widely applied in several fields e.g., disease management, climate change, habitat conservation, sustainable ecosystems or land-use planning, etc. (Diamond & Wright, 1988; Gilbert et al., 2006; Jayakumar et al., 2002; Münch & Conrad, 2007; Shahid, 2011). The technique requires that all input factors are classified into different groups and weighted to determine their relative influence accordingly. The analytical procedure for weighted overlay analysis in this study involves a two-stage process: (1) boosted regression trees (BRT) followed by (2) weighted overlay operations.

In the first stage, boosted regression trees is performed to determine the relative influence of each group for a given physical, environmental factor (e.g., chicken density, water bird density, elevation, and percentage of land used for rice paddy fields, aquaculture, built-up, and forest/perennial trees) in relation to HPAI H5N1 occurrence. BRT utilizes a combination of decision trees and boosting algorithms to improve prediction accuracy through an iterative process (Elith et al., 2006, 2008). A stochastic process which includes a probabilistic component used in the decision trees to select relevant predictor variables allows improvement in prediction
performance. The use of boosting improves accuracy in a single tree through a sequential process that allows trees to be fitted iteratively through a forward stage-wise procedure. Boosting with stochasticity is managed through a bag fraction which identifies the selected portion of data to be drawn from original data at each step. The model is best performed with a bag fraction ranging from 0.5 to 0.75 (Elith et al., 2008). The number of trees for optimal prediction is determined based on values assigned for learning rate which shrinks the contribution of each tree in the model and tree complexity which specifies the number of nodes in a tree. The rule of thumb recommended for BRT is to fit models with at least 1000 trees. A smaller learning rate and larger tree complexity are preferred since it increases the number of trees (Elith et al., 2006, 2008). Several combinations of learning rate and tree complexity are tested to choose the best setting for model performance which is determined through cross-validation (CV) technique. The final model setting is the combination of a tree complexity of 4 and a learning rate of 0.005 with a bag fraction of 0.75 which were previously used in (Martin et al., 2011).

Several BRT models are run through two phases. The first phase determines the relative influence of each group within a physical environmental factor to the occurrence of the HPAI H5N1 disease. Dummy variables representing each group within a factor are created and fitted into the BRT model with response variable of HPAI H5N1 outbreaks. There are 4 BRT models being run separately for 4 physical, environmental factors (chicken density, water bird density, elevation and land use/land cover category which include the percentage of land used for rice paddy fields, aquaculture, perennial trees and forest, and built-up areas). The second phase ascertains the relative influence of each physical environment factor (chicken density, water bird density, elevation, and percentage of land used for rice paddy fields, aquaculture, built-up and forest/perennial trees) associated with disease occurrence. This information is essential for the weighted overlay technique employed in the next stage which determines the focus areas for the vaccination campaign. The estimation procedure for BRT is conducted through R package version 3.0.2, founded by the members of the R Development Core Team as a part of the Free Software Foundation's GNU project.

The second stage determines the potential focus area for the vaccination program by performing a series of overlay operations in ArcGIS 10.1. The overlay operation is manipulated through raster analysis in ArcGIS 10.1 platform. Therefore, it is required that all input factors are stored in raster format. Therefore, all vector layers detailing categorical data for chicken density
and water bird density are converted to raster format together with elevation and land use/land cover classification. All raster data layers were converted to the same spatial resolution at 30x30 and clipped to the Red River Delta administrative maps. Steps for weighted overlay analysis are orderly followed (ESRI, 2014):

1. Assign the weighted relative influence obtained from the first phase of the BRT for each corresponding group within an input factor layer through raster reclassification processes.
2. Multiply reclassified input raster layers by weighted relative influence obtained from the second phase of the BRT. The output values are rounded to the closest integer number.
3. Add the resulting input raster layers to produce the output raster layer.

The analysis provides suitability maps with suitability scores in integer numbers scaled from 0 to 100. The higher suitability scores represent the higher probability of contracting the HPAI H5N1 disease. Areas with higher suitability scores are suggested as good candidates where the alternative vaccination program should be focused.

For the tradeoff between the current and the alternative policies, the efficacy and the costs of vaccination program are estimated for each policy. The second dataset which includes data of the fifth epidemic wave with 74 affected communes is used in addition to the first dataset. The efficacy of the vaccination program is the measure of proportionate reduction in the rate of disease occurrence as the result of the vaccination program. This can be achieved through the calculation based on the relative risk of disease (Weinberg & Szilagyi, 2010).

\[
\text{Efficacy} = \left(1 - \frac{\text{ARV}}{\text{ARU}}\right) \times 100
\]

where ARU and ARV are respectively the infection rates before and after the launch of the vaccination program. The infection rate is the number of affected communes divided by the total communes in the Red River Delta.

