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An *expost* economic assessment of the intervention against highly pathogenic avian influenza in Nigeria

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Abstract. This study assesses the intervention against avian influenza in Nigeria. It applied a simple compartmental model to define endemic and burn-out scenarios for the risk of spread of HPAI in Nigeria. It followed with the derivation of low and high mortality risks associated to each scenario. The estimated risk parameters were subsequently used to stochastically simulate the trajectory of the disease, had no intervention been carried out. Overall, the intervention costs US$ 41 million, which was yearly disbursed in various amounts over the 2006-2010 period. The key output variables (incremental net benefit, disease cost, and benefit cost ratio) were estimated for each randomly drawn risk parameter. With a 12% annual discount rate, the results show that the intervention was economically justified under the endemic scenario with high mortality risk. On average, incremental benefit under this scenario amounted to US$ 63.7 million, incremental net benefit to US$27.2 million, and benefit cost ratio estimated to 1.75.

Keywords. Avian influenza, infection control, biological risk management, damage function, incremental net benefit

JEL codes. Q02, Q18, Q14

1. Introduction

Nigeria has a poultry industry with about 160 million birds estimated at US$ 250 million (FDLPCS, 2007).The industry contributes up to 10% to the country's agricultural gross domestic product and accounts for 36% of the country's total protein intake. The overall sector attracts investment and yields a net worth of US$ 1.7 billion a year (FRN, 2007). The commercial poultry sector represents 15% of the total poultry population and is of significant economic importance to the country and the West Africa region because of its contribution to employment, food security and livelihoods. However, the sector is still hampered by difficulties linked to obsolete infrastructure for animal health, poor disease surveillance strategy, and weak diagnosis and control systems. These factors put Nigeria at a high risk of introduction and spread of trans-boundary animal diseases such as the highly pathogenic avian influenza (HPAI) subtype H5N1 as confirmed by the report of the technical committee of experts on the prevention and (eventual) control of HPAI H5N1 in Nigeria (FDLPCS, 2005). The necessity of this committee's work was triggered

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by the enormous and unprecedented social and economic impacts of avian influenza in Asia where over 200 million domestic poultry had either died or been destroyed with 175 people having contracted the infection, of which, 93 had died as a direct result of HPAI infection between 2003 and 2005 (World Bank, 2006).

The Federal Government of Nigeria (FGN) had developed emergency preparedness plans for dealing with any incursion of the disease into Nigeria (FDLPCS, 2006) because of the economic significance of poultry farming and the potential for the outbreak of becoming a pandemic with incalculable consequences. However, the first wave of outbreaks, which started in February 2006 lasted for 21 months and created panic among the populace. There was significant unease among scientists and policy makers as little was known about the disease although the role of migratory bird species of the Anseriformes and Charadriiformes as natural reservoirs for the disease had been confirmed (Stallknecht and Shane, 1988). Keeler, Berghaus, and Stallknecht (2012) also established that the persistence of virus on surface water depends on the temperature (ambient), degree of salinity (hypothesized), and pH (neutral to slightly basic). However, the case of Nigeria is complicated by common practices such as illegal poaching and trades of wild birds for food and medicines and maintaining captive wild birds next to domesticated poultry, which are major factors contributing to the spread of the disease (Teru *et al.*, 2012). The fact that 60% of all poultry produced in Nigeria originate from village extensive and backyard intensive production system referred to as "Sector 4" according to FAO classification of poultry production systems (FDLPCS, 2007) is also a compounding factor. "Sector 4" is the main supplier of birds to retailers, consumers, and live bird markets notwithstanding the limited, if at any, application of biosecurity measures (Muteia *et al.*, 2011).

