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September 2006

DSGD Discussion Paper No. 40

# Assessing Potential Impact of Avian Influenza on Poultry in West Africa - A Spatial Equilibrium Model Analysis

Liangzhi You and Xinshen Diao

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## ABSTRACT

In this paper, the authors analyze the potential economic impacts of avian influenza (AI) in West Africa, taking Nigeria as an example. They find that, depending on the size of the affected areas, the direct impact of the spread of AI along the two major migratory bird flyways would be the loss of about 4 percent of national chicken production. However, the indirect effect—consumers' reluctance to consume poultry if AI is detected, causing a decline in chicken prices—is generally larger than the direct effect. The study estimates that Nigerian chicken production would fall by 21 percent and chicken farmers would lose US$250 million of revenue if the worst-case scenario occurred. The negative impact of AI would be unevenly distributed in the country, and some states and districts would be seriously hurt. This study is based on a spatial equilibrium model that makes use of the most recent spatial distribution data sets for poultry and human populations in West Africa. The study shows that, while most of the attention has focused on preventing global influenza pandemic, preventive measures are also needed at the national, subnational, and local levels, because AI could potentially have a huge negative impact on the poultry industry and the livelihood of smallholder farmers in many regions in West Africa.

**Key words:** avian influenza, spatial equilibrium model simulation, West Africa, Nigeria

# ASSESSING POTENTIAL IMPACT OF AVIAN INFLUENZA ON POULTRY IN WEST AFRICA – A SPATIAL EQUILIBRIUM MODEL ANALYSIS

**Liangzhi You and Xinshen Diao** [1]

## I. INTRODUCTION

The potential for avian H5N1 virus to cause a deadly global human pandemic has convinced the international community to mobilize resources to implement prevention and eradication measures in the poultry population. While highly pathogenic avian influenza (HPAI) has been successfully checked in Western Europe and much of Southeast Asia, apart from Indonesia, it is still spreading in Africa and will remain a threat for years to come (FAO 2006a; FAO 2005). Since February 2006, HPAI outbreaks have been reported in Burkina Faso, Cameroon, Ghana, Niger, and Nigeria (FAO 2006b; OIE 2006). By April 2006, more than 325,000 chickens in Nigeria alone were identified as having H5N1 virus; of these, 223,000 died of H5N1 infection and the rest were slaughtered as a control measure. The spread of HPAI poses a challenge to the poultry industry in West Africa. Once domestic birds are infected, AI outbreaks can become difficult to control, causing major economic damage to poultry farmers in affected countries. While most of the attention has focused on preventing further outbreaks into other areas, or into other types of livestock or humans (Holmes, Taubenberger, and Grenfell 2005; Longini et al. 2005; Ferguson et al. 2005), little research is being conducted on the impact of these preventive measures on the poultry industry and on the livelihoods of smallholder farmers at country and regional levels in West Africa. The impact could be huge. As one of the most rapidly growing sectors, poultry production has

[1] Liangzhi You is a Senior Scientist of IFPRI's Environment and Production Technology Division and Xinshen Diao is a Senior Research Fellow of IFPRI's Development Strategy and Governance Division. This paper's conceptual framework and literature review are largely based on the joint IFPRI/ILRI proposal "Avian Influenza in East and West Africa: Modeling the Spatial Spread, Evaluating the Cost-Effectiveness of Alternative Control Strategies" (April 2006). As part of the research team, the authors benefited greatly from discussions with the other members of the research team who developed the proposal and will conduct further research under the IFPRI/ILRI avian influenza project.

become an important income source for many rural households in the region. Moreover, chicken contributes important protein to consumers' diets. Though there has been a major structural change in promoting intensive production in the poultry industry worldwide (Narrod and Pray 2001; Delgado, Narrod, and Tiongco 2003), most of the poultry producers in West Africa maintain small flocks. These backyard flocks, ranging from 10 to 50 heads, are an important source of cash income for poor farmers. Moreover, raising poultry is a particularly important means for women in many countries to develop assets or income because entry costs are low and the work can be integrated with their domestic responsibilities.

Published literature on the economics of transboundary animal diseases is relatively scarce (Otte, Nugent, and McLeod 2004), and the challenge of assessing the potential impact of AI is a difficult one because the virus itself is little understood and people's response to an outbreak is uncertain. In addition to the difficulty of modeling the disease's dynamics and human transmission, estimating the controlling cost and the potential social and economic effects is another challenge. After an outbreak is confirmed, eradication involves not only the direct cost of killing all the infected poultry, but also the indirect costs that accrue to poultry producers and consumers. The control method and its cost are likely to differ depending on how the virus is transmitted. The economic impact also varies across income groups and sectors of an economy: the rural poor, whose income depends in large part on poultry production, may feel these costs disproportionately.

Spatial pattern is an important characteristic of the complex interactions and the spread of AI. An outbreak of AI usually occurs in a particular geographic location and spreads from one place to another. The risk of exposure to HPAI is also spatial, depending on the distance from AI transmission routes and contact with infected flocks. Thus, analyzing the impact of AI requires a methodology that fully captures the spatial pattern.

In this paper, we combine several spatially explicit data sets and develop a spatial equilibrium model to assess the likely impact of HPAI on poultry production and price and on the income of farmers in West Africa. The spatial data sets include information on the distribution of poultry and humans, the location of recent HPAI outbreaks, and the flyways of migratory birds. The model is employed to analyze the potential economic impacts of avian influenza (AI) in West Africa, taking Nigeria as an example. We find that the direct impact of the spread of AI along the two major migratory bird flyways would be the loss of about 4 percent of Nigeria's chicken production. However, the indirect effect is generally larger than the direct effect. The study estimates that Nigerian chicken production would fall by 21 percent and chicken farmers would lose US$250 million of revenue if the worst-case scenario occurred. The negative impact of AI would be unevenly distributed in the country, and some states and districts would be seriously hurt.

In the next section, we examine the spatial patterns of both poultry and human populations in West African countries. Section 3 introduces the spatial equilibrium model for Nigeria's poultry sector, and Section 4 discusses results from different modeling scenarios and possible impacts of AI on poultry production and farmer income in Nigeria at both national and selected subnational levels. Section 5 concludes the paper and provides some suggestions for how to further improve the analytic framework.

## II. SPATIAL DATA SETS FOR WEST AFRICA

### Spatial Distribution of Poultry

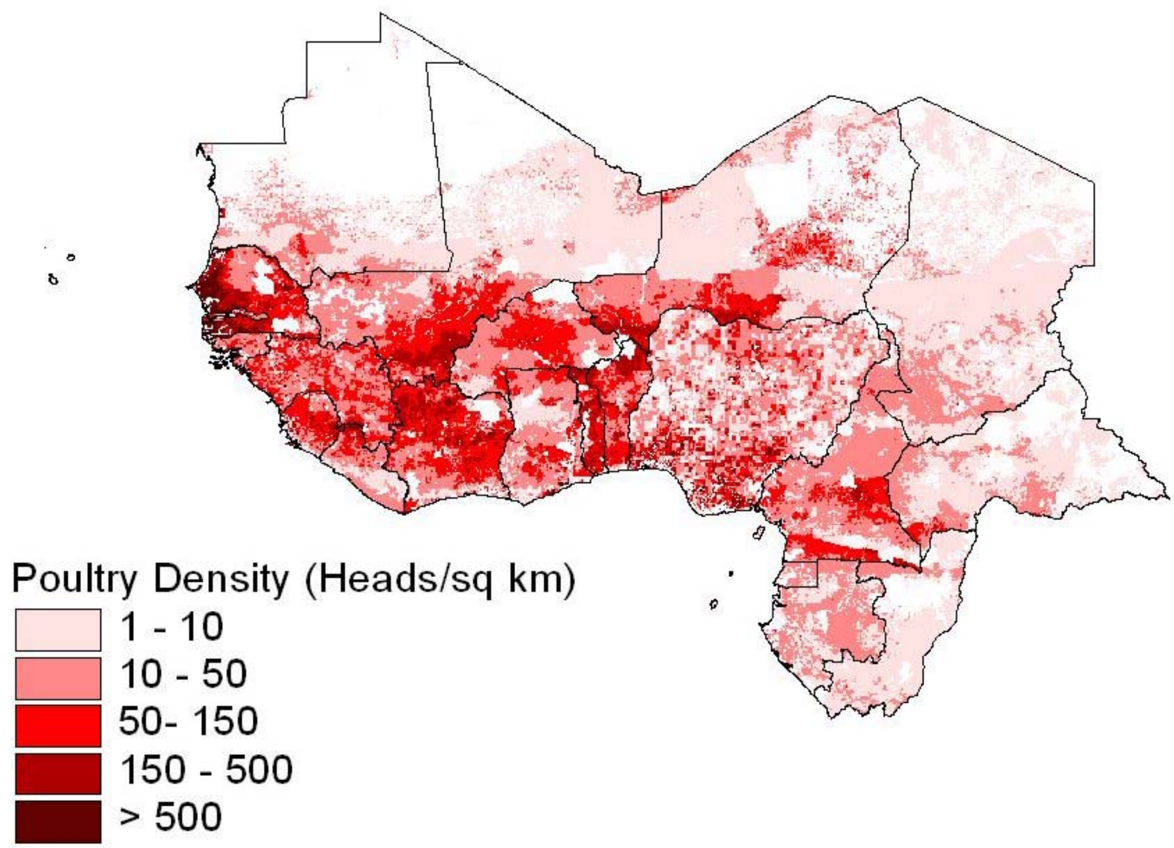
The impact of AI on production depends on where poultry are located; hence we need a data set that spatially describes the poultry distribution in a country or region. The Animal Production and Health Division of the Food and Agriculture Organization of the United Nations (FAO), in collaboration with the Environmental Research Group Oxford (ERGO), have developed a data set called *Gridded Livestock of the World,*[2] which includes the spatial distribution of cattle/buffalo, sheep, goats, pigs, and poultry.[3] The most recently available livestock data at the subnational level have been collected and converted into densities, taking into account areas unsuitable for raising livestock (either monogastric or ruminant). Figure 1 is based on this data set and shows the distribution of chickens in West Africa. Coastal countries such as Benin, Côte d'Ivoire, Guinea-Bissau, Liberia, Sierra Leone, and Togo as well as some subnational areas of other countries such as southern Burkina-Faso and southern Mali all have some high-density areas, but most of the chicken production in West Africa is small scale, with a density of less than 50 heads per square kilometer ($km^2$).