To implement the vaccination program, the government is responsible for all the costs including the costs of vaccine, labor and other costs associated with vaccination. The costs for the vaccination program is the product of the number of birds vaccinated, the cost of vaccination per bird and the number of vaccination rounds per year. However, the program did not fully contain the disease. The fifth epidemic wave was reported in 2007. To contain and prevent the disease, Vietnamese government implemented the stamping out method which culled all birds in affected communes and emergency vaccination to vaccinate all birds in surrounding communes.
These are extra costs of the vaccination program. The total costs of vaccination program, therefore, are comprised of the cost for the government vaccination program, the cost of emergency vaccination, government compensation for birds culled and farmer's loss because of value difference between market price and government's compensation when the disease occurs.

\[
\text{Cost} = A \times C \times N + B \times C + I \times G + (P - G) \times I \quad (2)
\]

where A is the number of birds vaccinated; C is the costs of vaccination per bird; N is the number of vaccination rounds per year; B is the number of birds vaccinated because of emergency vaccination; I is the number of birds culled due to the disease occurrence; G is the government compensation per bird culled and P is the market price per bird.

4.4. Results and discussions

4.4.1. Boosted regression trees analysis.

In the first phase, four BRT models are run separately for four physical, environmental factors, including chicken density, water bird density, elevation and land use/land cover to identify the relative influence of each group within a factor to the HPAI H5N1 occurrence. The weighted relative influence results are shown in Table 4-2.

The results revealed that lower groups of water bird density and chicken density are found to have higher relative influence as compared to other groups within each factor. Specifically, water bird density group 2 and group 1 have higher relative influence at 76% and 11% respectively as compared to 7% and 6% for group 3 and 4. Chicken density group 1 is found to have highest weight at 37% and followed by group 2 at 27% influence, group 3 at 25% and group 4 at 11%. It was noted that the traditional production methods with free range water bird farming and backyard chicken farming have been considered to be typical Asian production methods which have the potential of contracting and spreading the HPAI H5N1 virus to other neighboring farms (Alhaji & Odetokun, 2011; FAO, 2008a). Poultry sectors 3 and 4 (as classified by (FAO, 2004)) include open sheds, backyard chicken or free range water bird farming and characterized by small scale production with less than 2000 birds (Desvaux et al., 2008). On the other end, poultry sectors 1 and 2 are characterized by industrial and commercial poultry production which operate with standard procedures and keep poultry indoors continuously during production and maintain high biosecurity standards (FAO, 2004, 2007). These large producers have more than 2000 birds per production cycle. Therefore, it is expected that poultry sectors 3 and 4 would fall more in the medium low density group. This resulted in
higher density of free range water bird on paddy fields which was found likely to increase the probability of the disease occurrence in Vietnam (Gilbert et al., 2008; Pfeiffer et al., 2007b). Communes with medium water bird density are thought to have increased risk of contracting the disease (Henning et al. 2009).

Table 4-2: Relative influence of each group within a factor

<table>
<thead>
<tr>
<th>Name</th>
<th>Group</th>
<th>Relative influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water bird density</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Chicken density</td>
<td>1</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Elevation</td>
<td>1</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Land use/land cover</td>
<td>Agriculture</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Built-up</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Aquaculture</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Forest/perennial trees</td>
<td>2</td>
</tr>
</tbody>
</table>

Lower elevation was previously identified to be correlated with the HPAI H5N1 disease in Vietnam in general and in the Red River Delta, Vietnam in particular (Gilbert et al., 2008; Tran et al., 2013). This finding is further confirmed by BRT estimation. It is suggested that topographic elevation features noticeably contributes differently to the disease occurrence. Coastal areas with elevation less than 5m (Group 1 for Elevation in Table 4-1) play the most important role for disease occurrence. It is estimated to have 73% relative influence (Table 4-2). These are flat plain areas where rice production is the predominant agricultural activity in the Red River Delta. Lowland and midland areas are ranked the second and third at 26% and 11% influence. These areas are located to the west of the Delta, including the capital city of Hanoi. Land used for rice production also has the highest contribution to disease occurrence with a 46% influence and followed by land used for built-up purposes at 35% (Table 4-2). This result is in
agreement with studies by (Pfeiffer et al., 2007b) and (Gilbert et al., 2008) which suggested the link between HPAI H5N1 occurrence and the higher proportion of land use for rice paddy fields and closer distance to higher densely populated areas. Water bird movement through rice paddy fields has been defined as a potential source for the widespread HPAI H5N1 virus (Gilbert et al., 2006, 2007, 2008; Minh et al., 2009; Pfeiffer et al., 2007b). In contrast to lower elevation areas, upland areas with elevation greater than 200m were found not likely to affect the disease. Evergreen forests or forestry production dominates in these areas (EAP-AP, 1994). This result is also consistent with BRT estimation for land use/land cover which showed that the relative influence of land used for forest/perennial trees is small and measured at 2%.