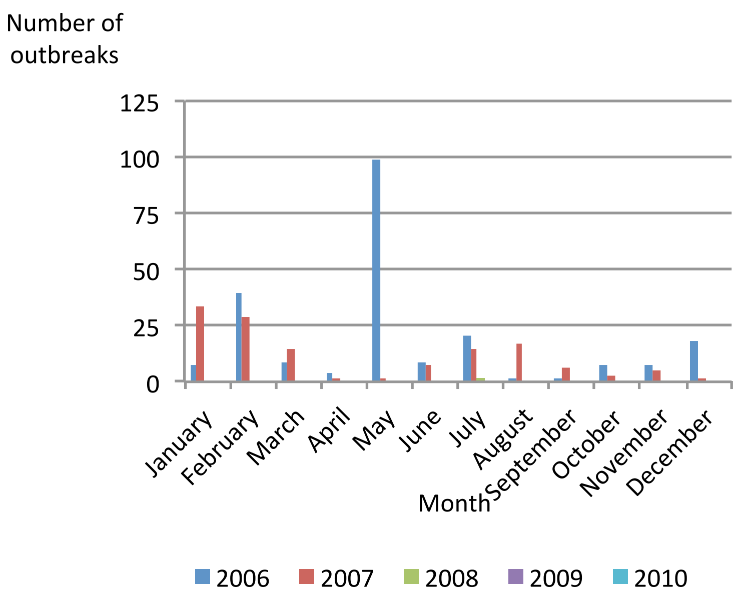
It was feared that this situation combined with a notable weak infrastructure for animal health, disease surveillance, diagnosis and control across sub-Sahara Africa, the effects of HPAI escaping the boundaries of Nigeria would be disastrous for the food security and livelihoods of millions of people (Gueye, 2007) and catastrophic for the continent if it evolved as an influenza pandemic. Such a dire scenario was possible given the virus' high propensity for random mutations and capacity to change in antigenicity, infectivity, and virulence (Holmes, 2010; Pfeiffer *et al.*, 2011).

The picture painted above was seriously taken and urgently addressed by the Nigerian government. It provided the near-perfect impetus for policy makers to decide to intervene based on the precautionary principle. In the immediate aftermath of the initial outbreaks, the worst of the fears became increasingly plausible. The disease spread rapidly to 97 local government areas in 25 states and the federal capital territory. Four hundred thousand birds were culled in the first two months; egg and chicken sales declined by 80% within two weeks following the announcement of HPAI outbreaks (OIE, 2007). There was a near total boycott of poultry products in the country with all the associated negative effects of a zoonotic and trans-boundary disease on the industry (Tiongco, 2009; Beach *et al.*, 2008; Akinwumi *et al.*, 2010; Rich and Wanyioke, 2010). At the West African regional level and in quick turns, Niger, Cameroon, Benin, Ghana, and Côte d'Ivoire, all confirmed outbreaks of the disease (OIE, 2011). These events galvanized the international community into action with Nigeria receiving significant in-kind aid materials such as disinfectants, protective gears, vehicles and equipment (Perry *et al.*, 2011).

On its part, the FGN began receiving funds from the World Bank through a loan contracted to support its effort to minimize the threats posed by H5N1, prepare against influenza pandemic, and prevent further spread of HPAI to other parts of the country under the Nigeria Avian Influenza Control Project (NAICP) (World Bank, 2006). The NAICP had a total of four components: Animal Health (budget US$ 29.2 million), Human Health (US$ 18.25 million), Social Mobilization and Strategic Communication (US$ 4 million), and Implementation Support/Monitoring and Evaluation (US$ 6.8 million). The allocation of funds across these activities let transpire an understanding by the FGN for a need to move beyond health issues to successfully deal with the disease. Using the case of Vietnam, Herington (2010) argued for the necessity to account for economic, political, and social factors in addition to the epidemiological factors in order to design the most objective and effective approach to deal with disease outbreaks. It is through this process known as securitization that a country could evoke the argument of national security interest to be able to undertake actions often not consistent with the narrow interest of market agents and politicians at the local level (Herington, 2010). International perception about the disease may not be enough to undertake actions such as culling birds, destroying eggs, and quarantining poultry farms according to Herington (2010). Drawing from the cases of severe acute respiratory syndrome (SARS) and avian influenza in China, Wishnick (2010) warned that securitization is not a panacea and advocated for a more balanced approach that enlists the public as a partner for the government to be successful in implementing its plans. This approach is broadly consistent with the actions taken by the FGN to quell HPAI.

In the entire event, Nigeria suffered two major waves of outbreaks in 2006 and 2007 with a small and final episode in July 2008 (Figure 1). In all, there were 362 outbreaks that led to one human case fatality and the destruction of 1.3 million infected birds for which

Figure 1. Distribution of total outbreaks in Nigeria by months for 2006-2010



$5.4 million was paid in compensation to 3,037 affected poultry farms/farmers (World Bank, 2010).

The NAICP was implemented from April 2006 to May 2011 during which time US$ 41 million were disbursed by the World Bank to the project. As the project was ending the World Bank commissioned the International Livestock Research Institute (ILRI) to conduct an independent impact assessment of the project to determine the degree to which the project outputs have contributed to the achievement of the project development objectives. The objectives of this study are threefold: (1) develop counterfactual scenarios to measure the extent to which the intervention had minimized losses; (2) assess the economic justification of the intervention; and (3) determine the threshold composite risk level necessary to justify the intervention.

