University of Nairobi

School of Mathematics

ISSN: 2410-1397

Master Project in Biometry

Assessment of Factors Influencing Adoption of Bio-Security on Poultry Farms: A PLS-PM Approach

Research Report in Mathematics, Number 47, 2019

Mildred Mmbone Lumwamu

November 2019

Submitted to the School of Mathematics in partial fulfilment for a degree in Master of Science in Biometry

Master Project in Biometry
University of Nairobi
November 2019

Assessment of Factors Influencing Adoption of Bio-Security on Poultry Farms: A PLS-PM Approach

Research Report in Mathematics, Number 47, 2019

Mildred Mmbone Lumwamu

School of Mathematics
College of Biological and Physical sciences
Chiromo, off Riverside Drive
30197-00100 Nairobi, Kenya

Master Thesis
Submitted to the School of Mathematics in partial fulfilment for a degree in Master of Science in Biometry

Submitted to: The Graduate School, University of Nairobi, Kenya

Abstract

Bio-security plays an important role in preventing transmission and introduction of diseases and increasing farm productivity. The aim of this study was to investigate factors influencing implementation of bio-security on selected poultry farms in Nigeria. Identifying the factors influencing adoption of bio-security on farms allows disease control measures to be better targeted. A total of 82 respondents were interviewed. Bio-security measures collected were given a score ranging from 0 to 4 where 4 represented excellent bio-security implementation while 0 represented poor or no bio-security on farms. A bio-security index was generated using PCA to measure the level of implementation on the farms. Half of the farms had a good bio-security index of 1 while the other half had a poor bio-security 0. The partial least squares path model was used to identify farm and farmer characteristics that influenced bio-security adoption. The results revealed that sex ($p = 0.0291$), farm characteristics(husbandry and production type) ($p = 0.0002$) and social status (highest level of education and main source of income) ($p = 0.00132$) all significantly influenced bio-security while HPAI history, farming experience and age did not influence bio-security.

Master Thesis in Mathematics at the University of Nairobi, Kenya.
ISSN 2410-1397: Research Report in Mathematics

DISTRIBUTOR: School of Mathematics, University of Nairobi, Kenya

Declaration and Approval

I the undersigned declare that this dissertation is my original work and to the best of my knowledge, it has not been submitted in support of an award of a degree in any other university or institution of learning.

Signature Date

MILDRED MMBONE LUMWAMU
Reg No. I56/75092/2014

In my capacity as a supervisor of the candidate's dissertation, I certify that this dissertation has my approval for submission.

Signature Date

Dr Nelson Owuor
School of Mathematics,
University of Nairobi,
Box 30197, 00100 Nairobi, Kenya.
E-mail: onyango@uonbi.ac.ke

Signature Date

Dr Bernard Bett
Food safety and zoonoses
International Livestock Research Institute,
Box 30709, 00100 Nairobi, Kenya.
E-mail: B.BETT@cgiar.org

Dedication

To my family, particularly my daughter Kinsi.

Contents

List of Figures

List of Tables

List of Abbreviations

PLS-PM	Partial Least Squares Path Modelling
SEM	Structural equation models
PCA	Principal component analysis
HPAI	Highly pathogenic avian influenza
LV	Latent variable
MV	Manifest variable
FAO	Food and Agriculture Organization of the United Nations
OIE	World Organisation for Animal Health

Acknowledgments

My utmost gratitude goes to my supervisors Dr. Nelson Owuor for his selfless and extreme support throughout the process and Dr. Bernard Bett for his guidance and kindness in helping me achieve this. I would also want to thank Nicholas Ndiwa for his mentorship and consistent advise during the research, The University of Nairobi for providing an enabling environment to complete my work and my family for the enduring support.

Mildred Mmbone Lumwamu

Nairobi, 2019.

1 Introduction

This chapter discusses topics like the study background, the problem statement, study hypotheses and objectives and definition of terms that are useful in this study.

1.1 Background

Nigeria's poultry farming is estimated to be the most rapidly growing livestock sub sector and provides the population with affordable eggs and meat which is a vital source of protein. As a result of the great involvement of women in the rearing of backyard poultry, their empowerment may significantly alleviate poverty, secure food supply and promote gender equality (Gueye,2000; You et al.,2007). The HPAI epidemic poses a significant threat on the households' livelihood depriving them of their chief source of income and protein (Alders and Pym,2009). HPAI viruses was first detected in Hong Kong in 1996 and eventually spread throughout the world. Nigeria was first to experience it in Africa and recorded its first outbreak in 2007 - 2008 (De Benedictis et al.,2007b; Joannis et al.,2006; Adene et al.,2006;) This resulted in high mortality of poultry and culling of infected birds in an effort to stem its spread. Consequently this had a massive economic impact on the country. Poultry exceeding 1.3 million have been killed from 2006 to date affecting 3,037 farms/farmers. The Nigerian government compensated farmers a total 5.2 million US dollars (Ahmed,2008). Ensuing the outbreak of H5N1 HPAI, the Nigerian Federal Government implemented emergency interventions that included:

- Banning the importation of poultry products and poultry.
- Development of surveillance systems.
- Culling and compensation.
- Training of farmers and other value chain actors on bio-security measures.