To better understand the different patterns of spatial distribution of chickens across countries, we further group chicken production into five categories according to the density (chickens per square kilometer) for each country (Table 1). As the table shows, the spatial distribution patterns of chickens are quite different across West African countries. For example, more than 90 percent of chickens in Congo are in areas with very low density (under 50 heads per $km^2$), while in Togo, nearly 70 percent of chickens are in areas of more than 150 heads per square kilometer. Low chicken population density is often associated with backyard smallholder production. A few countries have a significant proportion of chicken production located in high-density areas: in Ghana, for

[2] See FAO (2006c) for a description of the methodology and sources of data in detail.
[3] Poultry includes chickens, domestic ducks, geese, turkeys, and pigeons. Since chicken predominates in the poultry sector of West Africa, we focus on chickens in this study. Thus, poultry and chickens are used interchangeably in this paper.

example, 42 percent of chickens are located in areas where the density is more than 500 heads per $km^2$, indicating the increasingly important role of large-scale, commercial chicken farms in the country. Nigeria, the most populous country in Africa, has the biggest chicken sector in West Africa, and its chicken production seems to be equally distributed among different density groups.

**Figure 1. Poultry Density in West Africa**




*Source: FAO (2006c)*

**Table 1. Chicken Distribution by Density Groups in West African Countries**

| Country | Percent of Chicken Number by Density Classes | | | | | | Total Number of Chicken |
|---|---|---|---|---|---|---|---|
| | < 10/km$^2$ | 10~50/km$^2$ | 50~150/km$^2$ | 150-500/km$^2$ | >500/km$^2$ | Total | |
| | (%) | | | | | | (million) |
| Benin | 0.2 | 11.2 | 32.9 | 54.6 | 1.1 | 100 | 13.0 |
| Burkina Faso | 1.1 | 33.2 | 58.7 | 6.0 | 1.0 | 100 | 25.7 |
| Cameroon | 1.6 | 35.4 | 37.1 | 10.4 | 15.5 | 100 | 31.0 |
| Central African Republic | 23.3 | 55.1 | 17.9 | 2.8 | 0.8 | 100 | 4.8 |
| Chad | 42.3 | 55.3 | 0.3 | 2.1 | 0.0 | 100 | 5.2 |
| Congo | 52.3 | 41.1 | 6.1 | 0.5 | 0.0 | 100 | 2.4 |
| Equatorial Guinea | 9.7 | 84.0 | 1.3 | 0.0 | 4.9 | 100 | 0.3 |
| Gabon | 16.9 | 80.8 | 2.3 | 0.0 | 0.0 | 100 | 3.1 |
| Gambia | 0.2 | 21.4 | 33.6 | 36.1 | 8.6 | 100 | 0.7 |
| Ghana | 2.1 | 21.4 | 27.8 | 6.5 | 42.2 | 100 | 30.0 |
| Guinea | 0.7 | 33.1 | 59.1 | 4.6 | 2.5 | 100 | 15.0 |
| Guinea-Bissau | 0.8 | 34.0 | 30.4 | 3.7 | 31.1 | 100 | 1.6 |
| Ivory Coast | 0.4 | 8.4 | 43.3 | 40.9 | 7.1 | 100 | 33.0 |
| Liberia | 3.2 | 30.6 | 25.7 | 29.0 | 11.5 | 100 | 5.3 |
| Mali | 4.4 | 21.8 | 42.8 | 30.6 | 0.4 | 100 | 31.0 |
| Mauritania | 23.7 | 48.0 | 9.2 | 4.2 | 14.9 | 100 | 4.2 |
| Niger | 14.9 | 67.9 | 17.1 | 0.0 | 0.0 | 100 | 25.0 |
| Nigeria | 3.2 | 21.3 | 24.5 | 26.6 | 24.4 | 100 | 140.0 |
| Sao Tome and Principe | 0.1 | 0.0 | 1.1 | 11.6 | 87.3 | 100 | 0.4 |
| Senegal | 0.1 | 3.5 | 12.5 | 33.2 | 50.6 | 100 | 46.0 |
| Sierra Leone | 0.7 | 9.4 | 46.6 | 33.3 | 10.1 | 100 | 7.5 |
| Togo | 0.3 | 2.2 | 28.6 | 63.3 | 5.6 | 100 | 9.0 |

*Source: Authors' calculations from Gridded Livestock of the World database (FAO, 2006c)*

Table 2 presents the share of land held by the five density groups by country, taking the total land area for each country as 100. The first two low-density groups (less than 50 heads per $km^2$) account for a dominant share of land in most West African countries. The high-density area (with more than 500 heads per $km^2$) accounts for less than 2 percent of total land in most countries, with the exception of Sao Tome and Principe and Senegal, which indicates the limited role of large-scale production in West African poultry sector. Small flocks of chickens are normally kept outdoors and easily exposed to outside influences, making West African chickens vulnerable to AI.

**Table 2. Land Area Distribution by Chicken Density Group in West African Countries**

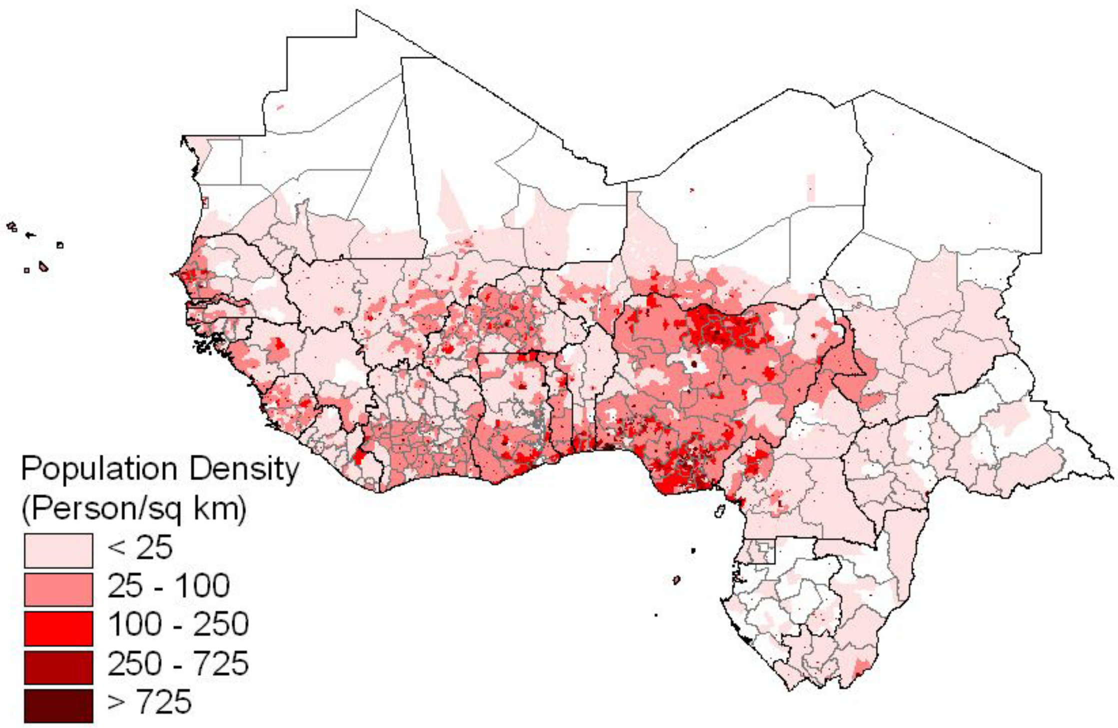
| Country | Percent of Land Area by Density Classes | | | | | | Total Land Area |
|---|---|---|---|---|---|---|---|
| | < 10/km$^2$ | 10~50/km$^2$ | 50~150/km$^2$ | 150-500/km$^2$ | >500/km$^2$ | Total | |
| | (%) | | | | | | (million ha) |
| Benin | 4.2 | 35.2 | 35.3 | 25.0 | 0.2 | 100 | 11.1 |
| Burkina Faso | 9.2 | 53.9 | 35.3 | 1.6 | 0.1 | 100 | 27.4 |
| Cameroon | 14.8 | 61.0 | 21.5 | 2.2 | 0.4 | 100 | 46.5 |
| Central African Republic | 68.8 | 28.7 | 2.4 | 0.1 | 0.0 | 100 | 62.3 |
| Chad | 81.8 | 18.1 | 0.0 | 0.0 | 0.0 | 100 | 125.9 |
| Congo | 80.6 | 18.9 | 0.5 | 0.0 | 0.0 | 100 | 34.2 |
| Equatorial Guinea | 20.4 | 79.1 | 0.3 | 0.0 | 0.2 | 100 | 2.8 |
| Gabon | 37.9 | 61.6 | 0.5 | 0.0 | 0.0 | 100 | 25.8 |
| Gambia | 2.7 | 49.0 | 36.1 | 11.2 | 1.0 | 100 | 1.0 |
| Ghana | 24.5 | 51.2 | 21.8 | 1.9 | 0.7 | 100 | 22.8 |
| Guinea | 5.8 | 50.9 | 42.0 | 1.2 | 0.2 | 100 | 24.6 |
| Guinea-Bissau | 8.8 | 62.0 | 26.9 | 0.8 | 1.5 | 100 | 2.8 |
| Ivory Coast | 6.9 | 27.0 | 45.9 | 19.3 | 0.9 | 100 | 31.8 |
| Liberia | 31.6 | 48.9 | 13.7 | 5.0 | 0.8 | 100 | 9.6 |
| Mali | 54.1 | 26.3 | 14.9 | 4.6 | 0.0 | 100 | 122.0 |
| Mauritania | 66.7 | 31.4 | 1.6 | 0.2 | 0.2 | 100 | 102.5 |
| Niger | 50.9 | 34.3 | 10.9 | 4.0 | 0.0 | 100 | 126.7 |
| Nigeria | 35.7 | 43.5 | 14.5 | 5.0 | 1.2 | 100 | 91.1 |
| Sao Tome and Principe | 6.7 | 0.0 | 6.7 | 26.7 | 60.0 | 100 | 0.1 |
| Senegal | 2.1 | 26.4 | 30.4 | 25.6 | 15.5 | 100 | 19.3 |
| Sierra Leone | 10.7 | 29.0 | 46.9 | 12.4 | 1.0 | 100 | 7.2 |
| Togo | 7.1 | 10.4 | 38.5 | 43.4 | 0.5 | 100 | 5.4 |

*Source: Authors' calculations from Gridded Livestock of the World database (FAO, 2006c)*

### Spatial Distribution of the Human Population

Spatial information on the human population is also essential for analyzing the impact of HPAI on poultry. The newly released alpha version of the population data base under the Global Rural-Urban Mapping Project (GRUMP), jointly conducted by the Center for International Earth Science Information Network (CIESIN), the International Food Policy Research Institute (IFPRI), the World Bank, and Centro Internacional de Agricultura Tropical (CIAT) in 2005, is used in this study. The distribution of human population is converted from national or subnational levels (usually administrative units) to geo-referenced quadrilateral grids at a resolution of 2.5 arc minutes (about 5 by 5 kilometers at the equator). Figure 2 shows the population density in West Africa. The urban areas with high population densities could easily be identified in the map. Since Nigeria has the most people, it has the most areas with relatively high population density too. Not surprisingly, more people live along the Atlantic coast than live in the dry Sub-Saharan regions.