In this article, we first outlined a theoretical framework of disease control to understand the economic foundation of disease risk management and mitigation. Second, we presented an assessment of HPAI risk based on observed data to derive the scenarios that were considered, followed by a presentation of the data, and a stochastic analysis of HPAI risk. We proceeded with the economic assessment of the intervention against HPAI followed by a final section on the concluding remarks.

2. Theoretical framework

Disease outbreaks induce cost due to production losses, untimely slaughters, and reduced productivity causing welfare losses at all levels of the supply chain (Wolf, 2005). These losses could be mitigated through strategically targeted interventions. Theoretically, these targeted interventions seek to minimize losses in expected damage from disease outbreaks. Accurate assessments of damages caused by animal diseases require integrating epidemic and economic models (Paarlberg *et al.*, 2005; Pritchett and Johnson, 2005). Rich and Winter-Nelson (2007) applied an integrated epidemiological and economic model to study the spatial and temporal impacts of foot-and-mouth outbreak in the southern cone of South America. Egbendewe-Mondzozo *et al.* (2013) applied similar approach with stochastic transmission rate for an ex ante assessment of using vaccination as an option to control avian influenza in the U.S.

Under this framework, the expected damage function could be calculated at the country level. It is proxied by the expected total (*TC*) a sum of expected direct (*DC*) indirect (*IC*), and could be formally defined as follows:

$$TC(\phi) = DC(\phi) + IC(\phi) \tag{1}$$

The specification of the direct cost component broadens the deterministic approach proposed by Bennett (2003). It contains a component ϕ to indicate the vector of intervention that links expected total cost of the disease, overall risk, and size of the intervention used to reduce risk. Equation (1) is a function of the probability, $p(\phi)$ of a bird being affected. This probability is a composite risk parameter derived as a product of risk of spread, $s(\phi)$, and mortality risk, $m(\phi)$. It is a function of the intervention cost, $r(\phi)$. Both the composite risk parameter and the cost of intervention are function of the vector of ϕ that includes surveillance, culling, carcass disposal, cleaning, compensation, and education, among other things. Under this specification, the optimal composite risk, $\overline{p}(\phi)$ under which the intervention would make economic sense could be numerically derived. At that point, the marginal cost of an additional unit of intervention equals its marginal benefit and the net social welfare gain of the intervention to its incremental net benefit.

The direct cost refers to the monetary values of physical losses as a result of mortality associated with HPAI calculated by applying the respective unitary prices to each category of physical losses. These physical losses include chicken death and egg losses (using the share of laying hens out of the dead chickens) as a result of the disease and the applied control strategies. The expected chicken death $L(\phi)$ the basis of the expected physical losses is calculated by multiplying the composite risk estimate and the population of Z and can be formally expressed as follows:

$$\begin{cases} L(\phi) = p(\phi) * Z \\ p(\phi) = s(\phi) * m(\phi) \end{cases} \tag{2}$$

The expected egg loss is found by multiplying annual production per layer by the share of layers out of the expected total dead chickens. The indirect cost involves the ripple effects such as effects of price shocks on supply chain actors, spill-over effects such as effects on the tourism sector, and long term macroeconomic effects of the disease (OIE, 2007). While the direct cost could be easily assessed with a partial budgeting approach, the indirect cost proves more complicated to determine. There is a general agreement based on the existing body of research on HPAI that the indirect cost of HPAI dwarfs the direct cost (OIE, 2007; Diao *et al.*, 2009). There is also an agreement that their measurements require extensive data that may be difficult to obtain, especially in developing countries (OIE, 2007). Hence, we utilised a ratio that puts the indirect cost at 1.24 times the direct cost derived from estimated direct and indirect costs of HPAI in Nigeria in an ex ante analysis that used a computable general equilibrium (Diao *et al.*, 2009).

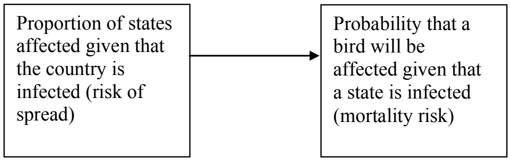
The incremental benefit represents the cost saving accrued to Nigeria as a result of the intervention. It is the difference between what would have been the total cost of HPAI to Nigeria had no action been taken and what it was under the intervention. The incremental cost corresponds to the World Bank's yearly disbursements between 2006 and 2010. The incremental net benefit is obtained by subtracting the incremental cost from the incremental benefit.