Table 4-3: Relative influence of each factor to the HPAI H5N1 occurrences

<table>
<thead>
<tr>
<th>Variable</th>
<th>Relative influence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water bird density</td>
<td>19</td>
</tr>
<tr>
<td>Land used for rice paddy field</td>
<td>18</td>
</tr>
<tr>
<td>Elevation</td>
<td>18</td>
</tr>
<tr>
<td>Land used for aquaculture</td>
<td>17</td>
</tr>
<tr>
<td>Land used for built-up</td>
<td>14</td>
</tr>
<tr>
<td>Chicken density</td>
<td>12</td>
</tr>
<tr>
<td>Land used for forest/perennial trees</td>
<td>2</td>
</tr>
</tbody>
</table>

In the second phase of the BRT, all categorical variables including chicken density, water bird density, elevation, percentage of land used for rice paddy fields, aquaculture, perennial trees and forest, and for built-up areas are fitted into the BRT model to determine the relative influence of each factor to the HPAI H5N1 occurrence. The results (see Table 4-3) suggest that water bird density has the largest effect on disease occurrence with relative influence estimated at 19%. Ducks, as a reservoir host for the HPAI H5N1 virus, have been discussed in earlier studies (Gilbert et al., 2006, 2008; Minh et al., 2009; Pfeiffer, 2007; Smith et al., 2006; Songserm et al., 2006; Webster et al., 2007). The number of recorded duck related disease occurrences steadily increased from 11% in 2003/2004 to its peak of 78% in 2006/2007 (Minh et al., 2009).

The next highest relative influence factors are land used for rice paddy field, elevation, land used for aquaculture, land used for built-up, chicken density and land used for forest/perennial trees. Land used for forest/perennial trees has the smallest effect with 2% relative influence. This result further confirms the findings from BRT estimations for elevation and land use/land cover in the first phase whereby upland areas with forest/perennial trees land cover type are not likely to favor HPAI H5N1 occurrence.
4.4.2. Weighted overlay results.

The BRT estimation results provide essential information for weighted overlay analysis. Relative influence values in Table 4-2 are assigned to corresponding groups in each raster layer through raster reclassification processes. For instance, in the land-use raster, agriculture, built-up, water and forest/perennial trees groups are respectively assigned their corresponding relative influence values of 46, 35, 17, 2 (Table 4-2). The same procedure is applied for other raster layers detailing water bird density, chicken density and elevation.

Each of the input rasters is then weighted using weighted relative influence from Table 4-3. In this weighted overlay, water bird density has a 19% influence, land used for rice paddy field an 18% influence, elevation a 18% influence, land used for aquaculture a 17% influence, land used for built-up a 14% influence, chicken density a 12% influence and land used for forest/perennial trees a 2% influence. The output suitability map is shown in Figure 4-4.

![Figure 4-4: Suitability scores for the HPAI H5N1 occurrence in the Red River Delta](image)

The highest suitability score areas are shown in red, followed by orange. Yellow, green and blue areas have lower suitability scores. It is noticeable that these areas (suitability scores
ranging from 0 – 10, 11 – 20 and 21 - 25) are mostly located to the west and northwest of the Red River Delta. The lowest suitability score areas are either in urban cores or mountainous areas. They include urban core areas of Hanoi, Hai Phong, Hai Duong, Bac Ninh, Hung Yen, Nam Dinh and Thai Binh provinces and mountain areas of Ba Vi of Hanoi, Tam Dao of Vinh Phuc, Cuc Phuong national park of Ninh Binh and mountain areas located to the north of Chi Linh district of Hai Duong province. These areas are characterized by various economic activities in urban cores, forestry production or tourism services in mountain areas other than agriculture and poultry production. One of the most popular tourist attractions in the Red River Delta that attract millions of visitors every year are Cuc Phuong National Park and Bai Dinh Temple located in the mountains in the West of Ninh Binh. Tourism is the main economic activity in this area.

