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Agricultural Household Response to Avian Influenza Prevention and Control Policies

Robert H. Beach, Christine Poulos, and Subhrendu K. Pattanayak

Recent outbreaks of highly pathogenic avian influenza in Asia, Europe, and Africa have caused severe impacts on the poultry sector through bird mortality and culling, as well as resulting trade restrictions and negative demand shocks. Although poultry producers play a major role in preventing and controlling avian influenza, little research has examined the influence of their farm-level decision making on the spread of the disease. In this study, we describe farm behavior under livestock disease risk and discuss data and analyses necessary to generate sound empirical evidence to inform public avian influenza prevention and control measures.

Key Words: agricultural household model, avian influenza, control measures, economic epidemiology, livestock disease, poultry production

JEL Classifications: Q12, Q18

Many subtypes of avian influenza (AI) viruses occur naturally among wild birds, and many cause only very mild symptoms from which these birds rapidly recover. However, certain subtypes (H5 and H7) can mutate and become highly pathogenic, especially when moving between different species of birds. In particular, it has been found that mild AI viruses adapted to migratory waterfowl have the potential to rapidly mutate into virulent and deadly strains when they infect domesticated poultry. The numerous strains of AI viruses are typically categorized into low pathogenicity avian influenza (LPAI), which generally causes only mild illness, and highly pathogenic avian influenza (HPAI), which is extremely infectious and causes severe illness with high mortality. Highly pathogenic avian influenza can reach mortality rates of 90% or greater in domesticated poultry, often within 48 hours of infection (CDC).

Recently, a strain of HPAI virus of type A of subtype H5N1 [HPAI A(H5N1)] has been responsible for disease outbreaks in poultry and/or wild birds in more than 50 countries. This strain was first identified in Hong Kong in 1997 and has spread from Asia to Europe and Africa. Since 2003, tens of millions of birds have died or been culled because of H5N1 outbreaks, primarily in Southeast Asia, which has resulted in severe impacts on the poultry sector (McLeod et al.; Verbiest and Castillo). The impacts have been exacerbated by trade restrictions and negative demand shocks in response to outbreaks (Moore and Morgan; Blayney).

In addition, HPAI A(H5N1) is generally considered to present the largest current global threat of a human influenza pandemic. The current strain does not readily infect humans, but there were 277 confirmed human cases of H5N1 infection and 167 deaths from 2003

Robert Beach is a senior research economist in the Food and Agricultural Policy Research Program, Christine Poulos is a senior research economist in the Environmental and Natural Resource Economics Program, and Subhrendu Pattanayak is a fellow in Environment and Development, RTI International, Research Triangle Park, NC.

through March 1, 2007 (WHO). There is concern that the virus could mutate into a form that can be passed from person to person. Under pandemic conditions, millions of people would likely be infected and global economic losses could be in the hundreds of billions or even trillions of dollars (McKibbin and Sidorenko). In response to this enormous potential liability, billions of dollars are being invested in disease prevention and control strategies.

Poultry disease prevention and control measures figure prominently in global HPAI mitigation strategies. Governments and donors are taking action and investing resources but frequently with limited empirical evidence. There are two bodies of research that inform the design of disease control measures. The first is epidemiological research, both theoretical and empirical. Primary introduction of AI into poultry within a region often occurs through contact with contaminated saliva, nasal secretions, and feces from infected wild birds or from contact with infected birds at live bird markets. Once AI is introduced into a poultry population, the epidemiological factors that influence secondary transmission between poultry and/or flocks of poultry are 1) infectivity (amount of virus produced by an infected flock), 2) susceptibility (amount of virus needed to infect a susceptible bird), 3) the amount of virus transferred during contact between birds, 4) the contact rate between birds, and 5) the number of flocks that make contact with each other (Stegeman and Bouma).

Collectively, epidemiological studies indicate that control measures that affect one or more of these factors (e.g., disease surveillance, biosecurity practices on farms and during transportation for marketing, depopulation of exposed and potentially exposed birds, vaccination) will affect transmission. However, these data shed little light on farm households' responses to disease dynamics, public disease controls, and the actions of other farm households.