**Figure 2. Human Population Density in West Africa**




*Source: CIESIN et al. (2005)*

We further distribute the human population by countries, according to the five chicken density groups defined in Table 1 (Table 3). More people are seen to live in areas with low chicken density (less than 50 heads of chicken per square kilometer). For example, in Central African Republic, Chad, Congo, Gabon, and Liberia, more than 90 percent of people live in areas with chicken densities of less than 50 heads per $km^2$. Even in the populous countries, such as Côte d'Ivoire, Ghana, and Nigeria, less than 4 percent of the total population lives in areas where chicken density is high. This fact seems to indicate that the risk of HPAI virus being widely transmitted from chickens to humans in West Africa is relatively low, compared with Southeast Asia, where population density is much higher.

**Table 3. Human Population Distribution by Chicken Density Group in West African Countries**

| Country | Percent of Population by Chicken Density Classes | | | | | | Total Population |
|---|---|---|---|---|---|---|---|
| | < 10/km$^2$ | 10~50/km$^2$ | 50~150/km$^2$ | 150-500/km$^2$ | >500/km$^2$ | Total | |
| | (%) | | | | | | (million) |
| Benin | 31.3 | 16.3 | 29.6 | 22.2 | 0.7 | 100 | 6.7 |
| Burkina Faso | 9.1 | 36.0 | 47.6 | 4.8 | 2.5 | 100 | 12.5 |
| Cameroon | 22.2 | 65.1 | 11.9 | 0.4 | 0.4 | 100 | 16.0 |
| Central African Republic | 59.6 | 38.4 | 1.9 | 0.1 | 0.0 | 100 | 3.9 |
| Chad | 81.8 | 18.0 | 0.1 | 0.1 | 0.0 | 100 | 8.6 |
| Congo | 77.5 | 22.2 | 0.2 | 0.0 | 0.0 | 100 | 3.7 |
| Equatorial Guinea | 48.4 | 50.4 | 1.2 | 0.0 | 0.0 | 100 | 0.5 |
| Gabon | 46.7 | 52.7 | 0.6 | 0.0 | 0.0 | 100 | 1.3 |
| Gambia | 42.5 | 23.6 | 21.6 | 12.0 | 0.3 | 100 | 1.4 |
| Ghana | 35.2 | 36.0 | 21.1 | 3.0 | 4.7 | 100 | 20.9 |
| Guinea | 9.4 | 45.7 | 43.5 | 1.1 | 0.2 | 100 | 8.5 |
| Guinea-Bissau | 18.0 | 45.3 | 30.7 | 1.0 | 5.0 | 100 | 1.5 |
| Ivory Coast | 23.6 | 25.8 | 36.4 | 13.1 | 1.1 | 100 | 16.6 |
| Liberia | 55.4 | 36.1 | 6.5 | 2.0 | 0.1 | 100 | 3.4 |
| Mali | 25.6 | 41.8 | 31.1 | 1.5 | 0.0 | 100 | 13.0 |
| Mauritania | 43.3 | 31.8 | 2.3 | 6.3 | 16.3 | 100 | 2.9 |
| Niger | 10.9 | 58.9 | 27.8 | 2.4 | 0.0 | 100 | 12.0 |
| Nigeria | 34.9 | 32.0 | 18.6 | 10.5 | 4.0 | 100 | 140.0 |
| Sao Tome and Principe | 52.3 | 0.0 | 0.0 | 15.9 | 31.8 | 100 | 0.2 |
| Senegal | 26.4 | 6.0 | 7.6 | 20.2 | 39.8 | 100 | 10.1 |
| Sierra Leone | 26.1 | 18.9 | 42.6 | 11.5 | 0.9 | 100 | 5.0 |
| Togo | 19.4 | 7.2 | 23.6 | 42.9 | 6.9 | 100 | 4.9 |

*Source: Authors' calculations from the Global Rural-Urban Mapping Project database (CIESIN et al. 2005)*

## Flyways for Migratory Birds

There is still no consensus on how HPAI came to West Africa. The transmission and spread of the AI virus is quite complex. Multiple transmission and spreading mechanisms exist, and much uncertainty remains about the degree of importance of each mechanism. While knowledge about AI transmission and spread is limited, we can distinguish between long-distance and short-distance (local) spread of the virus. Local spread of AI is likely due to the movement of poultry and poultry products. Domestic flocks may become infected with HPAI virus through direct contact with other infected poultry, infected wild birds, or through contact with surfaces (such as dirt or cages) or materials (such as water or feed) that have been contaminated with the virus (CDC 2005; FAO 2006b). Airborne transmission may occur if birds are in close proximity and air movement is adequate (FAO 2006b). The AI virus could be spread from farm to farm or from village to village by the transport of infected material. Although there is some disagreement among epidemiologists and ornithologists, migratory birds are potentially one of the major vectors for long-distance spread of AI (FAO 2006b). Recent epidemiological data show that wild waterfowl may play an important role in the AI cycle and could be the initial source of some HPAI virus. Liu et al. (2005) show that the H5N1 virus could have been transmitted through migrant waterfowls in Qinghai Lake in China. Additionally, the outbreaks of HPAI in poultry and wild birds in western China, Kazakhstan, Mongolia, and Russia indicate that some migratory species probably act as carriers for the transport of HPAI over longer distances (FAO 2005). However, wild birds infected by HPAI often die during migration. This possibly limits the ability of wild birds to carry HPAI for a long distance (Brown, 2006). Wild birds have been suggested (but to date not confirmed) to be the source of new outbreaks in West Africa. Instead, there is considerable evidence that the H5N1 virus in chickens in Nigeria was introduced through illegal imports of poultry from China or Turkey (Bird Life International, 2006).

Since HPAI cases have been confirmed in a few West Africa countries, there is a risk that migratory birds could continue to spread the virus within the region if the bird population became infected after contact with contaminated poultry. Given the experience of HPAI diffusion in Asia and Europe, there is a strong likelihood that domestic birds that lie along migratory flyways are at a greater risk than those that are farther away from it. Figure 3 shows the major flyways for migratory birds in the world. A flyway is the total area used by a group or species during its entire life cycle. The term can be used to describe such an area for a single species (for example, the flyway of the black tern), or to indicate a migratory area for entire populations of birds (for example, the African Eurasian Flyway), and of any geographic subunit of it (the East Atlantic Flyway). Three flyways, namely the Black Sea/Mediterranean flyway, the East Africa/West Asia flyway, and the East Atlantic flyway, cross several countries in West Africa. Based on the Asian experience, the regions along the flyways would be at greater risk of an HPAI outbreak.

Wild migrating water birds are seen as one of the causes of the spread of the avian flu, and millions of birds gathering in wetlands are seen as a huge risk. Based on the global flyways in Figure 3, we focus on those flyways crossing West Africa. Figure 4 shows the three major flyways affecting West Africa. Where a flyway passes through an area of high chicken density, the risk of AI might be high, if migratory wild birds indeed transmit the AI virus.

**Figure 3. Major Flyways of Migratory Birds in the World**

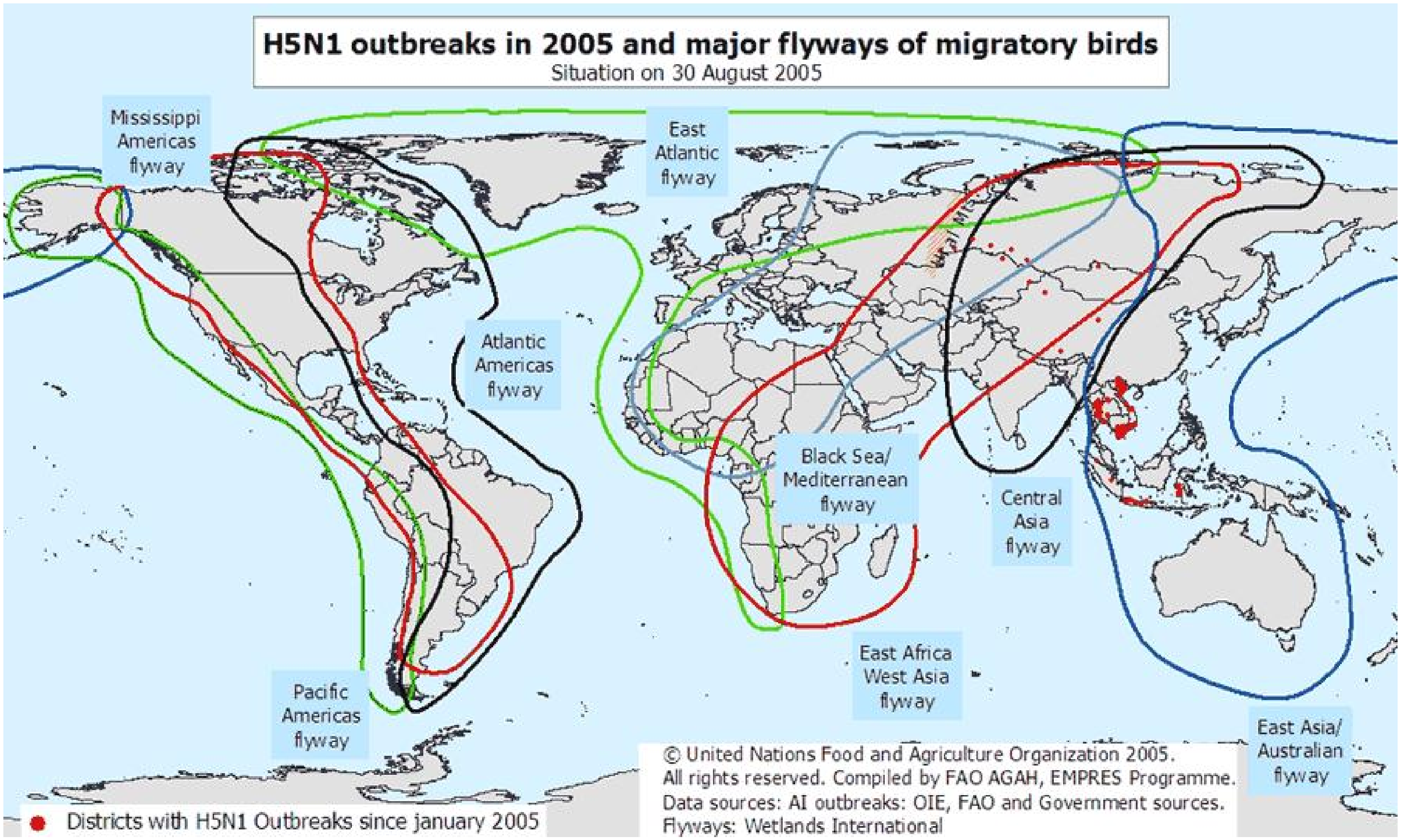
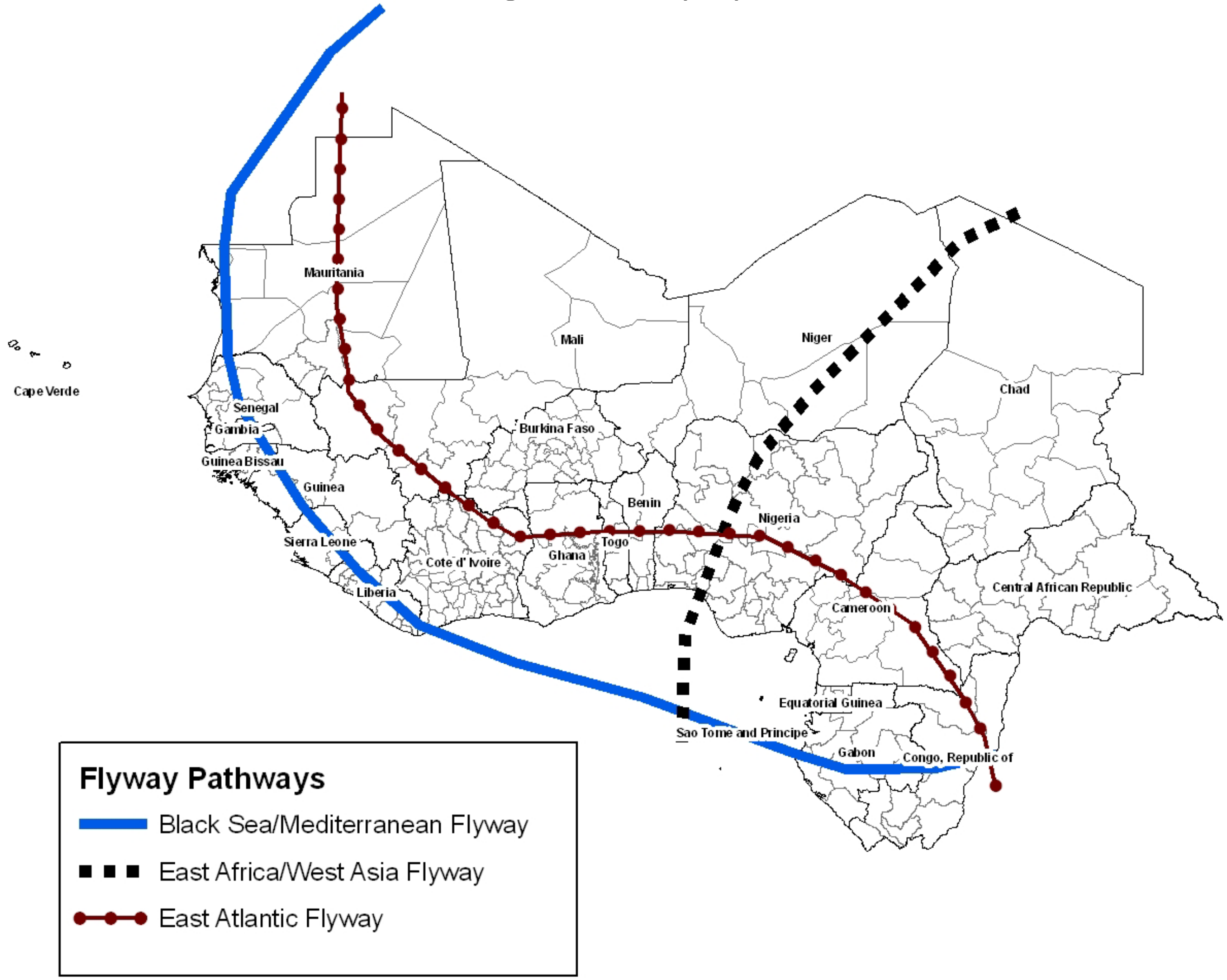