The areas with high suitability scores (ranging from 26 – 40) as shown in red and orange are chosen as the focus areas for the alternative vaccination program against HPAI H5N1. These areas are mostly located in the coastal areas to the east and south of Hanoi. A total of 1137 communes, corresponding to 50.6% of total communes in the Delta, are selected for the alternative policy. The areas were also previously identified to have highest probability of disease occurrence in the Delta (Tran et al., 2013). They include provinces near the Gulf of Tonkin, including Hai Phong, Thai Binh, Nam Dinh, Hai Duong and eastern part of Hung Yen and Ha Nam provinces. Almost the entire areas of Hai Duong, Hai Phong, Thai Binh and Nam Dinh provinces are identified as the focus areas for vaccination program except urban cores and mountains in the north of Hai Duong. Agricultural intensification is fully supported by water sources from the Red and Thai Binh river systems. Water bird production with free range farming is the most intensive in the Red River Delta together with the Mekong Delta (Edan & Bourgeois, 2006). Thanh Oai, Thuong Tin, Ung Hoa and Phu Xuyen districts of Hanoi are also identified as the focus areas. They are located to the south of Hanoi capital. These areas are famous for high quality free range duck meat product providing popularly for consumers in Hanoi market, especially the brand "Vit co Van Dinh".

4.4.3 Efficacy and Cost analyses of vaccination programs and policy implications

The ex-ante analysis identifies the focus areas for the alternative vaccination program against the HPAI H5N1 disease which involves shifting vaccination for HPAI H5N1 from the entire Delta to the identified focus areas within the Delta. These areas are extracted and overlaid
with the spatial distribution of the fifth HPAI H5N1 (Figure 4-5a). Although the current policy vaccinated all the poultry population in the Red River Delta, it was conducted only twice a year (April-May and October-November). This means unvaccinated poultry at different time of the year (Jan-Mar, Jun-Sep and Dec) is still at risk of the disease infection. The fifth wave of outbreak with 74 communes affected was the result of this missed vaccination in time. They were mostly located in the coastal areas to the east and south of Hanoi. The disease was mostly reported in unvaccinated poultry (OIE, 2007).

It was noted that the optimal length of a both chicken and duck production cycles was estimated at 10 weeks, including a two-week cleaning period (Tran, 2010; Tran & Yanagida, 2014). Assuming that producers continuously conduct production, there would be 5 duck production cycles per year. Therefore, the alternative policy would involve 5 vaccination campaigns throughout the year. (Henning et al., 2009) noted that the vaccination showed a viable means of protection against the HPAI H5N1 virus. As a result, it is expected that these high probability areas are protected from the HPAI H5N1 disease under the alternative policy. Figure 4-5(b) shows that a total of 61 out of 74 infected communes in the fifth epidemic is correctly predicted in the focus areas for the alternative vaccination program. As a result, the alternative policy would protect these 61 communes from the disease but the other 13 communes which are not covered by this policy are affected by the disease.
Figure 4-5: The focus areas for vaccination program.

The efficacy analysis of the vaccination programs is conducted by using Equation 1 to investigate which policy would be more successful in preventing the disease occurrence. The analysis results are shown in the Table 4-4. It is noted that the total number of communes in the Red River Delta are 2248 communes. There are 193 communes affected by the disease before the implementation of the current policy. It results in the infection rate $ARV = 0.0859$. The current vaccination policy contributed to the reduction of the affected communes to 74 as reported in the fifth epidemic waves, resulting in the infection rate $ARU = 0.0329$. The alternative is expected to further reduce the number of communes affected to 13 communes which yields the infection rate $ARU = 0.0058$. 
Table 4-4: The efficacy analysis of the two policies

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Before vaccination</th>
<th>Current policy</th>
<th>Alternative policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of communes</td>
<td>Communes</td>
<td>2248</td>
<td>2248</td>
<td>2248</td>
</tr>
<tr>
<td>Number of affected communes</td>
<td>Communes</td>
<td>193</td>
<td>74</td>
<td>13</td>
</tr>
<tr>
<td>Infection rate</td>
<td></td>
<td>0.0859</td>
<td>0.0329</td>
<td>0.0058</td>
</tr>
<tr>
<td>Efficacy</td>
<td>%</td>
<td>61.66</td>
<td>93.26</td>
<td></td>
</tr>
</tbody>
</table>

Using Equation 1 for the calculation of the efficacy of each policy, Table 4-4 shows that efficacy results for the alternative policy and for the current policy are respectively estimated at 93.26% and 61.66%. It is suggested that the alternative policy would be more successfully in reducing the rate of disease occurrence measured at 93.26% as compared to the current policy at 61.66%. It is expected that the alternative policy which involves more frequent vaccination in the identified high risk areas within the Red River Delta would better prevent the occurrence of the disease than the current policy.