3. Risk assessment and scenario derivation

The estimation of economic impacts of HPAI outbreak in Nigeria is based on losses from mortality/culling incurred in the course of the outbreak. The magnitude of these losses is assumed to depend on the risk of disease spreading between states and the risk of a bird dying from the disease following exposure in the affected states (Figure 2).

There are at least two levels of aggregation between the state and the bird that should have been considered (i.e., local government area and village) to minimize making erroneous inferences when using aggregated data (state level) to address issues at local level (local government and village level). This could not be done because the outbreak dataset

Figure 2. Components of the risk of occurrence of HPAI outbreak in Nigeria.



used had more reliable information at higher (state) than lower (village) levels. A composite estimate of the risk of a bird being affected could be obtained by combining the two measures of risk shown in Figure 2 and outlined in the theoretical framework.

Given the high uncertainty associated with the HPAI risk estimates defined above, two risk scenarios (i.e., the best and the worst case scenarios) that are expected to enclose the plausible risk levels are provided for each risk estimate. The risk of introduction of the disease is not considered in this analysis because the focus is on an outbreak that had already occurred. Though multiple introductions of the virus might have occurred over the three-year period when the outbreak was active, these introductions are not considered as being independent events since they happened at a period when HPAI epidemic was active in many parts of the world.

The risk of spread of HPAI in Nigeria was analyzed using a simple compartmental Susceptible-Infectious (SI) model assuming that all newly infected states were infected by indirect contact with infectious states during the same wave of the epidemic. This is a system of differential equations that calculates the effects of a disease in a population by using preceding disease parameters known as transition rates (Rich and Winter-Nelson, 2007). Two scenarios were considered: (i) the outbreak burns out due to a reduction in the number of susceptible states, and (ii) the outbreak becomes endemic after a short peak. The assumption made for the first scenario is that re-stocking is done 90 days after culling and adequate biosecurity measures are put in place that will protect a large proportion of the newly introduced birds from getting exposed to the virus. For the second scenario, it is assumed that restocking is done routinely after 90 days but inadequate biosecurity measures are implemented. In this case, the replacement stock has an equal chance of being exposed to the disease as the indigenous population.

The model assumes that all newly infected states (C) were infected by indirect contact with infectious states (I) during the same wave of the epidemic. The contact between states could be associated with purchases, movements of infected birds, or transfers of infectious material (e.g. feaces) via fomites from infected to uninfected villages. Let S be the number of susceptible states per day, I the number of infectious states per day, and N the total number of states, the number of newly infected states C is given $\beta SI/N$. The parameter β the transmission coefficient of the disease. It represents the average rate at which an infected state infects susceptible state in a day in a population consisting of susceptible states. The β therefore derived NC/SI (Ward *et al.*, 2009) for each day (t) of the epidemic. This model ignores spatial transmission dynamics as it assumes that states had similar epidemiological characteristics (defined by HPAI risk factors, contact patterns and recovery rates) and were equally at risk of infection at the start of the epidemic.

The outbreak dataset (NAICP, undated) was, hence, aggregated at the state level in order to obtain one record/state/phase of the outbreak. The first phase occurred between January and August 2006 while the second occurred between November 2006 and November 2007. The duration of α was assumed to be equal to the duration between the dates when the outbreak was reported and when depopulation was done at the state level (Bett *et al.*, 2014). The transmission coefficients and the duration of infectiousness were estimated using the outbreak data set. The transmission coefficient was estimated $\beta = 0.02$ and the mean duration of infectiousness $\alpha = 49$ days while the incubation period of the disease, was assumed to be $\gamma = 3$ days. Henning *et al.* (2009) reported that incubation period could be anywhere between 2 and 14 days. The transmission rate, mean duration of infectiousness, incubation period, number of days, say ρ, required before restocking after culling, and number of states were used to solve the system of differential equations (3) and (4) for the number of susceptible, infected, incubating, and resolved cases, R, at each day (t). The prevalence at each day (t) is derived as I/N and the average prevalence over time represents the risk of spread of the disease between states. The estimates of the risk of spread over a 1 year period are 0.13 and 0.27 for the burn-out and endemic scenarios, respectively.