The second area of research includes theoretical economic analyses of farm behavior in response to the risks of animal disease. These theoretical economic studies of animal disease have used an economic epidemiological framework (Beach et al.), a game theoretic framework (Hennessy 2005a, 2005b, 2006), and a social welfare framework (McCarthy et al.) to capture several key aspects of the issue. These include potential agricultural income losses; externalities associated with the spread of animal disease; public provision of services (e.g., technical support, public animal disease surveillance, vaccination); and use of policy instruments, including compensation and restrictions on marketing and transport.

There are clearly incentives for private investment in HPAI prevention and control due to potential agricultural income losses. However, externalities associated with the spread of HPAI will not be fully taken into account by farm households. The complexity of the HPAI disease control landscape is underscored by Delquigny et al.'s finding that the responses to three outbreaks in Vietnam were highly varied, with depopulation carried out inconsistently, continued consumption and sale of sick and exposed poultry, and a variety of procedures for disposing of infected carcasses, including disposal in public rubbish areas.

Given the endogeneity of disease risk and externalities in AI transmission, empirical analysis of farmer response to public HPAI policy interventions is critical for understanding disease transmission and the effectiveness of policy instruments, as well as informing refinements to instrument design. In this paper, we briefly review previous research on farm behavior and animal disease risk, discuss poultry production and disease risk, identify available HPAI control measures and policy instruments, and discuss data requirements for analyses that would improve our understanding of effective HPAI prevention and control.

Analytical and Empirical Research on Endogenous Disease Risk

The economic epidemiology literature emphasizes three important implications of externalities and endogeneity in human disease risk (Philipson; Gersovitz and Hammer). First, private behaviors determine public risks and vice versa. Second, private disease control

Table 1. Classification of Poultry Production Systems

	Sector 1	Sector 2	Sector 3	Sector 4
System	Industrial integrated	Commercial	Commercial	Village or backyard
Biosecurity	High	Moderate to high	Low to minimal	Minimal
Bird and product marketing	Commercial	Usually commercial	Birds usually sold in live bird markets	Birds and products consumed locally

Source: FAO (2004).

measures respond to incentives provided by public disease control measures. The nature of the incentives created and the response depends on the epidemiological and economic conditions. Third, under these conditions, the appropriate role for government is ambiguous (Pattanayak et al.). On one hand, Philipson predicts that private disease control measures will increase with population risk, such that public disease control would displace private measures. On the other hand, Gersovitz and Hammer suggest that externalities in disease transmission, as well as other market and institutional failures, limit the opportunities for and effectiveness of private control. They argue that public disease control is essential for overcoming these distortions.

Although we are not aware of applications of the standard economic epidemiology framework to animal health, some economic models of farm behavior account for externalities in disease transmission. McCarthy et al. model farms' adoption of trypanosomosis control options and explore the role of public provision of disease control. They find that private disease control is underprovided, although the extent of under provision varies with the disease control technology. In a series of papers, Hennessy (2005a, 2005b, 2006) explores farm biosecurity practices using a game theoretic framework. His findings underscore the need for greater coordination among producers to achieve more efficient levels of disease control.

Poultry Production and Avian Influenza

The typical scale and production technology employed in the poultry sector varies enormously between countries as well as within a country. Table 1 presents a general classification system developed by the Food and Agriculture Organization (FAO) and used previously to describe conditions with respect to HPAI. This classification system defines four sectors based on the typical level of biosecurity and marketing practices, two key factors in the spread of HPAI. Poultry can become infected through direct contact with infected birds or through contact with contaminated carcasses, manure, or poultry by-products. People (e.g., shoes, clothing), equipment (e.g., cages, vehicles), insects, rodents, or other agents contaminated with the virus may also spread the disease (Jacob et al.). Marketing practices, particularly marketing of live birds, are important because another key source of potential infection is the transmission of disease between regions through movement of animals, people, or infected material.