Table 4-5: The cost analysis of the two policies.

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Before vaccination</th>
<th>Current policy</th>
<th>Alternative policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of birds vaccinated</td>
<td>Thousand heads</td>
<td>0</td>
<td>59,241</td>
<td>31,171</td>
</tr>
<tr>
<td>Times of vaccination per year</td>
<td>Unit</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Vaccination cost</td>
<td>Million US$</td>
<td>0</td>
<td>4.50</td>
<td>5.92</td>
</tr>
<tr>
<td>Number of affected communes</td>
<td>Communes</td>
<td>193</td>
<td>74</td>
<td>13</td>
</tr>
<tr>
<td>Number of birds culled</td>
<td>Thousand heads</td>
<td>6,375</td>
<td>2,165</td>
<td>395</td>
</tr>
<tr>
<td>Government compensation</td>
<td>Million US$</td>
<td>7.95</td>
<td>2.68</td>
<td>0.49</td>
</tr>
<tr>
<td>Number of communes included in emergency vaccination</td>
<td>Communes</td>
<td>543</td>
<td>304</td>
<td>92</td>
</tr>
<tr>
<td>Number of birds vaccinated in emergency vaccination</td>
<td>Thousand heads</td>
<td>0</td>
<td>8,625</td>
<td>2,898</td>
</tr>
<tr>
<td>Cost of emergency vaccination</td>
<td>Million US$</td>
<td>0</td>
<td>0.33</td>
<td>0.11</td>
</tr>
<tr>
<td>Farmers loss</td>
<td>Million US$</td>
<td>4.95</td>
<td>1.65</td>
<td>0.30</td>
</tr>
<tr>
<td>Total loss</td>
<td>Million US$</td>
<td>12.90</td>
<td>9.16</td>
<td>6.82</td>
</tr>
</tbody>
</table>

For the cost analysis of the current and the alternative policies, the results are shown in Table 4-5. It is noted that the current vaccination campaign covered the entire poultry population in the Red River Delta and was conducted twice a year. The cost for a HPAI H5N1 vaccination in Viet Nam are estimated at US$ 0.038/head, including vaccine cost of US$ 0.016 per dose, a labor cost of US$ 0.013 and other costs associated with vaccination of US$ 0.009 (Hinrichs, 5)

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5 The calculation of efficacy follows the Equation 1
Sims, & McLeod, 2006). As a result, the costs of the current policy is estimated at US$ 4.50 million per year. The alternative policy consists of about half of total communes in the Delta, covering 1137 communes with poultry population of 31,171 thousand birds. Having vaccinated poultry five times per year would cost US$ 5.92 million year. By examining at the costs of vaccination only, this shows that the costs of the alternative policy is higher than the current policy (US$ 5.92 million vs US$ 4.50 million).

When the disease occurs, the all birds in affected communes are culled due to the stamping out program and all birds in surrounding communes. However, before the official vaccination campaign was launched in the end of 2005, the only emergency response to the disease occurrence was stamping out program. This results in 6,375 thousand birds in 193 affected commune culled in the second and the third epidemic waves. After the implementation of the current policy, a total of 2,165 thousand birds are affected and culled and 8,625 thousand birds are vaccinated as the result of the emergency response to the disease occurrence. Under the alternative policy, it is estimated that 395 thousand birds in 13 communes are affected and culled by the disease. Other 2,898 thousand birds in 92 surrounding communes are vaccinated due to the emergency vaccination.

The government incurs more losses from the stamping out and emergency vaccination. The average amount of compensation per bird culled due to the disease occurrence was regulated at US$ 1.24/head (23,000VND/head)\(^6\), in Decision No 719/QD-TTg dated 5 June 2008. In addition, the average market value of a bird was estimated at US$ 2 (Sims & Do, 2009). The farmers also suffer losses of US$ 0.76/head from production because of value difference between market price and government's compensation. This results in the Government's additional loss from compensation and farmers' loss of US$ 7.95 million and US$ 4.95 million, respectively, in the second and the third epidemic waves. Under the current policy, the emergency vaccination was implemented which caused the government estimated US$ 0.33 million in addition to the government compensation and farmers loss measured at respectively US$ 2.68 million and US$ 1.65 million. These losses are also estimated at US$ 0.49 million, US$ 0.11 million and US$ 0.30 million for the government and farmers respectively under the alternative policy.