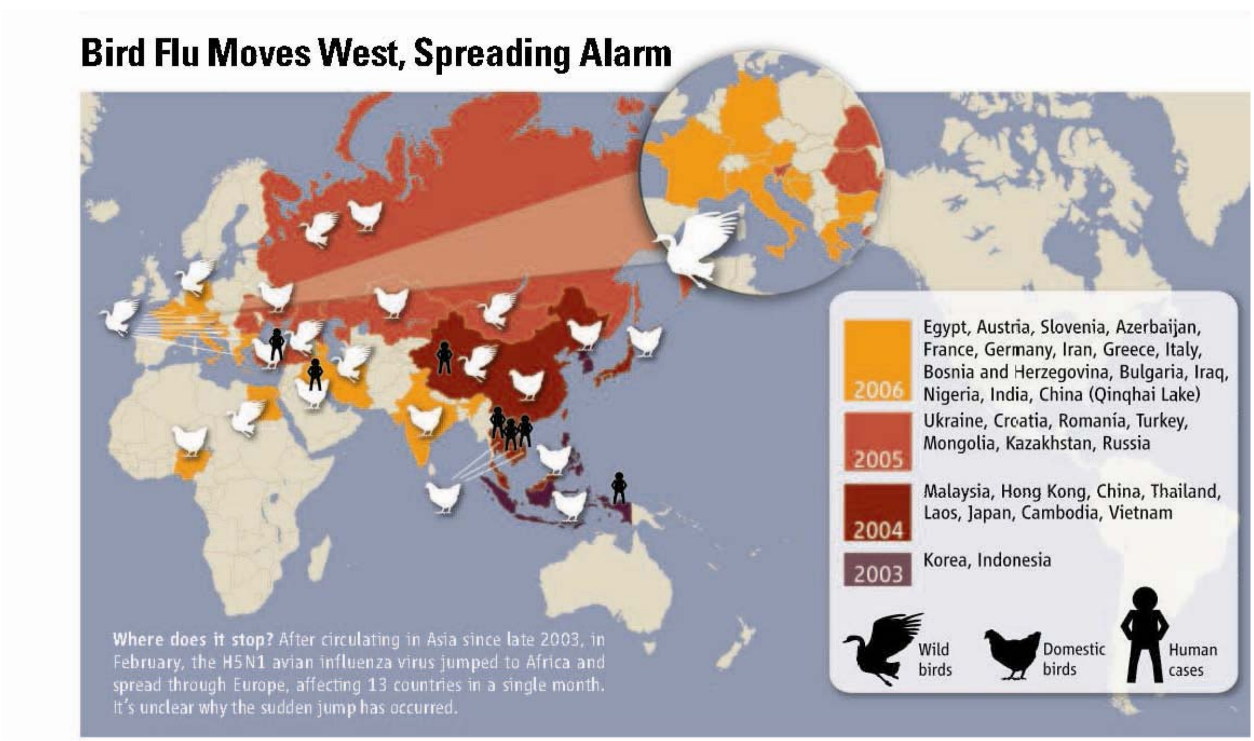
**Figure 4. Flyways in West Africa**



## III. SPATIAL ANALYSIS OF THE SPREAD OF AI IN WEST AFRICA

The first AI case in West Africa (also the first one in Africa) was reported in Igabi District, Nigeria, in February 2006, and more AI cases have been reported and confirmed since then in Burkina Faso, Cameroon, Niger, and Nigeria. Figure 5 shows the spread of AI between 2003 and March 2006, and Figure 6 shows the locations of outbreaks of AI in West Africa. Table 4 presents details of the HPAI outbreaks until April 2006. Nigeria has the largest number of reported cases within West Africa, and AI has spread quite rapidly in the country, whereas the other three countries have only a few isolated cases. By April 2006, more than 325,000 chickens in Nigeria had been identified as having H5N1 virus; of these, 223,000 died of the infection and the rest were slaughtered as a control measure.