The overwhelming majority of poultry production in developed countries would be classified under Sector 1. These large integrated industrial operations, as well as commercial operations classified in Sector 2, are generally considered less likely to be infected by HPAI. They typically follow far more stringent biosecurity procedures and are expected to have managers with greater awareness of the risks, available control measures, and public policies and regulations, as well as more substantial resources to take actions to mitigate risk. However, if HPAI is introduced into these systems, the infection is likely to spread through the flock extremely quickly. A large number of birds will likely be killed by disease or culling, and the overall economic impacts may be larger than for infections in the smaller backyard systems.

Sectors 3 and 4 are generally considered to be more susceptible to infection because of their low levels of biosecurity. Asia, where the majority of recent HPAI infections have occurred, has very large numbers of small-scale poultry producers, and live bird markets are widespread. Rice paddies are a particularly important source of contact between wild birds and poultry, specifically free-grazing domesticated ducks, which have been identified as a key risk factor in spreading HPAI in duck-producing regions of Asia because they come in contact with wild birds as well as other domestic poultry as they are rotated between areas (Gilbert et al.).

Although far less prevalent in developed regions, nonindustrial production and live bird markets are frequently identified by animal health agencies in these regions as an important potential source of HPAI. Power identifies low levels of biosecurity practiced by some producers in a high-density poultry production region as a primary reason for the rapid spread of HPAI during the 2004 outbreak in British Columbia, Canada.

Prevention and Control Measures

A variety of disease control measures reduce the probability of HPAI primary infection of poultry and the spread of the disease once introduced into an area, including poultry disease surveillance, improved biosecurity practices, humane depopulation and proper disposal of infected and possibly exposed birds, and vaccination. Each is described briefly below.

Poultry Disease Surveillance

Farm-level surveillance may be conducted by private producers or by the public sector. Private producers are likely to devote time to disease surveillance as part of their normal production activities, but only to the point that it is profitable to their operation, not taking into account the benefits to other producers of rapid identification and containment of outbreaks. Public veterinary services may also conduct farm-level surveillance, but this is a major undertaking in many countries, and it would likely be difficult to have adequate surveillance without private sector involvement. Nonetheless, many aspects of a surveillance program are more appropriately carried out by the public sector. For instance, tracking the epidemiology, spatial and temporal patterns, and movements of poultry and poultry products at the regional and national levels is valuable in identifying the origin in the event of an outbreak.

Improved Biosecurity Practices

Strict biosecurity practices that prevent exposure to any animals or other items potentially contaminated with AI are vital for preventing and controlling the spread of disease. These include preventing exposure of poultry to wild birds by keeping poultry in closed housing and ensuring that wild birds cannot access poultry feed and water supplies; preventing exposure to potentially infected new poultry introduced into existing flocks by isolating new birds or avoiding their introduction into existing flocks; restricting live markets and poultry movement; and preventing exposure to infectious agents transported by people or equipment by limiting access to poultry houses and thoroughly cleaning all clothing, shoes, and equipment before and after coming into contact with birds (Canadian Food Inspection Agency).

Depopulation and Proper Disposal

Depopulation of infected birds and birds that may have been exposed to the virus has been a typical public policy response to an HPAI outbreak in many countries when any H5 or H7 strains are found and is often credited with limiting the spread of the disease, particularly in such countries as Hong Kong and Thailand, which moved quickly to quarantine and destroy potentially affected flocks. The cooperation of poultry producers and the availability of veterinary expertise are key factors affecting the effectiveness of these programs.

Vaccination

Vaccination reduces both the probability of infection and the amount of virus produced by a flock if infected (van der Goot et al.). Vaccination is currently being used in several countries, including China, which instituted a major initiative to inoculate 2.68 billion birds in areas considered susceptible to AI infection (USDA, FAS). There are several potential barriers to wider adoption of vaccination. It is potentially costly to administer and presents problems for trade because many countries will not import poultry products from countries that vaccinate. There are also concerns that vaccination may suppress the symptoms of the virus for vaccinated birds that get infected, allowing AI to continue spreading without notice and increasing the probability that it would become endemic (Stegeman and Bouma).