While the HPAI virus predominantly resides in waterfowls which play a major part in transmission of the disease, the majority of cases are attributed to local secondary spread between domestic poultry after initial introduction as a result of poor or no bio-security compliance on poultry farms. People cause most secondary spread by moving live birds including both domestic and captive species, spreading the virus indirectly through contaminated materials like clothing and hunting activities (FAO,2008). The disease spreads rapidly in flocks and can cause mortality of almost 100 percent of cases.

Many countries still experience outbreaks despite implementing various strategies to curb the disease (Paul et al.,2011). This is attributed to the widespread practise of backyard poultry farming where few or no bio- security measures are usually implemented which in turn allows the virus to spread within poultry populations and other flocks. To this effect, bio-security is considered as the most important tool for the control and eradication of H5N1 HPAI hence proper implementation of bio-security on farms can prevent and contain the disease reducing losses and improving livelihoods of farmers. Farm-level bio-security provides a basis for bio-security along the poultry value chain (Siekkinen et al.,2012).

1.2 Bio-security

Bio-security is defined as a set of measures which if properly implemented, prevents introduction and transmission of diseases on a farm. The two objectives of bio-security include bio-exclusion (preventing the introduction of agents that could cause infection into the farm) and bio-containment (preventing transmission of the diseases in case of an outbreak). Farms often focus on bio-exclusion while markets focus on bio-containment. Bio-security constitutes of three principle elements - segregation, cleaning and disinfection (FAO,2008).

Segregation

Segregation is the first and most important line of defence in preventing and eliminating the disease. This involves separation of infected and the uninfected by imposing barriers that prevent infected animals and fomites contaminated with secretions from entering the uninfected areas. If viruses are kept out of a poultry holding then no infections can occur. It is expected that segregation has the greatest impact on achieving good levels of bio-security. This involves creation of barriers and controlling entry through the barriers. They could be physical or temporal as deemed appropriate. Barriers could include gates at the entrance of the premises and pen. Setting up barriers alone is not enough, barriers will only be effective if there is strict control of whatever gets in to avoid entry of contaminated material. Controlling entry through the barriers could be done through measures such as changing footwear and clothes for people crossing the barrier, foot-baths with disinfectants at the entrance and restricting entry of vehicles. For intensive poultry system, segregation is the basis of all bio-security measures from the gate to the poultry pens.

Cleaning

Infected birds release the virus in respiratory secretions and faeces which can contaminate anything that comes into contact with them. Materials that enter the farm have to therefore be thoroughly cleaned to remove any dirt or virus. Small objects should be washed with a brush, water and soap while large ones like lorries should be washed with a high pressure washer. This will get rid of any virus that could contaminate materials hence leading to infection in poultry. Thoroughly cleaning large items like lorries can be a challenge, as a result emphasis is put on segregation as a first line measure of bio-security.

Disinfection

This is regarded as the least effective as it is mostly done incorrectly. Disinfectants do not always destroy the virus due to various reasons such as cases when the dirt is in high concentrations and when the material being disinfected is inorganic - disinfectants are inactivated by inorganic and faecal material. However, this should be regarded as the final step after extensive cleaning to inactivate virus on materials entering the farm.

In this project, we will mainly focus on the farmer and farm characteristics that influence implementation of bio-security. The farm and farmer characteristics investigated in this project include:

- Farmer characteristics - Age, gender, poultry farming experience
- Farm characteristics - Husbandry type, chicken production type
- History of HPAI occurrence on the farm
- Social status of farmers - Highest level of education, main source of income

A linear combination of the indicators of bio-security will be used as the exogenous variable in the model.

1.3 Problem statement

A better understanding of present bio-security measures implemented and the level of adoption by farmers is necessary for establishment of appropriate government policy to reduce HPAI prevalence. The findings from this study will shed more light on the bio-security measures already adopted, the level of implementation and the reason behind this implementation on poultry farms.

The test of hypothesis involves variables with unknown but realistic dependency structure that cannot be analyzed by commonly used predictive models (such as regression) that assume independence of covariates hence the need for structural equation type of models.