Table 4-5 suggests that without vaccination, total losses imposed to the government and farmers are higher than the vaccination program and estimated at US$ 12.90 million. Except for

\(^6\) Exchange rate  at 1USD = 18,500 VND
the costs of vaccination (US$ 4.50 million vs US$ 5.92 million), and other costs, the alternative policy are lower than the current policy. The total losses comprising vaccination costs, government loss for compensation of birds culled and for emergency vaccination and farmers loss are calculated at US$ 9.16 million for the current policy as compared to US$ 6.82 million for the alternatively policy. The cost analysis indicates that the alternative policy would save government and farmer resources due to lower costs associated with disease eradication and prevention. The results of the analysis suggest that Vietnam may face lower costs with the alternative policy.

Poultry production is much more complicated in reality. Producers may have different production cycles. Therefore, for the implementation of the alternative policy, it is recommended that the vaccination be done at the local level in order to minimize the number of different production cycles. It could be done at the commune level where the commune veterinary officers are required to monitor and vaccinate all poultry for alternative production cycles.

5. Conclusions

The challenge is to develop the most effective vaccination program against the HPAI H5N1 disease from a public policy perspective. The current vaccination policy which implemented an annual two round vaccination plan for the entire geographical area of the Red River Delta has not successfully controlled the disease. This study explores implications of an alternative policy, which is likely to be more successful in containing and preventing the disease from recurrence in the Red River Delta, Vietnam and reducing vaccination costs. It involves shifting from a two-round vaccination plan for the entire Delta to a more frequent vaccination plan for specific areas identified as higher risk areas for the disease occurrence within the Delta. It should be done at the local level for all production cycles.

To address the tradeoff between the two policies, this study first identifies the location and spatial distribution of higher probability areas of disease occurrence in the Red River Delta for the alternative policy using an ex-ante analysis framework and then process the tradeoff between the current and the alternative policy through the analysis of the efficacy and the costs of vaccination programs. Weighted overlay analysis is applied for the ex-ante analysis. The analytical procedure involves a two-stage process: (1) boosted regression trees (BRT) to determine the relative influence of each factor followed by (2) weighted overlay operations to identify the areas at higher risk of the disease based on their suitability scores. The efficacy and
cost analyses are then implemented to assess the proportionate reduction in the rate of disease occurrence and the costs imposed by each policy on the government and farmers. The study takes into account factors which were previously found to have effects on the occurrence of the disease such as the percentage of land used for rice paddy fields and aquaculture, elevation and domestic water bird and chicken density.

The ex-ante analysis suggests the focus areas for the alternative vaccination program against HPAI H5N1 are mostly located in the coastal areas to the east and south of Hanoi with elevation less than 5m. A total of 1137 communes, corresponding to 50.6% of total communes in the Delta, are selected for the alternative policy. The efficacy analysis suggests that the alternative policy which involves more frequent vaccinations in the identified high risk areas within the Red River Delta would be more successfully in reducing the rate of disease occurrence measured at 93.26% as compared to the current policy at 61.66% which implements an annual two-round vaccination plan for the entire Delta. The cost analysis indicates that the alternative policy would save government and farmer resources because of lower costs associated with disease eradication and prevention. Total losses imposed on both the government and farmers are higher for the current policy (US$ 9.16 million) than for the alternative policy (US$ 6.82 million).

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CHAPTER 5: SUMMARY AND CONCLUSION

This dissertation addresses the problems of Highly Pathogenic Avian Influenza subtype H5N1 in the Red River Delta of Vietnam. It aims at providing policy implications and production options which assist policy makers and smallholder poultry producers in their decision to prevent, control and eradicate HPAI H5N1. Through a series of three essays, this dissertation seeks to:

(i) Identify how weather variability, as measured in terms of monthly temperature, precipitation and humidity together with poultry density and elevation factors is related to the emergence of HPAI H5N1 and predict the probability and spatio-temporal distribution of the disease.

(ii) Analyze economic impacts of HPAI H5N1 on smallholder duck producers by estimating the expected economic losses under disease occurrence as compared to the maximum profit gained under the disease free situation.

(iii) Explore implications of an alternative policy, which is likely to be more successful in containing and preventing the disease from recurrence in the Red River Delta, Vietnam and reducing vaccination costs as compared to the current policy.