**Figure 5. HPAI Spread**




*Source: Science (2005)*

## Figure 6. Outbreaks in West Africa

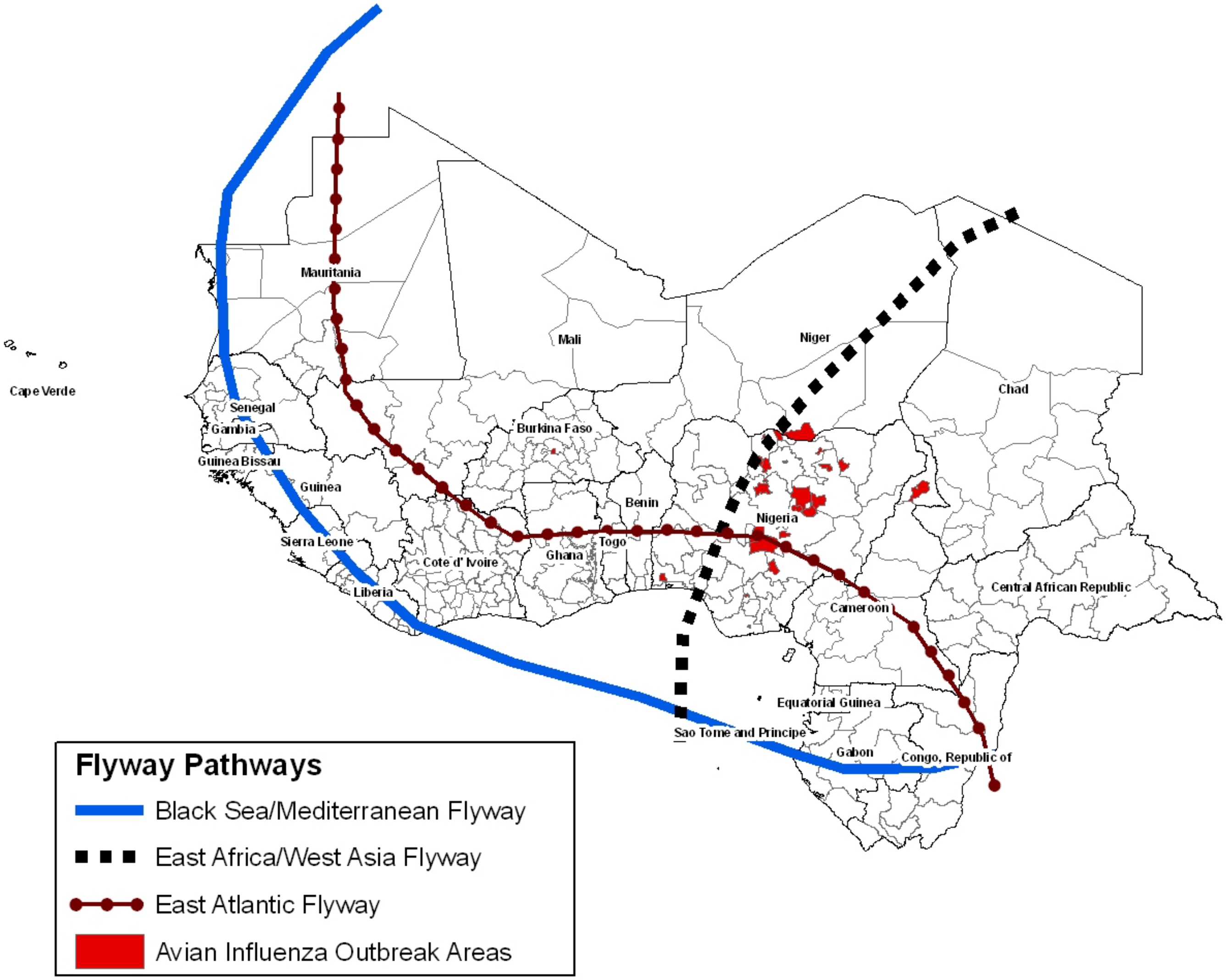


**Table 4. Details of AI Outbreaks in West Africa**

| Country | Region/State | District | Epidemiological Unit | Location | Outbreak Starting Date | Number of Animals in the Outbreaks | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Suscep-tible | Confirmed | Deaths | Destroyed |
| Burkina Faso | Kadiogo | Saaba | village | Gampéla | 1 March 2006. | 130 | 130 | 123 | 7 |
| Cameroun | Northernmost | Diamaré | village | Maroua | 21 Feb. 2006 | 58 | 50 | 50 | 8 |
| Niger | Zinder | Magaria | village | NA | 13 Feb. 2006 | 20,000 | … | … | … |
| | Anambra | Idemili South LGA | farm | various locations | 25 Feb. 2006 | 500 | | 353 | |
| | Bauchi | various locations | farm | various locations | 11 Feb to 24 March 2006 | 3,375 | 1,266 | 61,433 | 83,988 |
| | Benue | Otukpo LGA | farm | various locations | 25 Feb. 2006 | 600 | | 594 | |
| | Fed. Capital Territory | various locations | farm | various locations | 18 Feb to 25 Feb 2006 | 593 | 150 | 187 | 0 |
| | Jigawa | Hadejia | village | Gayawa Mallam | 27-Feb-06 | | | 9,020 | |
| | Kaduna | various locations | farm | various locations | 10 Jan to 16 Mar 2006 | 76,515 | 43,630 | 45,736 | 16,539 |
| Nigeria | Kano | various locations | farm | various locations | 19 Jan to 3 Mar 2006 | 53,676 | 1,974 | 1,996 | 23,426 |
| | Katsina | various locations | farm | various locations | 13 Feb to 5 Mar 2006 | 4,262 | 2 | 2 | 0 |
| | Lagos | Agege | farm | various locations | 10-Mar-06 | 18,000 | | | |
| | Nasarawa | Kokona LGA | farm | Guraku | 17 Feb. 2006 | | | | |
| | Ogun | Ifo | farm | Onibudu | 18-Jan-06 | 135,000 | | 94,000 | |
| | Plateau | various locations | farm | various locations | 29 Jan to 20 Mar 2006 | 31,518 | 10,746 | 8,596 | 20,733 |
| | River | Portharcourt LGA | farm | Katako Area, Jos | 24 Feb. 2006 | 1,200 | | 700 | |
| | Yobe | Nangere LGA | farm | Potiskum | 16 Feb. 2006 | | 6 | | |
| | **Total** | | | | **Feb to March 2006** | **325,239** | **57,768** | **222,617** | **144,686** |

*Source: OIE (2006)*

Although AI can be transmitted in a number of ways, only two types of risk are considered in this paper. One type is local contamination from existing outbreaks and the other type is contamination from migratory birds, a suspected transmission mechanism over long distances. For both transmission channels, we limit the analysis to the poultry sector only; the risk of potential transmission to other livestock and humans is not considered. While the transmission of diseases from animals to humans appears to have increased in recent years—perhaps due to increasingly intensive livestock production in areas of proximity to human populations (Delgado et al. 1999), H5N1 has so far not mutated into a form transmittable from one human being to another (FAO 2006a). Recorded human illnesses and deaths have all been traced back to direct contact with poultry or uncooked poultry products (McLeod et al. 2006), often related to poultry-handling practices of smallholders in backyard poultry production (Olsen et al. 2005). However, the result could be a pandemic of vast proportions if transmission of the disease from human to human occurred.[4]

**A Spatial Partial Equilibrium Model for Nigeria's Poultry Sector**

The economic impacts of AI have been studied in several Southeast Asian countries where data have been collected over a few years, following outbreaks of AI in the region. Most such studies are at the micro level and are often based on small sample surveys conducted at the village level or detailed data on the microeconomics of household production. Magalhaes (2006), for example, has developed a stochastic state-dependent disease transmission model to simulate the relative impact of different control options for HPAI outbreaks in Viet Nam, where farm-level data were confined to four provinces in North and South Viet Nam. Otte, Roland-Holst, and Pfeiffer (2003) have studied household income effects of AI in Viet Nam, based on 600 representative

[4] According to FAO (2006a), about 200 million poultry in the world have been culled in the last two and half years as a result of the present AI emergency, with losses of US$10 billion in Southeast Asia alone. By early July 2006, there were 229 human cases of H5N1 infection, resulting in the deaths of 131 persons. Human-to-human transmission of H5N1, however, has been suggested in several household clusters (Hien et al. 2004). Several other modes of transmission, such as environment to humans, are also theoretically possible (Beigel et al. 2005).

households aggregated from the 2002 Viet Nam Household Living Standards Survey (VHLSS). The study emphasizes the importance of microeconomic analysis and localized design and implementation of policies to reduce HPAI risk. Aimed at promoting a more comprehensive analysis of AI's impact, several salient insights are obtained from the study. For example, the study points out that the rural poor majority should have been recognized as part of the solution to reducing disease risk, not as part of the problem; hence, risk-reduction strategies must be designed with them in mind.

In this study, a spatial partial equilibrium model for the poultry sector in an entire country (Nigeria), based on the spatial data set discussed in the previous section, is developed. Spatial models have been widely used in land use and environmental analysis. Flamm (2006), for example, integrates spatial ecological models into land-use decisionmaking at the local level; Chomitz and Gray (1996) develop a spatially explicit model of land use, and the model is applied to data for southern Belize to analyze the effect of road building on rural development and deforestation. The model developed for this study is somewhat simpler than the above models, in which the complex interdependent relationship of spatial factors is taken into account and some time is estimated. In our model, we focus on decisionmaking with regard to demand and supply of a single commodity—chicken— at a disaggregated pixel level for the entire country. There are more than 300,000 pixels in West Africa. To build a spatial equilibrium model for the whole of West Africa at the pixel level seems to be impossible, even for a single commodity, given the current computer calculation capacity constraint when the software (GAMS) is used by the model. Instead, we develop a spatial equilibrium model for a single country (Nigeria), which can be easily adapted to other countries for region-wide analysis of the impact of AI on the poultry sector. In the model, Nigerian chickens are spatially distributed among 25,600 pixels, and hence, there are a total of 25,600 chicken supply functions defined at the pixel level. While the chicken supply function depends on the chicken price, AI can directly wipe out chicken production in certain pixels in which AI occurs (that is, AI can interrupt chicken producers' decisions spatially).

The demand function for chicken, which is a function of chicken prices and income, is defined at the national level but spatially disaggregated to the pixel level. Income is generated from both chicken production and the rest of the economic activities. Only the revenue coming from the chicken sector is endogenously determined, while the rest of the income is exogenously fixed in the model. To take into account the direct impact of AI on consumers' demand, chicken consumption is assumed to decline significantly in the AI affected areas defined at the pixel level (in other words, AI can interrupt consumers' decisions spatially too), while consumers' preference at the national level is also affected due to consumers' psychological concerns about AI.

The amount of imports and exports of live chickens, chicken meat, and eggs captured in the official statistics is very small for Nigeria. Thus, both imports and exports of chicken are ignored,[5] which allows the chicken prices to be endogenously determined in the model by equalizing chicken supply and demand in the domestic market. Through changes in chicken supply, demand, price, and income endogenously generated from chicken production, the model captures both direct and indirect effects of AI on chicken production and farm revenue.

**Spatial Distribution of AI Outbreaks in Nigeria**

Since early 2006, Nigeria has confirmed a series of AI outbreaks both in the backyards of small farms and on large, commercial chicken farms. The risk of AI spreading is high within the districts where AI outbreaks have occurred. The disease spreads locally either through live animal markets or contaminated materials and surfaces, making the neighboring areas also vulnerable. Because of the difficulty of pinpointing at the pixel level the exact location of AI outbreaks that have already occurred, we assume entire districts where infections have occurred to be the high-risk areas (Figure 6). About 10 million chickens are estimated to live in districts with AI outbreaks in Nigeria, as more than 60 AI outbreaks were confirmed in the country by April 2006.

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[5] Another way to justify such a model setup is to assume that imported and domestic chickens are very different and hence can be treated as different commodities in consumers' utility function.

Beyond the current outbreaks, migratory birds play a potential role in transmitting AI over long distances, and, therefore, are a potential source of future AI outbreaks. We assume different possible transmission ranges along the bird migratory flyways passing through West Africa. The pixel size used in the spatial data is about 5 $km^2$, and those pixels through which the flyways pass are assumed to be at the highest risk for AI. The second-highest risk areas are the pixels next to the highest risk ones, that is, bands about 5 km wide on both sides of the flyways. We further assume a transmission area 5 kilometers wide on the outside of each secondary risk band to be at modest risk. Figure 7 illustrates a flyway and identifies the three types of pixels. The highest risk zone is 5 km wide along the flyway, the second highest risk zone, which includes the areas defined in the highest risk zone, is 15km wide, and the modest risk zone, which includes the areas defined in the second highest risk zone, is about 25 km wide. Two flyways, the East Africa-West Asia (north-south) and Atlantic (east-west) flyways, pass through Nigeria (Figure 8), and therefore are the focus of the study.