$$\begin{bmatrix} S_t \\ C_t \\ I_t \\ R_t \end{bmatrix} = \begin{bmatrix} 1-\beta & 0 & 0 & 1/\rho \\ \beta & 1-1/\gamma & 0 & 0 \\ 0 & 1/\gamma & 1-1/\alpha & 0 \\ 0 & 0 & 1/\alpha & 1-1/\rho \end{bmatrix} \times \begin{bmatrix} S_{t-1} \\ C_{t-1} \\ I_{t-1} \\ R_{t-1} \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} S_t \\ C_t \\ I_t \\ R_t \end{bmatrix} = \begin{bmatrix} 1-\beta & 0 & 0 & 0 \\ \beta & 1-1/\gamma & 0 & 0 \\ 0 & 1/\gamma & 1-1/\alpha & 0 \\ 0 & 0 & 1/\alpha & 1 \end{bmatrix} \times \begin{bmatrix} S_{t-1} \\ C_{t-1} \\ I_{t-1} \\ R_{t-1} \end{bmatrix} \tag{4}$$

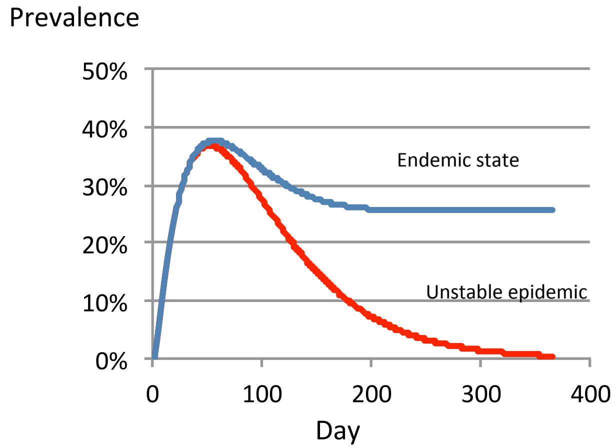
The initial conditions are $S_0 = N$, $N = 37$, $C_0 = 0$, and $R_0 = 0$. The parameters α, γ, β, and ρ remains as previously defined. Figure 3 provides an illustration of the evolution of HPAI prevalence under these two scenarios.

The risk of infection (or mortality risk, as the case fatality rate is 100%) was derived using the mean proportions of poultry that died (combining case fatalities and culled birds) out of the total population at risk in 2006 and 2007 for the states that had population at risk data. The mean proportions obtained were 2% and 1% for 2006 and 2007, respectively. Overall, given the high uncertainty associated with the HPAI risk estimates defined above, two risk scenarios (i.e., the best and the worst case scenarios) that are expected to enclose the plausible risk levels are provided for each risk estimate.

4. Data consideration

This study utilises both factual data and projected data under the counterfactual scenarios. The factual data include outbreak numbers, number of affected states, number of

Figure 3. Risk of spread of a HPAI outbreak in Nigeria.



dead chickens, number of culled chickens, compensation cost, and cost of culling and disposal per bird were compiled by NAICP and available on the project's website at www.aicpnigeria.org. The production and price data are from FAO (FAO, 2010). Table 1 illustrates the data used in the study.

Projected mortalities under the counterfactual scenarios are derived using the disease risk parameters as described in Table 2. About 85% of the flocks that was affected by HPAI in Nigeria were layers (Fasina *et al.*, 2007). The rest was mainly comprised of broilers and village chickens. The expected physical losses in egg and broiler and their expected monetary values were calculated using these parameters accordingly with the composite risk estimate (i.e., product of risk of spread and mortality risk) and the population at risk.

5. Stochastic Analysis

Outbreak data at state level were used to simulate an empirical distribution of the mortality risk. The risk of spread was also simulated using a truncated normal distribution generated from the previously described average risk spread estimates. Both the risk of spread and the risk of a bird becoming infected were assumed to evolve stochastically over the studied period. The simulation was conducted using SIMETAR, an excel add-in software that randomly draws from the distribution of the risks of spread and the mortality risk to iteratively solve for the key output variables. Richardson *et al.* (2004) provide detailed information about the algorithm. Figures4 and 5 illustrate the distribution of risk of spread and risk of infection, respectively. The stochastic averages of risk of spread were 0.2746 and 0.1663 under the endemicity and burn-out scenarios, respectively. The stochastic averages of infection risk were 0.0088 and 0.0174for the low and high mortality risk scenarios, respectively.

All key output variables (disease cost, incremental benefit, incremental net benefit, and benefit cost ratio) were stochastically determined. The resulting outputs were a set of

Table 1. Data sources.