Public Policy Instruments

In addition to direct public provision of disease control measures, a variety of public policy instruments are available to help induce optimal private behavior to prevent and control the spread of HPAI. One of these instruments is the public provision of information and technical assistance. Some poultry producers, such as backyard growers, may not be aware of the potential severity of HPAI and could have difficulty identifying an outbreak. Growers in many developing countries may accept significant poultry losses as "normal" (Rushton et al.). Public provision of information regarding HPAI lowers the private cost of control measures for producers by reducing the time and human capital required to identify and adopt appropriate actions.

Other instruments include incentives for disease reporting, improved biosecurity practices, and poultry vaccination. For instance, it may be welfare improving for government to compel or provide incentives for at least some producers to adopt biosecurity measures (Hennessy 2005b). Incentives may be provided through such policies as regulation with appropriate and enforceable penalties for noncompliance, farm subsidies tied to following best management practices, compensation for losses (costs of depopulation and appropriate disposal, as well as lost market value, in the event of an outbreak), and/or cost sharing for adoption of prevention and control measures.

One key policy lever is the level of compensation provided for destroyed poultry, which varies widely among countries. If compensation is too low, it presents a major barrier to the surveillance and rapid disease reporting necessary to identify outbreaks, as well as to producer cooperation with depopulation of infected and exposed birds. Producers may hide information about diseased animals because of concerns about their economic losses in the event of quarantine or depopulation, which can facilitate the spread of disease, delay public responses, and lead to a situation in which HPAI is endemic in smallholder production systems. If compensation is too high, then there are disincentives for private adoption of prevention and control measures, and it is even possible that farmers would prefer their poultry to become infected, especially if marketing restrictions in the region prevent the sale of healthy but potentially exposed poultry.

In the United States, the government provides full compensation for the eligible costs associated with eradication. Canada fully compensates for lost market value of poultry after adjusting for age and salvage value. In most Southeast Asian countries, compensation is less generous. Thailand compensated farmers at 100% of market value during the initial major outbreak in that country in 2004 but has since reduced compensation to 70% of market value. Vietnam had been providing compensation of about 20 to 30% of market value before November 2005, when they reported an increase in compensation levels to 50 to 60%. At the extreme, the Cambodian government has declared that they will not provide any compensation, which is a significant impediment to disease reporting (Rushton et al.).

Conceptual Model

Producer behavior under risk of HPAI infection can be modeled using an economic epidemiology model to capture the relationships between disease transmission characteristics, private and public disease control measures, and the spread of disease (Beach et al.). Below we briefly describe both epidemiological and agricultural household components of such a model.

Epidemiological Model

The probability that the HPAI virus is introduced onto farm i (π_i), the primary infection rate, increases with the number of wild waterfowl in the region (N_w) and the total number of poultry in the region ($N_p = \Sigma_i N_{pi}$), because of increases in the contact rate between wild and domesticated birds. Given the AI virus' tendency to mutate and the role of farm management and environmental conditions in fostering those mutations, π_i also increases with regional AI disease prevalence (α). In addition, the probability of HPAI infection decreases with the proportion of animals protected from disease because of the adoption of private control measures (a_i), $\pi_i = \pi_i(a_i, N_{pi}, N_p, N_w, \alpha)$.

Several epidemiological analyses of infectious disease in animals and humans (e.g., van Boven et al.; Dieckmann and Heesterbeek) show that the equilibrium value of the average number of secondary infections that result from each additional primary infection in the region (typically referred to as R, or the reproductive ratio, in the epidemiology literature) affects the risk of major disease outbreaks.[1] Adapting van Boven et al.'s model, R depends on the proportion of animals in the region that are susceptible to infection (g) (animals lacking natural or vaccine-induced immunity), the infectiousness of infected animals (f) (the rate at which infections are transmitted to susceptible hosts), the region's case fatality rate (μ), and the fraction of animals protected from disease due to private control measures in the region (a), $R = R(a, f, g, \mu)$.[2] Although the number of wild birds in the area is outside farmers' control, the total number of poultry in the region and the proportion of poultry protected are determined by the aggregate of farm-level behavior, subscripted by i (for example, $a = \Sigma_i[(a_i N_{pi})/N_p]$).