**Figure 7. Risk Levels along the Flyway in Pixels**

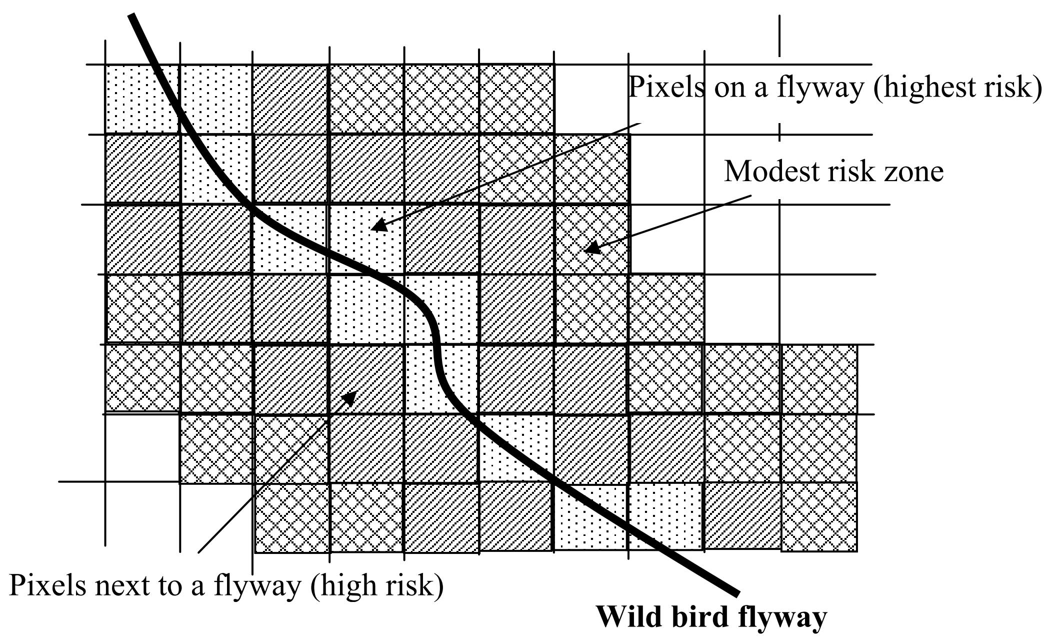


**Figure 8. Locations where Risk of AI is High in Nigeria**

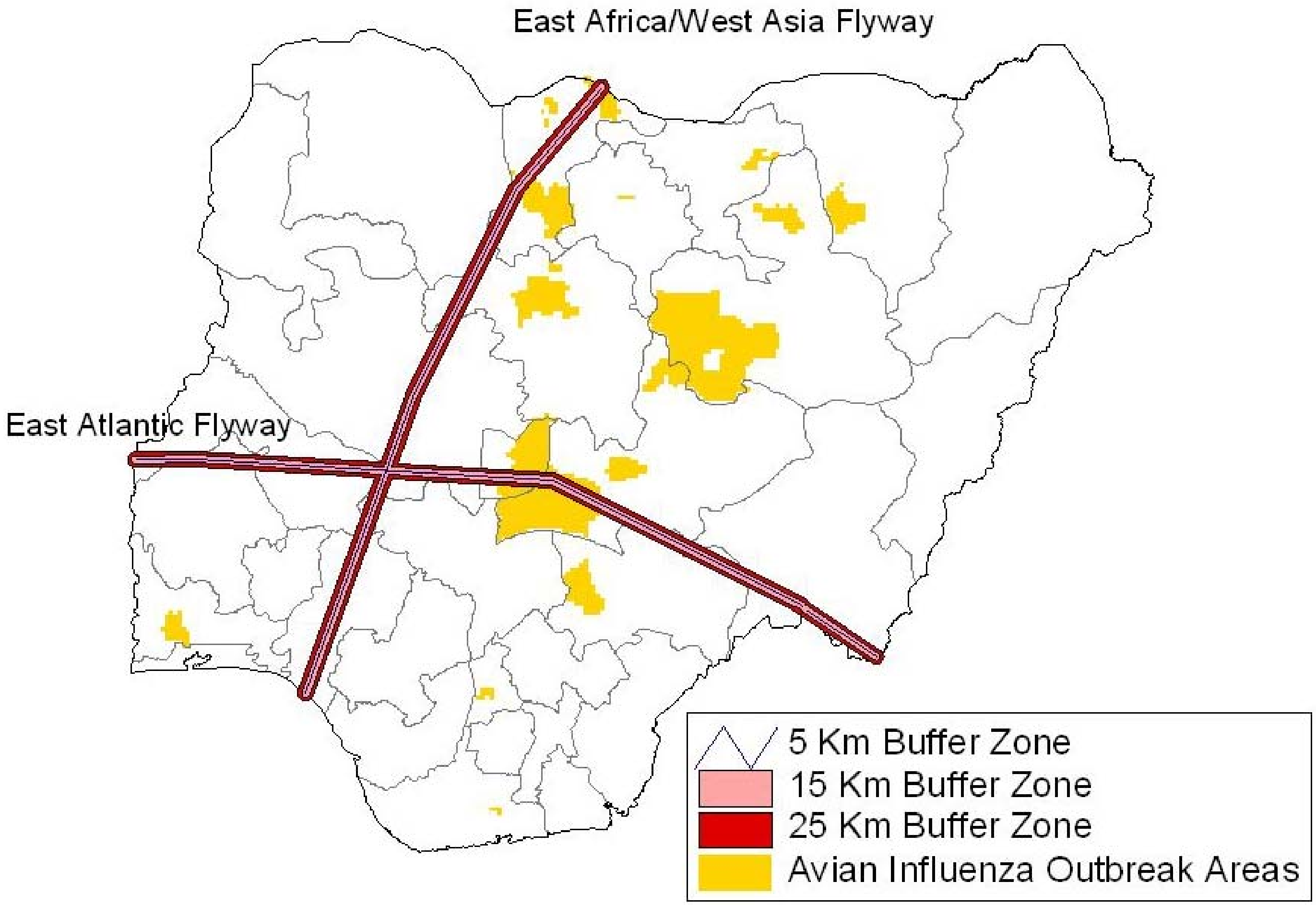


**Table 5. Comparison of Human and Chicken Populations in Identified Risk Areas in Nigeria**

| | % of National Population | | | % of Chicken Numbers in the Country |
|---|---|---|---|---|
| | Rural & Urban | Rural | Urban | |
| *North-south flyway* | | | | |
| Narrow zone | 0.45 | 0.55 | 0.34 | 0.60 |
| 10 km wide zone | 1.89 | 2.39 | 1.30 | 2.66 |
| 20 km wide zone | 3.28 | 4.25 | 2.14 | 4.41 |
| *East-west flyway* | | | | |
| Narrow zone | 0.26 | 0.41 | 0.09 | 0.46 |
| 10 km wide zone | 0.64 | 1.10 | | 1.35 |
| 20 km wide zone | 1.15 | 2.06 | | 2.35 |
| Current outbreaks | | | | |
| Districts | 8.19 | 4.64 | 12.35 | 6.99 |

*Source: Authors' calculations*

Table 5 summarizes and compares human and chicken population distributions in each identified risk zone in Nigeria: three risk zones along the East Atlantic (east-west) flyway, three along the East Africa-West Asia (north-south) flyway, together with the current outbreak zones. About 19 percent of chicken production, 15 percent of rural population, and 16 percent of urban population are within the areas defined as having some risk of AI in Nigeria. The at-risk shares for both chickens and humans in the current outbreak zone are relatively large because we are using the entire district areas within which an outbreak case has been confirmed. Table 6 provides the subnational (administrative state) distribution of chickens within the identified risk zones in Nigeria (the national total in each identified risk zone is 100). In the identified risk zones along the East Africa-West Asia (north-south) flyway, more than 80 percent of chicken production is located in two states: Ondo and Katsina, while the at-risk chicken population along the East Atlantic (east-west) flyway spreads relatively widely into four states: Benue, Kwara, Plateau, and Taraba, and Niger. Thirteen states in Nigeria have confirmed cases of avian flu. Seven heavily affected states (Anambra, Bauchi, Katsina, Kaduna Lagos, Ogun, and Plateau) account for almost 90 percent of total poultry exposed to the current outbreaks. Table 7 shows the regional distribution of the human population in potential risk areas in the country. The distribution pattern is similar to the one for poultry, reflecting the close association between the distribution of poultry and humans.

**Table 6. AI Risk Distribution of Chickens by Regions in Nigeria (National Total is 100)**

| Name of Regions | Production Share | In East Africa/West Asia Flyway | | | In East Atlantic Flyway | | | In Current Outbreaks | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | Highest Risk | 2nd high Risk | Modest Risk | Highest Risk | 2nd high Risk | Modest Risk | | |
| Abia | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Adamawa | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Delta | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Anambra | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.8 | 2.9 |
| Lagos | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 24.8 | 12.6 |
| Bauchi | 3.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 12.3 | 6.3 |
| Benue | 8.8 | 0.0 | 0.0 | 0.0 | 44.8 | 48.0 | 37.5 | 3.2 | 8.0 |
| Kano | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 1.0 |
| Kwara | 1.9 | 10.3 | 2.8 | 1.9 | 16.9 | 13.2 | 16.8 | 0.0 | 3.5 |
| Rivers | 5.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Abuja Cap. Territory | 0.3 | 0.0 | 0.0 | 0.0 | 3.4 | 2.1 | 3.0 | 2.8 | 2.0 |
| Edo | 2.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Enugu | 3.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jigawa | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.4 |
| Kogi | 2.1 | 4.6 | 8.0 | 6.9 | 10.7 | 3.6 | 2.9 | 0.0 | 2.7 |
| Ogun | 5.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.1 | 3.6 |
| Ondo | 6.2 | 52.4 | 57.5 | 60.7 | 0.0 | 0.0 | 0.0 | 0.0 | 19.5 |
| Kebbi | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Plateau | 3.7 | 0.0 | 0.0 | 0.0 | 5.4 | 8.5 | 8.9 | 11.9 | 7.6 |
| Akwa Ibom | 4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cross River | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Kaduna | 3.4 | 0.3 | 0.6 | 0.5 | 0.0 | 0.0 | 0.0 | 15.5 | 8.1 |
| Katsina | 3.2 | 24.0 | 23.8 | 22.8 | 0.0 | 0.0 | 0.0 | 11.0 | 12.9 |
| Osun | 2.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oyo | 4.4 | 0.0 | 0.0 | 0.0 | 8.0 | 4.0 | 6.0 | 0.0 | 1.0 |
| Borno | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Imo | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sokoto | 3.3 | 0.6 | 0.5 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| Taraba | 2.5 | 0.0 | 0.0 | 0.0 | 7.7 | 16.4 | 15.0 | 0.0 | 2.6 |
| Niger | 3.5 | 7.8 | 6.8 | 6.4 | 3.1 | 4.2 | 9.8 | 0.0 | 3.7 |
| Yobe | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 | 1.5 |
| National | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

*Source: Authors' calculations*

**Table 7. Human Population Distribution by Regions in Nigeria (National Total is 100)**

| Name of Regions | Population Share | In East Africa/West Asia Flyway | | | In East Atlantic Flyway | | | In Current Outbreaks | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | Highest Risk | 2nd high Risk | Modest Risk | Highest Risk | 2nd High Risk | Modest Risk | | |
| Abia | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Adamawa | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Delta | 2.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Anambra | 3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.1 | 5.2 |
| Lagos | 7.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.2 | 5.4 |
| Bauchi | 4.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 14.6 | 9.5 |
| Benue | 2.8 | 0.0 | 0.0 | 0.0 | 22.4 | 32.8 | 28.8 | 2.1 | 4.0 |
| Kano | 6.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.2 | 6.0 |
| Kwara | 2.0 | 1.7 | 1.5 | 1.6 | 19.7 | 14.6 | 15.5 | 0.0 | 1.8 |
| Rivers | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 1.1 |
| Abuja Cap. Territory | 0.4 | 0.0 | 0.0 | 0.0 | 8.3 | 6.0 | 7.8 | 3.8 | 3.2 |
| Edo | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Enugu | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jigawa | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.2 | 3.4 |
| Kogi | 2.4 | 1.1 | 1.4 | 1.5 | 1.5 | 0.6 | 0.7 | 0.0 | 0.4 |
| Ogun | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.4 | 1.5 |
| Ondo | 4.4 | 57.0 | 54.4 | 51.1 | 0.0 | 0.0 | 0.0 | 0.0 | 13.3 |
| Kebbi | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Plateau | 3.6 | 0.0 | 0.0 | 0.0 | 6.9 | 11.8 | 12.8 | 14.5 | 10.6 |
| Akwa Ibom | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cross River | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Kaduna | 4.6 | 1.6 | 1.8 | 1.9 | 0.0 | 0.0 | 0.0 | 9.2 | 6.5 |
| Katsina | 4.1 | 30.2 | 31.9 | 31.4 | 0.0 | 0.0 | 0.0 | 18.2 | 20.0 |
| Osun | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oyo | 4.1 | 0.0 | 0.0 | 0.0 | 27.8 | 13.7 | 13.5 | 0.0 | 1.2 |
| Borno | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Imo | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sokoto | 4.6 | 2.9 | 2.9 | 3.7 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| Taraba | 1.4 | 0.0 | 0.0 | 0.0 | 9.5 | 15.4 | 14.2 | 0.0 | 1.3 |
| Niger | 2.5 | 5.4 | 6.1 | 8.7 | 3.8 | 5.2 | 6.7 | 0.0 | 2.9 |
| Yobe | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.7 | 1.8 |
| National | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