	Names	Value	Sources
Disease Parameters	Number of outbreaks	320	NAICP (undated)
	Number of states affected	25	NAICP (undated)
	Mean incubation period (days)	3	Assumed. See Henning, Pfeiffer, and Vu (2009)
	Mean duration of infectiousness (days)	49	Assumed. See Bett *et al.* (2014) at village level
	Case fatality rate	100	WHO (2011)
	Transmission rate	0.02	Calculated from outbreak data
	Mortality risk	0.01 and 0.02	Calculated from outbreak data
	Risk of spread	0.13 and 0.27	Calculated from outbreak data
Population affected	Number of susceptible	Varies year-to-year	Calculated
	Number of infected	Varies year-to-year	Calculated
	Number of dead	See Table 3	NAICP (undated) for factual data and derived for counterfactuals
	Number of culled	See Table 3	NAICP (undated) for factual data and derived for counterfactuals
Production parameters	Chicken losses	Vary year-to-year	Calculated based on epidemiological and production parameters
	Egg losses	Vary year-to-year	Calculated based on the share of layers (85%) among affected bird (Fasina, 2007) and epidemiological and production parameters
	Price of chicken	Varies year to year. US$ 2.76/head on average	FAO(2010)
	Price of egg	Varies year to year. US$ 1.8/kg on average	FAO (2010)
Compliance and compensation	Compensation cost	US$ 1.96/head	OIE (2007)
	Cost of culling and disposal per bird	US $ 1.00	OIE (2007)
	Control cost per bird	US $ 0.38	OIE (2007)
Other parameter	Ratio indirect to direct cost	1.24	Derived from Diao *et al.* (2009)

Table 2. Composite risk estimates for the various risk scenarios considered.

Scenario		Risk estimate		Composite estimate
Spread	Mortality	Spread	Mortality	
Burn-out	Low	0.13	0.01	0.0013
Burn-out	High	0.13	0.02	0.0026
Endemic	Low	0.27	0.01	0.0027
Endemic	High	0.27	0.02	0.0054

500 possible solutions from which parameter of central tendencies and distribution were derived and presented.

6. Disease cost and economic assessment of intervention

Table 3 presents a comparison between observed and expected birds' mortalities from culling and the disease itself under the four previously outlined scenarios. These estimates were based on the stochastic averages of the spread and infection risk parameters. The results show that the additional number of birds that would have been saved by the intervention between 2008 and 2010 under the burn-out scenario would be 46,960and 93,794 for the low and high mortality paths, not significant enough to warrant the investment from a financial standpoint. Hence, the analysis mainly focused on the two scenarios of endemicity.

The descriptive statistics on the key output variables in Table 4 indicate that had the intervention not been carried out, the average cost of HPAI to the Nigerian economy over the 5-year period (2006-2010) would have amounted to US$ 144.97 million under the high mortality path. Studies such as Fasina (2008) estimated the total cost of HPAI at US$ 244 million for a mild case scenario whereby 10% of the commercial flock would be affected and US$690 for a severe scenario. You and Diao (2007) estimated the direct cost at US$ 250 million under a worst case scenario that involves the disease spreading along the two major flyways and between US$ 48 and US$ 52 million for a best case scenario where the disease would be confined to a single flyway. These studies deal with ex ante analysis of HPAI. The distribution of the potential cost of the disease was also evaluated. As indicated in Table 4, there was 30% chance that the economic damage caused by HPAI would be above US$ 173.61 million under the most disastrous scenario and 90% chance that it would be greater than US$ 53.36 million. The incremental benefit of the intervention over the five-year period would amount to US$ 63.7 million. The incremental net benefit is obtained by subtracting the Bank disbursements from the net benefit, which yielded US$ 27.22 million. This amount is the net gain of the intervention. The results in Table 4 indicate that there is 40% chance that the intervention would not lead to positive incremental benefit. The distribution of the generated incremental net benefit of the intervention ranged from a minimum of -US$65.10 million to a maximum of US$702.33 million. The derived incremental benefit and the cost of the intervention are used to calculate the benefit cost ratio of the project. The average benefit cost

Figure 4. Simulated risk of spread of HPAI to other states.