Agricultural Household Model

We now turn to a model of farm behavior under risk of HPAI infection, based on Singh et al.'s agricultural household model, which describes farm households' production and consumption decision using a single consistent framework. In this paper, we assume households' production and consumption decisions are separable. Thus, poultry farmers seek to maximize expected farm profits subject to time, production, and budget constraints. The implications of the separability assumption and potential extensions are discussed in the next section.

The farm household uses its endowments of family labor (T_p) and other variable and fixed inputs (X_p), including number of birds (N_{pi}), to produce poultry (Q):

$$Q = Q(T_p, X_p, N_{pi}),$$

where

$$\frac{\partial Q}{\partial X_p}, \frac{\partial Q}{\partial T_p}, \frac{\partial Q}{\partial N_{pi}} > 0.$$

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[1] van Boven et al. note that R should be kept below 1 (such that each animal [or farm] infects less than one other animal [or farm]) to prevent a major outbreak of HPAI in the event of an infection or R should be reduced below 1 to stop an outbreak in progress.

[2] Susceptibility (g) also depends on such characteristics as the natural immunity of birds to AI (Z_g), and infectiousness (f) depends on characteristics of the virus (Z_f), including virulence, incubation period, and duration of infectivity. Farms could affect Z_g through their selection of species/breeds, accounting for AI resistance.

The poultry production function is concave and has the usual regularity characteristics. In addition, as described above, there is some risk that poultry will be infected with HPAI and will die or be destroyed, π_i, as well as some risk that a regional outbreak will result in the grower having poultry culled even if their flock is not infected, P. The government is assumed to compensate farmers for losses due to HPAI at some fraction (0=I=1) of the per-unit market price for poultry, p_p.[3]

The total time available to the household (T) is allocated between working on farm to produce poultry (T_p), off-farm labor (T_o), and leisure (T_l)[4]: $T = T_p + T_o + T_l$. Household expenditures on consumption goods ($p_m C_m$) and poultry production ($w_p X_p + w_{N_p} N_{pi} + w T_p + p_a a_i$) cannot exceed the sum of income from poultry production ($I^s p_p Q$, where s is an exponent equal to 1 if poultry on the farm is destroyed because of HPAI and 0 otherwise), off-farm labor income (wT_o), and nonlabor income (V): $I^s p_p Q + wT_o + V = w_p X_p + p_m C_m + w_{N_p} N_{pi} + wT_p + p_a a_i$.

Farm households then maximize expected profit (Y):

$$\max_{T_p,\, N_{pi},\, a_i} Y = \begin{bmatrix} (1 - P)(1 - \pi_i)p_p Q + \\ [P(1 - \pi_i) + \pi_i(1 - P) \\ + P\pi_i]\, I p_p Q - w_p X_p - w_{pN} N_{pi} \\ - wT_p - p_a a_i \end{bmatrix}. \quad (1)$$

The first-order condition for private disease control measures in the case in which farmers do not consider impacts external to their farm is

$$\frac{\partial Y}{\partial a_i} = \begin{bmatrix} -(1 - P)\frac{\partial \pi_i}{\partial a_i} p_p Q \\ + (1 - P)\frac{\partial \pi_i}{\partial a_i} I p_p Q - p_a \end{bmatrix} = 0.^{5} \quad (2)$$

Equation (2) indicates that households will engage in preventive activities (e.g., increase time spent monitoring their flock for disease, vaccinate their flock) until the value of increased expected revenue (due to the reduced probability of HPAI introduction on the farm) is equal to the unit price of private control measures (e.g., vaccine price). Consider the impacts of the government's choice for the value of I. If the government does not provide any compensation for culled and depopulated birds ($I = 0$), the benefits of private control increase to $-(1 - P)(\pi_i/a_i)p_p Q$. At the other extreme, if the government fully compensates farmers for all losses ($I = 1$), then the benefits of private disease control disappear and farmers have little incentive to implement these measures. More generally, private investment in disease prevention tends to decrease with the compensation level. However, if compensation is low, then farmers are likely to conduct less disease surveillance and may attempt to hide disease rather than report it to public health authorities. The net effect on disease outcomes at different compensation levels is an empirical question. There are numerous potential extensions to this basic model that could be used to analyze interactions between alternative public and private prevention and control measures and assess socially optimal public policy measures.