5.1. Major findings and policy implications

Understanding the mechanisms affecting the emergence and spread of HPAI H5N1 across space and time scales and predicting the probability and spatio-temporal distribution of the disease provides provisions of where, when and why the H5N1 virus occurs and disseminates. This information can assist animal health authorities to focus limited resources for the prevention, control and eradication of the disease.

Logistic regression results in Chapter 2 revealed that HPAI H5N1 occurrences were significantly related to consistent and predictable circumstances. The key factors increasing the probability of the occurrence for HPAI H5N1 were lower average monthly precipitation, humidity and elevation and higher average monthly temperature and poultry density. Predicted probabilities suggested that months from October to January and April to June, contribute to the higher probability of HPAI H5N1. Of which, November, April and January are most vulnerable to disease occurrence as compared to other months.

The temporal pattern together with geographical location provide interesting insights into the epidemic. Given the dynamic changes in the key factors over space and time, the probability
and spatial distribution of HPAI H5N1 occurrence changed accordingly. The monthly predictive maps identified areas that have a higher probability of HPAI H5N1 occurrence. The areas more vulnerable to the disease are lower elevation provinces to the east and south of Hanoi, near the Gulf of Tonkin, including Hai Duong, Hai Phong, Ninh Binh, Thai Binh and Nam Dinh provinces. Examining the spatio-temporal distribution of the HPAI H5N1 disease showed hot spots in these provinces with higher probabilities of disease occurrence. Therefore, it is critical for the government and policy makers to focus more resources for preparedness prevention and contingency planning, especially for those provinces near the Gulf of Tonkin and during the time periods October to January and April to June.

Given the existence of the HPAI H5N1 disease, it is likely that the disease may occur at any time during a production cycle. The occurrence of the disease usually results in the complete loss of the infected flocks since all ducks are culled to prevent spread and eradicate the disease. No HPAI H5N1 occurrence allows the producer to continue production as usual. Profit earned depends on the producer's decisions at each period of production – continue production, sell in the market or cull flocks of duck because of disease.

Chapter 3 examined the duck producer's decision making process during a production cycle. The analysis assumed profit maximizing action and emphasized the economic impact of HPAI H5N1 occurrence/non-occurrence on the producer at the farm level. The results suggested 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 (the first 2 weeks are the cleaning period during the production cycle). Maximum profit gained is US$ 805 for a producer with an average flock size of 794 ducks. In case of the disease occurrence, however, the loss is much higher than the maximum profit gained. The severity of the loss depends on the time of the 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 (for an average flock size of 794 ducks). The estimated loss increases substantially if the disease occurs during later periods. The most serious loss is measured at week 10 of production with the loss equal to US$ 5283.40 when ducks are optimally ready for sale in the market. The expected loss for the entire duck production cycle is estimated at US$ 2665.19 per duck producer or US$ 3.36/duck. Sensitivity analysis uncovered substantial variability in expected profit under the disease free status versus expected loss under disease occurrence. Given changes in parameters of the revenue and cost functions,
the results suggest that producer profit ranges from US$ 803.95 to US$ 821.25 if disease free, but suffers expected losses ranging from US$ 2659.23 to US$ 2670.60 if HPAI H5N1 occurs.

These results imply that a duck 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 maximum profit). If the disease is found in the flock and eradication is necessary, the economic loss can be devastating to the average duck producer. This shock can have long term consequences. Studies by Barnett et al. (2008); Carter & Barrett (2006); Carter et al. (2004) and Dercon (1996, 2005) have found that production may face severe difficulties to recover without financial assistance.

At the national level, each HPAI H5N1 event can have devastating economic as well as public health consequences. It not only damages the livelihood of affected duck producers and possibly their health but other producers as well. Dramatic decreases in duck meat demand and declines in market prices affect the entire sector. The disease indirectly impacts on other economic sector of the country such as tourism. Therefore, it is crucial for the government and policy makers to insure that the vaccination program is more successful in containing and preventing the spread of the Highly Pathogenic Avian Influenza subtype H5N1 from reoccurring in the Red River Delta, Vietnam.