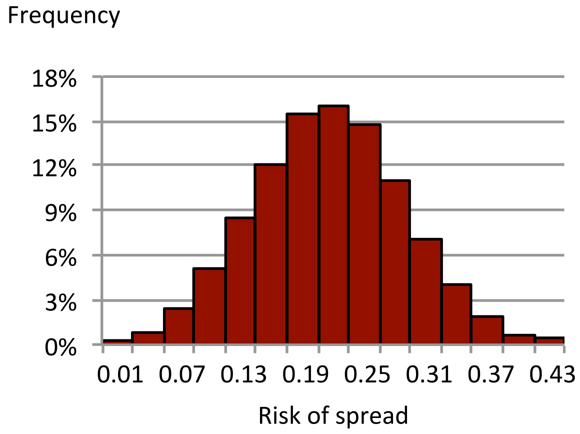
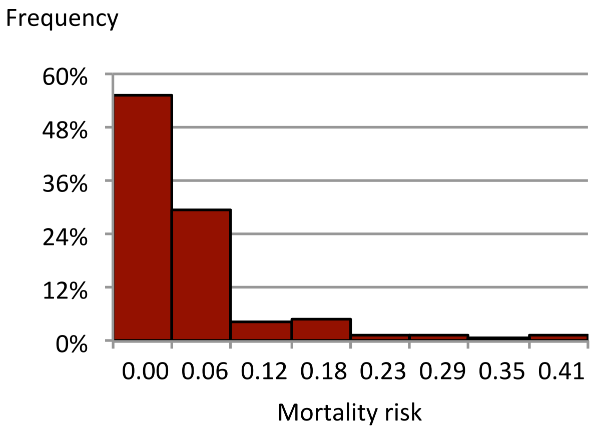


Figure 5. Simulated risk of bird infection in affected states.



ratio amounts to 1.75 (Table 4). It indicates for the endemic scenario with high mortality path, the intervention would have made economic sense. However, there is no certainty to the economic justification, as it is determined by the magnitude of the risk of bird infection in affected states. In any case, as illustrated in Table 4, there is more than 50% chance that the investment would be economically justified under the endemic scenario with high mortality path. Furthermore, there is 15% chance that the benefit cost ratio would be above 3.86, 10% chance that it would be above 5.36, and 5% chance that it would reach at least 8.79. Results of the economic justification of the project should be interpreted with care. For instance, the diagnostic capability of the Nigerian veterinary public health service has improved under the intervention, the diagnostic laboratories have been upgraded, and the morale of veterinarians in public sector has been boosted as a result of their performance during the outbreaks. Currently these veterinarians are better trained and equipped to deal with HPAI and other diseases than they were before the outbreaks (Perry *et al.*, 2011). These are referred to as preventive spillover benefits by Gramig and Wolf (2007). These benefits are difficult to quantify in a cost benefit analysis framework although documented in the assessment of the intervention, which call for more caution in the interpretation of the results.

A breakeven analysis was conducted to find the minimum HPAI risks (of spread and of infection) that would justify the investment. Various combinations of risk of spread and risk of bird infection led to the threshold benefit cost ratio, as the two parameters simultaneously determine losses. Notwithstanding, our findings indicate that a composite risk estimate at 0.006 would be necessary to cause economic damage high enough to justify the intervention. This would correspond to an infection risk of 0.022 under the endemic scenario, considering the disease is already present in the country. At breakeven risk level, the disease would have caused economic damages amounting to US$ 118 million over the five-year period.

Table 3. Observed and projected mortalities under the counterfactual scenarios (thousand birds).

		2006	2007	2008	2009	2010
Factual(a)						
	Died	612	135	2	0	0
	Culled	405	360	3	0	0
	Total	1,017	496	5	0	0
Counterfactual scenarios(b)						
Burn-out Low	Died	612	135	46	23	11
	Culled	405	77	37	19	9
	Total	1,017	212	83	42	21
Burn-out High	Died	612	184	90	45	22
	Culled	405	151	74	37	18
	Total	1,017	335	163	82	41
Endemic Low	Died	612	155	151	151	151
	Culled	405	127	124	124	124
	Total	1,017	282	274	274	274
Endemic High	Died	612	304	296	296	296
	Culled	405	250	243	243	243
	Total	1,017	554	540	540	540

Notes: (a) Monthly distribution of the observed mortalities is presented in Appendix 1. (b) Expected mortalities are obtained by multiplying population at risk with the risk of spread and the mortality risk. The number of culled birds is derived from the susceptible birds that have not died. The expected egg loss is found by multiplying annual production per layer by the share of layers out of the expected total dead birds (see Table 1 for more information).

Table 4. Descriptive statistics and percentile distribution of the effects of intervention against HPAI on key output variables over 2006-2010 under the high mortality path.