Data Requirements

One of the primary challenges facing empirical economic studies of AI is the difficulty in collecting and compiling the data necessary to test economic epidemiology models of farm behavior and the highly dynamic disease situation. As described above, three primary types of data are needed. First, disease data including cases, incidence and prevalence, and

[3] We assumed that farms' costs of destroying and disposing of birds are also compensated.

[4] We focused on poultry production as the only farm production activity for simplicity, but the model could readily be expanded to reflect production of other farm products.

[5] Other first-order conditions show that as long as I<1, production under exogenous risk unambiguously reduces the optimal allocation of labor (and other inputs) for poultry production, assuming the price of poultry is unaffected. If a sufficiently large proportion of poultry production is affected, market-level effects could increase price and potentially even increase optimal input allocation in poultry.

epidemiological information should be geocoded and linked to data describing farms, including farm size and classification, among other characteristics (e.g., investments, products). Second, the detailed, geocoded farm level data should ideally include data on private disease control measures (e.g., biosecurity practices, vaccination). These data should also include or be linked to community-level data on environmental conditions, the availability of animal health services, and markets. Third, data on available public animal health services, public disease control measures, and public regulations are required. To explore the causal relationships among private and public disease control measures designed to prevent the introduction and spread of HPAI, these three types of data should ideally be available for multiple periods, particularly since 1997, when the current strain of H5N1 was first identified.

Disease data are collected by national and subnational governments in many countries and compiled by the World Organization for Animal Health (OIE), which reports these data on its website, as well as on the websites of the World Health Organization and Food and Agriculture Organization. In many countries, HPAI and LPAI in poultry are notifiable diseases, meaning that national regulations require that detected or suspected cases be brought to the attention of the national veterinary authority as soon as possible. The OIE's reports of AI outbreaks by country include the date the outbreak started; the status of the outbreak; the epidemiological unit affected (e.g., farm, region, nation); the species and population affected; and the number of susceptible, diseased, dead, destroyed, and slaughtered animals. The morbidity and case fatality rates are estimated, and the control measures that have been applied and those that are planned are summarized. When known, the reports indicate the source of infection. A standard report format is used in most cases, but many reports are incomplete.

Although these data are detailed, the principal limitation is that they are not available in a database format that is readily useable and/or suitable for statistical analyses. Using these reports, as well as data from FAO, various government sources, and the United Nations FAO Emergency Prevention System (EMPRES) for Transboundary Animal and Plant Pests and Diseases, Declan Butler, a senior reporter for *Nature*, has created a database and global map of AI cases (see http://www.declanbutler.info/Flumaps1/Timeseries.kml). In many cases, the latitude and longitude of outbreaks reported in the database had to be estimated because this information is not routinely reported. Although this effort does facilitate descriptive analyses, there remain additional limitations.

One issue is that the geographic data is fairly coarse and in most cases, the location of outbreaks is only identified at the regional or possibly district level. Consequently, it is difficult to link these disease data to important spatial data on risk factors and control variables. Another limitation is that the characterization of affected species is often very general. For example, the species affected may be identified only as "duck" or "chicken."

To understand the disease risk in different locations, it is necessary to know the population of susceptible birds in the affected area. The FAO's ProdSTAT database records poultry production data for 1961 to 2005 by country, but these data are not available for all countries; they are only available at the national level, and they likely exclude information on backyard farms, where HPAI risks may be highest.

The second type of data needed, farm-level data on private disease control measures (as well as relevant community or environmental measures), is hard to obtain and difficult to combine with information on disease outbreaks in the absence of detailed geographic information. There are a variety of microlevel datasets on farms and agricultural production, such as the World Bank's Living Standards Measurement Surveys, that generally provide valuable data on agricultural production, prices, revenues, costs, and capital investments. However, these data have several limitations for empirical economic analyses of livestock disease. First, the location of farms, measured by latitude and longitude, is typically not available. Second, there is little or no detailed information on private disease control measures, including biosecurity practices, vaccination, marketing, and transportation practices. Third, there are typically insufficient data on community-level measures, such as environmental risk factors (e.g., populations of wild fowl), veterinary services, and public disease control measures. Finally, although these data are collected every few years in many countries, the lag times between data collection and public availability are relatively long and detailed agricultural modules are not present in all waves. Thus, there are currently few publicly available datasets that contain relevant data from recent years when outbreaks have become increasingly common. For instance, the Vietnam Living Standards Survey (VLSS) was conducted in 1992–1993 and 1997–1998 prior to the recent H5N1 outbreaks in Vietnam and in 2002 and 2004–2005 after the outbreaks. The detailed agricultural module was included in the 2004–2005 VLSS, but the datasets are not yet available.