*Source: Authors' calculations*

## IV. AI SCENARIOS AND MODEL SIMULATION RESULTS

### Model Assumptions

Based on the above risk analysis, the spatial equilibrium model is used to simulate different risk scenarios. Four groups of scenarios are designed to study both local and long-distance modes of AI transmission. The first group of scenarios focuses on the north-south flyway passing through Nigeria, while the second group focuses on the east-west flyway zone. The third group of scenarios focuses on the local mode of transmission, using the current outbreak zones as examples, and the last group is a combination of long-distance and local modes of transmission, the worst-case scenario. In simulating the potential impacts of AI spread along the two flyways, three alternative scenarios are considered: the highest risk corridors along the bird migratory flyways, that is, the pixels that the flyways directly pass through (the 5 km buffer zone in Figure 8); secondary risk corridors, including the pixels within a range of 5 km along either side of the flyways (the 15km buffer zone in Figure 8); and the modest risk corridors, including the pixels within a range of 10 kilometers along either side of the flyways (the 25km buffer zone in Figure 8). To simulate the AI risk within current outbreak zones, the districts within which current outbreaks have occurred are defined as directly hit areas.

As in any other partial equilibrium model, many assumptions have to be employed in the simulations. Because these assumptions will affect the model results, we also conduct a series of sensitivity tests to evaluate the relationships between the model assumptions and simulation results. The first group of assumptions is about elasticities employed in both supply and demand functions. The income elasticity is assumed to be 1.5 in the demand function. This elasticity is based on the authors' own estimations, using household-level total expenditure and chicken consumption data for Ghana.[6] Price elasticity in the demand and supply functions is assumed to be the same and is half of the income elasticity (negative 0.75 in the demand function and positive 0.75 in the supply functions). The second group of assumptions is about the direct effects of AI on chicken

[6] Recent household survey data from Nigeria were not available to the authors. However, they can easily replace the elasticity used in the model if Nigerian data become available.

production in the affected areas. Since mortality rates are high and the spread to other livestock and even humans is a threat, a commonly adopted method to control the spread of AI is to destroy (cull) the infected fowl. Based on this, we assume that chicken production is wiped out temporarily in the pixels possibly affected by AI in the model. The size of the direct hit on local chicken production varies in different scenarios, depending on how big the affected areas are. The third group of assumptions is about the direct impact of AI on consumers' demand. We assume that consumers in the affected areas will significantly reduce chicken consumption. There is also a direct effect on chicken consumption in the nearby areas, as consumers may be concerned that the chicken in their local markets may possibly come from the affected areas. These two kinds of direct impacts on consumption are defined locally at pixel levels. Given that there are no spatial consumption data available, we use national average per capita consumption in combination with the spatial population distribution data to disaggregate chicken consumption to each pixel. Consumers living in the areas far away from AI affected areas may also start to consume less chicken for psychological reasons. We model this by altering the consumers' preference parameter in the demand function.

**Model Results at the National Level**

The simulated impacts of AI on chicken production vary depending on differences in the sizes of the affected areas (Table 8). In the model, the direct effect on chicken production encompasses the areas directly hit by the AI outbreak. We assume that chicken production is completely wiped out in these pixels if there is an AI outbreak. The indirect impact on chicken production, mainly affecting parts of the country where AI has not occurred, indicates a reduction in consumer demand, which causes a decline in chicken prices. If AI occurs through long-distance transmission in the highest risk zone— in those pixels that fall within a migratory bird flyway— the direct effect on chicken production is quite modest at the national level: total chicken production would fall by less than 1 percent along either the north-south or east-west flyway. If AI spreads along relatively broad corridors (to the secondary high-risk areas in the long-distance model), that is, in a band 15 kilometers wide (5 along each side of each flyway, plus 5km wide of the flyway), the direct impact results in a 2.7 percent decline in chicken production along the north-south flyway and a 1.4 percent decline along the east-west flyway. If AI spreads to the modest risk areas of 25 kilometers along the flyways, the direct impact significantly increases: total chicken production would fall by 4.4 percent if AI is widespread along the north-south flyway and 2.4 percent along the east-west flyway.

**Table 8. Direct and Indirect Impacts of AI in Model Simulations, Nigeria**

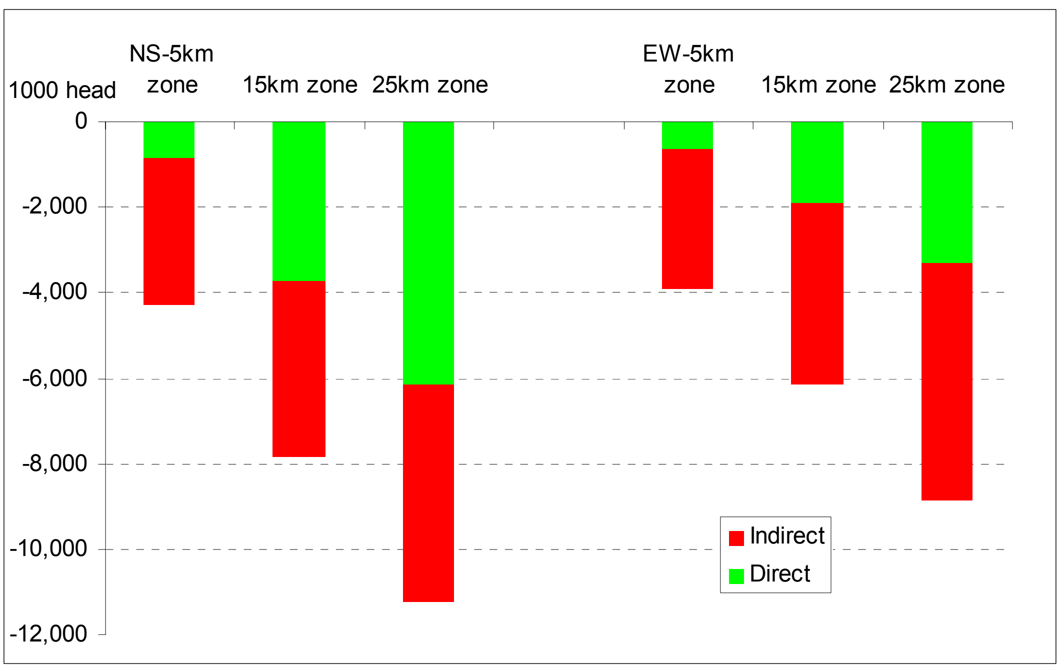
| | | Declines in Chicken Production (1000 Head) | | | % in Current National Production | | | Declines in Revenue | | % Decline in Chicken Price |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Direct Effect | Indirect Effect | Total Effect | Direct Effect | Indirect Effect | Total Effect | (1000 US$) | % National Current | |
| | *North-south flyway* | | | | | | | | | |
| Scenario 1 | Narrow zone | 839 | 3,456 | 4,295 | 0.60 | 2.47 | 3.07 | 52,043 | 6.26 | 3.30 |
| Scenario 2 | 10 km wide zone | 3,730 | 4,119 | 7,849 | 2.66 | 2.94 | 5.61 | 78,023 | 9.39 | 4.01 |
| Scenario 3 | 20 km wide zone | 6,169 | 5,063 | 11,232 | 4.41 | 3.62 | 8.02 | 104,951 | 12.63 | 5.01 |
| | *East-west flyway* | | | | | | | | | |
| Scenario 4 | Narrow zone | 641 | 3,251 | 3,892 | 0.46 | 2.32 | 2.78 | 48,121 | 5.79 | 3.1 |
| Scenario 5 | 10 km wide zone | 1,890 | 4,279 | 6,169 | 1.35 | 3.06 | 4.41 | 69,244 | 8.33 | 4.1 |
| Scenario 6 | 20 km wide zone | 3,290 | 5,593 | 8,882 | 2.35 | 3.99 | 6.34 | 94,854 | 11.42 | 5.4 |
| Scenario 7 | Combining 3 & 6 | 9,459 | 7,911 | 17,371 | 6.76 | 5.65 | 12.41 | 161,277 | 19.41 | 8.0 |
| Scenario 8 | Current outbreak districts | 9,780 | 6,076 | 15,856 | 6.99 | 4.34 | 11.33 | 139,559 | 16.80 | 6.1 |
| Scenario 9 | Combining 7 & 8 | 19,239 | 10,265 | 29,504 | 13.74 | 7.33 | 21.07 | 251,438 | 30.27 | 11.6 |

*Source: Model simulation results*

An AI outbreak may cause consumers to panic and hence change their behavior. Chicken consumption may fall significantly in affected areas. If multiple outbreaks occur in a country, consumers nationwide may reduce their consumption of chicken due to psychological factors. When the reduction in chicken nationwide consumption is more than the decline in chicken production in the area direct hit by AI, which is often the case in any country where AI has occurred, chicken prices start to fall, which negatively affects chicken production in other areas that are not directly hit by AI outbreaks. The indirect effects are often larger than the direct effect, and are highly related to the country's consumer response and price elasticity in the chicken supply function.

Intuitively, if AI occurs in an area of high population density, the negative impact on the consumption side will be larger than that in an area of low population density. Human population density is fortunately lower than the chicken densities in the corridors along both flyways in Nigeria (Table 5). For example, 0.6 percent of the country's chicken production is located in the highest-risk area along the north-south flyway corridor, while 0.5 percent of the national population and 0.3 percent of the urban population live in these areas. Even in the widely defined flyway corridors (the modest risk areas), shares of both total and urban population in the national total are still lower than the share of the chicken population located in the area.

**Figure 9. Direct and Indirect Impacts on Chicken Production in Nigeria along the Two Flyways**




*Source: Model simulation results*

Taking into account the population distribution, the model simulations show that chicken production could decline 2.3–4.0 percent nationally as a result of the indirect effect of a decline in chicken consumption, if AI occurs in the highest risk corridors along the two flyways. In this case, the direct and indirect effects of AI could cause chicken production to fall 2.8–8.0 percent. If the AI virus further expands into the modest risk corridors along the migratory flyways, the worst-case scenario indicates a 12.4 percent decline in chicken production in the country. A comparison between the direct and indirect impacts on chicken production under the different scenarios can be found in Figure 9.