Percentiles	Risk of Spread	Risk of Infection	Disease Cost	Incremental Benefit	Incremental Net Benefit	Benefit Cost Ratio
Stochastic average	0.27	0.02	144.97	63.70	27.22	1.75
Standard deviation	0.06	0.02	115.99	115.99	115.99	3.18
5%	0.18	0.00	52.94	-28.33	-64.81	0.00
10%	0.20	0.00	53.36	-27.91	-64.39	0.00
30%	0.24	0.00	55.14	-26.14	-62.62	0.00
40%	0.26	0.00	64.40	-16.87	-53.35	0.00
50%	0.27	0.02	124.20	42.93	6.45	1.18
60%	0.29	0.02	150.53	69.26	32.78	1.90
70%	0.31	0.02	173.61	92.34	55.86	2.53
75%	0.31	0.03	190.12	108.85	72.37	2.98
80%	0.32	0.03	201.70	120.43	83.95	3.30
85%	0.33	0.03	222.25	140.98	104.50	3.86
90%	0.35	0.04	276.87	195.60	159.12	5.36
95%	0.37	0.07	401.91	320.64	284.16	8.79

Note: The results presented in each column should be interpreted separately. They are based on the 500 possible solutions. The risk parameters and the benefit cost ratio are unitless while cost of inaction, incremental benefit, and incremental net benefit are in US$ million over five year period with 2006 as base year. A 12% discount rate was applied. The rate is consistent with that currently applied by the Central Bank of Nigeria (CBN) (CBN, 2012). The stochastic averages of yearly values of key output variables are presented in Appendix 2.

7. Conclusion

Outbreak data in Nigeria were used to simulate the risk of spread of HPAI to states in Nigeria and the risk of bird infection. These risk parameters were applied to assess the potential cost of HPAI to Nigeria under four scenarios (burn-out with low mortality, burn-out with high mortality, endemic with low mortality, and endemic with high mortality) had the intervention not been carried out. Our findings indicate that for the two burn-out scenarios, the number of birds that would have been saved would not have been enough to warrant the investment of US$ 41 million. This conclusion, for the burn-out scenarios, is purely financial as it discounts the possibility of loss of human lives and the application of precautionary principle informed by the poor state of infrastructure and known weaknesses of the Veterinary Service in Nigeria at the time of the outbreak. From a global view point, the potential evolution of the disease to a pandemic could have been enough to warrant such an investment given concerns within the international community on the high likelihood of the disease becoming endemic in Nigeria.

Nevertheless, the analyses show that under the scenario where the disease became endemic with high mortality risk, the investment would generate incremental net benefit significant enough to justify the investment. In reality, the Nigeria HPAI outbreaks claimed more than 1.3 million birds and could not be classified under any of the two burn-out scenarios explored in this paper. Similarly, the outbreaks did not persist with high mortality as the last one occurred in July 2008. If the intervention is perceived to have helped averting the endemic and high mortality scenario, then the benefit would have by far exceeded the cost, hence the investment would be highly justified. There also are multiple positive externalities that are difficult to account in the calculations of the benefit of the intervention. For example, the investment helped Nigeria improve its health service delivery infrastructure and strengthened its public health and veterinary services capacity in biosecurity protocols and communications to deal with disease outbreaks of significant magnitude. So, the lessons learnt from this intervention, including the induced behavioral changes within the populace and the acquired knowledge of what to do when confronted with similar situations in the future, are incalculable. From the financial, economic and welfare standpoints also outlined in this paper, an overall conclusion could be reached that the intervention was useful.

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Appendix 1. Monthly distribution of dead and culled chickens, 2006-2010.

Month	Year						Total
	2006		2007		2008		
	Dead	Culled	Dead	Culled	Dead	Culled	
January	63,166	92,692	35,582	107,915	0	0	299,355
February	59,087	100,539	7,456	47,592	0	0	214,674
March	3,616	14,920	2,754	9,944	0	0	31,234
April	329,549	44,128	168	462	0	0	374,307
May	3,443	10,946	734	1,350	0	0	16,473
June	18,108	8,626	8,735	42,736	0	0	78,205
July	7,409	13,910	23,970	54,179	1,913	2,587	103,968
August	47,703	3,968	30,189	62,178	0	0	144,038
September	3,004	4,000	3,134	10,736	0	0	20,874
October	1,402	2,486	573	1,821	0	0	6,282
November	58,528	82,600	8,439	18,296	0	0	167,863
December	17,314	25,988	4,606	3,030	0	0	50,938
Total	612,329	404,803	126,340	360,239	1,913	2,587	1,508,211

Appendix 2. Yearly discounted stochastic averages of key output variables of the intervention against avian influenza in Nigeria (in US$ million).

Key output variables	Years					Total
	2006	2007	2008	2009	2010	
Incremental cost	20.00	5.32	7.31	3.34	0.49	36.48
Incremental benefit	-3.55	0.28	24.29	22.32	20.34	63.70
Incremental net benefit	-23.55	-5.03	16.98	18.98	19.85	27.22

Note: The figures are stochastic averages of discounted yearly key output variables (except for incremental cost). A 12% discount rate was applied with 2006 as base year.