Finally, consistent time series data on public disease control measures, necessary for measuring the causal effect of public disease control on disease and private behavior, are also difficult to acquire. These data may be reported in government documents or in research or technical reports, but the information is provided inconsistently and may report official rather than actual practice. Also, regulations and government or donor reports on public disease control measures focus on current conditions and rarely detail historical measures in an organized manner. Further, these reports typically describe only a single country or region. One exception is a 2006 World Bank report prepared cooperatively with OIE, FAO, and IFPRI on policies regarding compensation for avian flu (The World Bank). This document compiles current compensation schemes for culling in the event of animal disease outbreaks (including AI) across multiple countries, but historical policies are not reported.

Although data availability has been and continues to be a key issue for empirical analyses of livestock disease prevention and control, post-HPAI outbreak data are beginning to become available for some countries. In recognition of the importance of HPAI as well as other livestock diseases, many countries, organizations, and individual researchers have increased efforts to collect and compile relevant data. The availability of these data will enhance the ability of researchers to conduct empirical studies and inform important policy decisions for the prevention and control of HPAI.

Conclusions and Future Research

This paper describes the use of an economic epidemiology model to examine the relationships among HPAI infection and epidemic risk, farms' private disease control measures, and public disease control measures. The epidemiological relationships reflect two characteristics that have important implications for the effectiveness of disease control: the endogeneity of disease risk and the externalities in disease transmission. Farms are likely to under invest in private disease control in the presence of externalities. In particular, farms may not account for the influence their behavior has on the risk of infection for neighboring farms and for their entire region. In addition, there are important tradeoffs between potential reductions in some private control measures (e.g., biosecurity, vaccination) and increases in others (e.g., surveillance, reporting) in response to higher levels of public compensation for depopulated and culled poultry.

We plan to extend the theoretical model presented in Beach et al. to explore the effectiveness of alternative public policy measures for epidemic prevention, including subsidizing private control, information campaigns, and encouraging coordination among farms, as well as examining the role of mandatory culling and marketing restrictions. In addition, we will more explicitly model additional private control options to gain more insight into the influence of production technology and epidemiology on private decisions. We will then explore the implications of interactions between private and public controls and the optimal combinations of public and private measures. Finally, we will relax our assumption about the separability of production and consumption. Although separability is likely to hold in developed countries, where farm households are generally well integrated into the international poultry market, as well as markets for other inputs or related products, farm households in developing countries may face thin or missing markets (e.g., credit, insurance) and information constraints. Missing markets and incomplete information alter the farms' incentives for disease prevention and affect the epidemiology of AI and the effectiveness of alternative public disease control policies. Given the concentration of HPAI in small-holder production systems in developing nations, it is important to examine the implications of nonseparability.

Empirical research is necessary to quantify these key relationships between disease risk, public policy, and farm behavior regarding prevention and control of livestock disease and to provide additional information that can better inform public policy decisions. Detailed farm household–level data on farm characteristics, production, and disease prevention and control measures; local information on disease outbreaks; local ecological and market conditions; and applicable public technical support and policies are necessary for such analyses. As noted above, the availability of many of these data has been limited in the past, but they are expected to become more readily available in the near future as governments and other organizations increase the resources devoted to livestock disease control and specifically HPAI in recognition of the enormous potential liability.

Finally, the agricultural household model can serve as the basis for studying broader impacts. In subsequent work, it would be valuable to explore an economy-wide model of impacts that accounts for price effects as well as impacts on production, consumption, trade, and other effects on the economy through computable general equilibrium modeling.

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