1.4 Hypothesis

H0: Farm and farmer characteristics do not influence adoption of bio-security against HPAI H5N1 in backyard poultry farming
H1: Farm and farmer characteristics influence adoption of bio-security against HPAI H5N1 in backyard poultry farming

1.5 Objectives

- To compute the bio-security adoption index on the studied poultry farms.
- To assess factors influencing implementation of bio-security on poultry farms across 8 states in Nigeria.

2 Literature review

This chapter mainly talks about work that has been done before with regard to this project and justification of the choice of methods used in the study.

2.1 Scoring farm bio-security

From the literature search, various methods have been used to score the bio-security measures. Lestari et al. grouped the bio-security measures into 9 categories namely; distance from sources of pathogens to pens, susceptibility of the flock,farm inputs, bio-security at the pen door, exposure of farm,traffic onto farms, farm boundary bio-security, bio-security between pens and farm boundary and traffic into the pens. The bio-security measures were scored as a percentage of the total within the group it belongs(Lestari et al.,2012).

Susilowati et al. on the other hand collected data on 44 biosecurity measures then grouped them into 7 groups namely: traffic onto farm, bio-security at the shed door, bio-security at farm boundary, traffic into the shed, vector/fomite status of farm inputs, bio-security between farm boundary and shed and susceptibility of the broiler and layer flock. Each measure was given a score of 1 for low bio-security and a score of 3 for high bio-security, the bio-security scores for each stage were summed up then divided by the total bio-security score within the group. The paper also suggests another method where all the 44 bio-security measures were added together for each farm regardless of the stage in which each belongs(Susilowati et al. 2013). Bio-security measures are not all equally important as some measures if not implemented pose a greater risk of transmission than others so the this factor should be considered when scoring the measures (Amass and Baysinger, 2006) though Susilowati argues that there are no significant differences between the two methods when applied.

Gelaude et al. groups the bio-security components into external (measures that keep disease agents out) and internal(measures that contain the disease after infection). Different experts in the field assigned a score ranging between 0 and 10 for each measure which were later averaged to get the final score(Gelaude et al.,2014). In a study conducted in Jos, Nigeria on bio-security on commercial farms, a score 1 was assigned for good bio-security whereas 0 was assigned for no or poor bio-security compliance, the total bio-security score for a farm was calculated as the average of the scores for the farm (Maduka et al.,2016). From Martindah's paper assessing bio-security measures in Indonesia, bio-security was given scores ranging from 0 to 3 where 0 was given for poor bio-security, 1 and 2 both represented moderate and 3 for good bio-security. A total of 14 bio-security practises were collected for every farm.The scores allocated were summed to get the overall bio-security for each farm. (Martindah et al.,2014).

A study conducted in Cameroon grouped the bio-security measures into three components namely: sanitation, isolation and traffic control and later allocated a score 0 or 1 for absence or presence of measure respectively. These scores were aggregated for each farm to get the total score by farm. The result was divided by the total number of measures within a component to get the final score (Kouam et al.,2018).

Rowlands et. al conducted a study to generate an index of classification of ECF reaction. PCA was conducted on 13 measures and the first principal component was used to derive the index as it explains the most variation (Rowlands et al.,2000).

Truscott, in his paper states the higher the number of farms rearing poultry in the immediate vicinity, the higher the risk of disease transmission . The distance to the closest poultry farm should be at least 500m and preferably less than 1 km to reduce the risk of transmission between poultry farms (Truscott et al, 2007; Steenwinkel et al, 2011)

2.2 Factors influencing adoption of bio-security

To provide interventions that are better targeted, it is important to understand what bio-security measures are currently being practised and the reason behind the level of implementation. Different methods have been used to investigate factors influencing adoption of bio-security. A study conducted in Indonesia used multiple regression with the total bio-security control score as the dependent variable and farm and farmer characteristics as independent variables. Correlations between the bio-security score and the farm and farmer characteristics were used to select predictor variables that were to be used in the model. Farmer characteristics that had a significant correlation with adoption were education, age and farming experience while farm characteristics were capacity of farms, number of sheds, ownership type, land area of farm and management type. This study concluded that age and education level of farmer significantly influenced adoption of bio-security and that different characteristics of farms and farmers should be considered during intervention to improve bio-security compliance (Susilowati et al,2013).

Another study in South Sulawesi, Indonesia - using the multiple regression model- found that farm income, experience, gender, education, age,social capital and family size have a positive relationship with adoption. However, only farm income, family size and social capital were significant factors influencing bio-security adoption ($P < 0.05$) (Lestari et al,2012).

In a study conducted in 2018 in Cameroon, ANOVA was used to test the differences in implementation of bio-security measures among three categories of bio-security (sanitation, traffic control and isolation).The relationship between the bio-security score and farm and farmer characteristics was assessed using a multivariate linear regression.The VIF and tolerance were inspected to rule out collinearity. The results showed that husbandry had a negative relationship with bio-security but was a significant factor that influenced bio-security. Other variables including age, gender, training in animal husbandry, education, main activity, membership in a cooperative, husbandry system, herd size and farm size were not significant at $p < 0.05$ (Kouam et al.,2018).