Chapter 4 addressed the tradeoff between the current policy which implements an annual two-round vaccination program for the entire geographical area of the Delta and an alternative policy which involves more frequent vaccination in higher probability areas of disease occurrence within the Delta. To address the tradeoff between the two policies, this study first identified the location and spatial distribution of higher probability areas of disease occurrence in the Red River Delta for the alternative policy and process the tradeoff between the current and the alternative policy through the analysis of the efficacy and the costs of vaccination programs. Weighted overlay analysis was applied for the ex-ante analysis. The analytical procedure involved a two-stage process: (1) boosted regression trees (BRT) to determine the relative influence of each factor followed by (2) weighted overlay operations to identify the areas at higher risk of the disease based on their suitability scores. The efficacy and cost analyses are then used to assess the proportionate reduction in the rate of disease occurrence and the costs imposed by each policy on the government and farmers. This study took into account factors
which were previously found to have effects on the occurrence of the disease such as the percentage of land used for rice paddy fields and aquaculture, elevation and domestic water bird and chicken density.

The ex-ante analysis suggests that the alternative policy which involves more frequent vaccinations in the identified high risk areas within the Red River Delta would better prevent the disease from occurrence than the current policy which implements an annual two-round vaccination plan for the entire Delta. The focus areas for the alternative vaccination program against HPAI H5N1 are mostly located in the coastal areas to the east and south of Hanoi with elevation less than 5m. A total of 1137 communes, corresponding to 50.6% of total communes in the Delta, are selected for the alternative policy. The efficacy analysis suggests that the alternative policy would be more successfully in reducing the rate of disease occurrence measured at 93.26% as compared to the current policy at 61.66%. The cost analysis indicates that the alternative policy would save government and farmer resources because of lower costs associated with disease eradication and prevention. Total losses imposed on both the government and farmers are higher for the current policy (US$ 9.16 million) than for the alternative policy (US$ 6.82 million)

5.2. Further study

Understanding mechanisms affecting the occurrence of the HPAI H5N1 disease in complex and dynamic environments, analyzing the economic impacts to smallholder producers and assessing the risk of regional economic loss due to the disease are always challenging. Although the analyses showed statistically significant results, there are some limitations that require further study.

First, Chapter 2 examined and discovered the statistical relationship between weather variability, as measured in terms of average monthly temperature, precipitation and humidity, and other anthropogenic and physical environmental factors, such as poultry density and elevation in association with the occurrence of the HPAI H5N1 virus. However, studies done elsewhere e.g., Saksena et al. (2014), Fang et al. (2008), Paul et al. (2010) and Si et al. (2010) found other factors to be associated with HPAI H5N1 occurrence. These other factors include communes with mixed land uses, normalized difference vegetation index (NDVI), minimum distance to water bodies, minimum distance to national highway, food resource availability, etc., which could expand the analysis done in Chapter 2.
Second, for the estimation of the economic impacts of the HPAI H5N1, Chapter 3 primarily focused on producers who raise ducks for meat while HPAI H5N1 also affects producers of other poultry species such as chickens, swans and geese, etc... Because of the restrictions on time and facilities, the surveys were only conducted for 98 duck producers in two provinces: Hai Duong and Bac Ninh. These producers represent only a small proportion of poultry producers in the Red River Delta. The data collected thus fails to capture all characteristics of poultry production systems in the Delta. Furthermore, the dynamic model is constructed based on the assumption that producers have the same production system and that they have the same production cycles, all ducklings are about the same age and production is continuous throughout the year. In reality, poultry production is more complicated. Different producers have different production cycles. One producer may have different species of poultry. Therefore, some important information may be missing from the model. Future research could be conducted in more provinces and in a fashion that captures the complex production systems and the differences in production systems of different sizes. A new study would involve developing new models covering different production systems and using larger datasets collected through surveys of poultry farms in more provinces.

Third, Chapter 4 focused on the implications of the vaccination program as a means of prevention of the HPAI H5N1 disease by proposing an alternative vaccination policy which targets specific areas identified as higher probability areas for the disease occurrence within the Delta. The prediction error was measured at 17.57%. It is likely that the disease may still occur in the areas that are not covered by the alternative vaccination policy. Therefore, other prevention methods are needed such as biosecurity and best management livestock production practices. Biosecurity, involving the separation, cleaning or disinfection, is known as an effective and relatively low cost method for prevention, control and eradication of the disease (FAO, 2008, 2011). Investment to improve biosecurity is not likely to be attractive to smallholder poultry producers because of the additional costs on production (Thieme, 2007). The key for making biosecurity successful is to convince smallholder producers that there are advantages to biosecurity measures and these advantages outweigh the costs. Therefore, it is critical to conduct socio-economic analysis with respect to biosecurity planning to determine the level of acceptance of these proposed measures and the level of acceptance that will ensure that the biosecurity measures are effective.
References