We also simulate the potential impact of local transmission of AI on national chicken production and consumption. Focusing on the current AI outbreak zones and assuming that chicken production in the entire district of these zones will be wiped out, the simulated direct impact is a 7 percent reduction in national chicken production. The indirect impact is smaller than the direct impact because of its local transmission nature. The reduction in chicken output is equivalent to 4.3 percent of current national production. When we combine local transmission with long-distance transmission along both flyways in the worst-case scenario (scenario 9), the country's chicken production could fall as much as 21.1 percent. This number seems to be realistic, considering what occurred in some Asian countries (such as Thailand) faced with AI.

Chicken farmers are hit not only by reduced demand in domestic markets, but also by declining chicken prices. In the worst-case scenario (scenario 9), in which it is assumed that AI is transmitted along both flyways and locally in the current outbreak zones, the national average chicken price falls by 11.7 percent. In total, chicken farmers would lose US$250 million in revenue, equivalent to 30.3 percent of current chicken revenue in the country. We included egg revenue as a part of chicken revenue by adding egg prices to chicken prices. Using producer prices reported in FAO data, the combined chicken and egg price is about US$5.90 per bird.

**Model Results at the Subnational Level**

An AI outbreak has typical spatial patterns, and national-level impact assessment may underestimate its severity in some subnational regions. As the model is a spatial one and changes in chicken production are identified at the pixel level, we can also assess the impact of AI within specific administrative or geographic regions. For this study we only aggregate chicken production into two levels of subnational administrative regions for Nigeria, which includes 30 states and 526 districts. We focus on the spread of AI through long-distance transmission and first look at its impact at the state level.

**Table 9. Chicken Risk Distribution by Regions in Nigeria (regional total is 100)**

| Name of Regions | In East Africa/West Asia Flyway | | | In East Atlantic Flyway | | | In Current Outbreaks | Total |
|---|---|---|---|---|---|---|---|---|
| | Highest Risk | 2nd high Risk | Modest Risk | Highest Risk | 2nd high Risk | Modest Risk | | |
| Abia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Adamawa | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Delta | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Anambra | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 19.7 | 19.7 |
| Lagos | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 47.7 | 47.7 |
| Bauchi | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 23.3 | 23.3 |
| Benue | 0.0 | 0.0 | 0.0 | 2.3 | 7.3 | 10.0 | 2.5 | 12.5 |
| Kano | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.4 | 4.4 |
| Kwara | 3.2 | 3.9 | 4.4 | 4.0 | 9.3 | 20.5 | 0.0 | 24.9 |
| Rivers | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Abuja Cap. Territory | 0.0 | 0.0 | 0.0 | 5.2 | 9.3 | 23.8 | 66.5 | 90.3 |
| Edo | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Enugu | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jigawa | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.5 | 3.5 |
| Kogi | 1.3 | 10.1 | 14.4 | 2.3 | 2.3 | 3.3 | 0.0 | 17.7 |
| Ogun | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.5 | 8.5 |
| Ondo | 5.1 | 24.8 | 43.3 | 0.0 | 0.0 | 0.0 | 0.0 | 43.3 |
| Kebbi | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Plateau | 0.0 | 0.0 | 0.0 | 0.7 | 3.1 | 5.7 | 22.6 | 28.3 |
| Akwa Ibom | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cross River | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Kaduna | 0.1 | 0.5 | 0.7 | 0.0 | 0.0 | 0.0 | 31.7 | 32.4 |
| Katsina | 4.5 | 19.9 | 31.5 | 0.0 | 0.0 | 0.0 | 24.1 | 55.5 |
| Osun | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oyo | 0.0 | 0.0 | 0.0 | 0.8 | 1.2 | 3.2 | 0.0 | 3.2 |
| Borno | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Imo | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sokoto | 0.1 | 0.4 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| Taraba | 0.0 | 0.0 | 0.0 | 1.4 | 8.7 | 13.9 | 0.0 | 13.9 |
| Niger | 1.3 | 5.2 | 8.0 | 0.4 | 1.6 | 6.6 | 0.0 | 14.7 |
| Yobe | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.9 | 10.9 |
| National | 0.6 | 2.7 | 4.4 | 0.5 | 1.4 | 2.3 | 7.0 | 13.7 |

*Source: Authors' calculations*

In Nigeria, the north-south flyway passes through seven states and the east-west flyway through eight states. There are only two states, Kwara and Kogi, through which both flyways pass (Table 9): 7.2 percent of chicken production in Kwara and 3.6 percent in Kogi are in areas directly under the two flyways. If we include the modest risk areas, chicken production located in the risk areas of the two states increases to 25 and 18 percent, respectively. Only the east-west flyway passes through Abuja Capital Territory,

**Table 10. Human Population Distribution in AI Risk Areas by Regions in Nigeria (regional total population is 100)**

| Name of Regions | In East Africa/West Asia Flyway | | | In East Atlantic Flyway | | | In Current Outbreaks | Total |
|---|---|---|---|---|---|---|---|---|
| | Highest Risk | 2nd high Risk | Modest Risk | Highest Risk | 2nd high Risk | Modest Risk | | |
| Abia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Adamawa | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Delta | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Anambra | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 20.0 | 20.0 |
| Lagos | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.1 | 9.1 |
| Bauchi | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 25.6 | 25.6 |
| Benue | 0.0 | 0.0 | 0.0 | 2.1 | 7.5 | 11.9 | 6.3 | 18.2 |
| Kano | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 11.1 | 11.1 |
| Kwara | 0.4 | 1.4 | 2.7 | 2.6 | 4.7 | 9.1 | 0.0 | 11.9 |
| Rivers | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.4 | 4.4 |
| Abuja Cap. Territory | 0.0 | 0.0 | 0.0 | 5.3 | 9.4 | 21.9 | 76.2 | 98.1 |
| Edo | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Enugu | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jigawa | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 13.4 | 13.4 |
| Kogi | 0.2 | 1.1 | 2.0 | 0.2 | 0.2 | 0.3 | 0.0 | 2.3 |
| Ogun | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.8 | 6.8 |
| Ondo | 5.9 | 23.4 | 38.1 | 0.0 | 0.0 | 0.0 | 0.0 | 38.1 |
| Kebbi | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Plateau | 0.0 | 0.0 | 0.0 | 0.5 | 2.1 | 4.1 | 33.1 | 37.3 |
| Akwa Ibom | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cross River | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Kaduna | 0.2 | 0.7 | 1.4 | 0.0 | 0.0 | 0.0 | 16.4 | 17.8 |
| Katsina | 3.4 | 14.9 | 25.4 | 0.0 | 0.0 | 0.0 | 36.7 | 62.1 |
| Osun | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oyo | 0.0 | 0.0 | 0.0 | 1.7 | 2.1 | 3.8 | 0.0 | 3.8 |
| Borno | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Imo | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sokoto | 0.3 | 1.2 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 | 2.7 |
| Taraba | 0.0 | 0.0 | 0.0 | 1.8 | 7.0 | 11.7 | 0.0 | 11.7 |
| Niger | 1.0 | 4.6 | 11.5 | 0.4 | 1.3 | 3.1 | 0.0 | 14.6 |
| Yobe | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 14.1 | 14.1 |
| National | 0.5 | 1.9 | 3.3 | 0.3 | 0.6 | 1.2 | 8.2 | 12.6 |

*Source: Authors' calculations*

but about 24 percent of the region's chicken production is within the widely defined flyway corridor. The situation is more serious in Ondo and Katsina, where 43 and 32 percent, respectively, of the regions' chicken production is within the widely defined north-south flyway corridor. It can be expected that these five states will be seriously hit by the possible spread of AI. Fortunately, human population density in the area directly under the two flyways is low in most states (Table 10). For example, 3.0 percent of human population in Kwara and 0.4 percent in Kogi are living in the ereas directly under the two flyways. Taking into account spatial distribution of human and chicken population, as well as the direct and indirect impacts, chicken production would fall 23–47 percent in these states if AI occurred along both flyway corridors in scenario 7 (Table 11). In the worst-case scenario (scenario 7) in Ondo, chicken farmers' revenue would fall by more than 50 percent. Since the region accounts for 6.2 percent of national chicken production and 40 percent of high-risk production, early preparation to deal with an AI outbreak in the region is essential.

**Table 11. Declines in Chicken Production and Revenue, Selected Regions, Scenario 7**

| Region | Declines in Chicken Production | Declines in Chicken Revenue |
|---|---|---|
| Kogi | -22.7 | -28.8 |
| Kwara | -29.5 | -35.1 |
| Abuja Capital Territory | -28.4 | -34.1 |
| Ondo | -46.7 | -51.0 |
| Katsina | -35.6 | -40.8 |

*Source: Model simulation results*

At the district level, there are 32 districts in which chicken production would fall by more than 50 percent if the worst-case scenario should occur. Among these 32 districts, 16 districts would lose 75–100 percent of chicken production under the worst-case scenario. Moreover, 8 of the 16 districts are in Ondo, further indicating the importance of early preparation for Ondo to deal with an AI outbreak.

## V. FINAL REMARKS

Evaluating the potential impact of AI is challenging because knowledge about the virus (and the methodology for analyzing it) is limited. Based on what is known about the spread and transmission of the disease, here we have developed a spatial equilibrium model, using recent spatial data on the distribution of both chicken and human populations to analyze the potential economic impact of AI in West Africa, taking Nigeria as an example. The analysis shows that the extent of the loss of chickens depends on the size of the affected areas and on whether AI is spread through long-distance transmission along the two migratory bird flyways or spread through local transmission in the current outbreak zones. The negative impact of a direct hit on Nigerian chicken production could mean the loss of 2.4 to 4.4 percent of the total number of chickens if the spread is by long-distance means and 7 percent if the spread is from currently infected local areas. However, the indirect effect on the economy, induced by consumers' reduction of chicken consumption causing a decline in chicken prices, is generally larger than the direct effect. In the worst-case scenario, which combines both local and long-distance modes of disease transmission, Nigerian chicken production would fall by 21 percent and chicken farmers would lose US$250 million in revenue.

National-level assessment may underestimate the severity of the effects of AI, as the negative impact of AI will be unevenly distributed throughout the country. Analysis at the subnational level shows that chicken production could decline as much as 40–50 percent in some states and 100 percent in some districts. Early preparation is critical for these regions in order to minimize the impact of AI on farmers.

Admittedly, the current study simplifies some factors and does not take many other factors into account. Lack of adequate knowledge about the possible transmission and spread of the AI virus to other livestock and humans prevents any analysis going beyond the chicken sector at this time. Given that AI could potentially become a high-risk epidemic for both livestock and humans, it deserves a solid assessment of its economic and social impacts. Such an analysis should be crosscutting, including experts from many different fields.

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