From the search of available literature, there is need to device a method that performs dimension reduction and multiple regression all in one run. PLS-PM is the recommended method for as it allows for multiple regressions and data dimension reduction all in one run without imposing stringent requirements on the distribution of the data (Sanchez,2013).

3 Methodology

This chapter extensively discusses study area surveyed, the data collection process and the methods used to analyse data in this project.

3.1 Study area

A total of 8 states was surveyed; 2 states were selected from each of the 4 clusters. Within each cluster, a high risk state was matched with a low risk state. High risk states were those considered to have reported the most number of outbreaks while low risk states were those with fewer cases of outbreaks.

- Cluster 1: Ogun/Lagos and Oyo
- Cluster 2: Anambra and Enugu
- Cluster 3: Plateau and Nassarawa
- Cluster 4: Kano and Jigawa

Three farmers were selected from each state which gave a sample size of 96 farms.A total of 82 poultry farmers participated in the survey.

3.2 Data collection

Questionnaires were designed and used to collect data. The questionnaire structure was: farmer/farm characteristics, practices of controlling poultry disease like the use of vaccines, bio-security practices, poultry house characteristics, farmer trainings received and whether lessons learnt were implemented on the farms. For cases where a farm had an outbreak, additional information was collected on number of birds affected, sold, and culled; experiences with compensation and restocking and exposure of family member to disease.

Enumerators were identified and trained; questionnaires were pre-tested as part of the enumerator training.

3.3 Data analysis

Data were entered into a in MS Access based database and statistical analyses conducted using R. As part of the PLS-PM requirement all missing values were re-coded to 999. The partial least squares path model was used to investigate the relationship between the bio-security score of farms and the farm and farmer characteristics.

3.4 Partial Least Squares Path Modeling

Structural equation models are categorised as covariance based and Component-Based techniques SEM (PLS-PM). PLS-PM is an iterative algorithm that first estimates the latent variables using the corresponding manifest variables and then computes path coefficients explaining the relationships between the latent variables using multiple regressions (Sanchez, 2013). PLS-PM is considered an explanatory approach unlike covariance based SEM which confirms (or rejects a previous theory) by reproducing a sample covariance matrix. PLS-PM is not stringent in terms of requirements: does not require distributions assumptions of the data, the sample size restrictions and the measurement scale. We focus on the PLS-PM Component-Based approach to SEM.

The PLS Path Model is formed by two sub models: the structural/inner model, and the measurement/outer model. The structural model deals with the relationships between the latent variables while the measurement model deals with the relationships of a latent variable with its block of manifest variables measuring it. Formative indicators do not necessarily measure the same underlying construct hence should not be correlated. Unlike formative indicators, reflective indicators should be correlated. In this section, we pay close attention to reflective indicators as all the assessment criteria is based on the loadings due to the aspect of collinearity between indicators.

Sub-models of the PLS-PM model:

3.4.1 Measurement model

Latent variables cannot be observed and measured directly and are therefore measured by a set of observable variables known as the manifest variables. The measurement or inner model focuses on the relationships between the LVs and MVs. There are two main ways in which LVs and MVs relate:

Reflective

In this mode, each manifest variable reflects the corresponding latent variable. The latent variable is considered to be caused by the manifest variable. In the model, the bio-security (BIO), social status (SST) and farm characteristics (FAM) blocks are all related to their respective manifest variables in the reflective way. This is because their MVs are a set of correlated variables that are reflect and are caused by the latent variable. Figure 1 represents a path diagram of a reflective block.

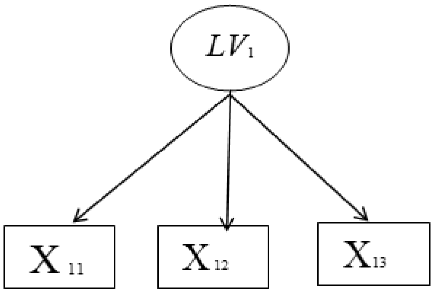

Figure 1. Path diagram of a reflective block

The relationship between each MV and corresponding LV is modelled as a linear relationship:

$$X_{jk} = \lambda_{0jk} + \lambda_{jk} LV_{jk} + \varepsilon_{jk} \tag{1}$$

Where, λ_0 is the intercept term, λ_{jk} is the loading and ε_{jk} is accounts for the residuals Reflective indicators should be highly correlated which means that the blocks need to be uni-dimensional and homogeneous.

Formative

In this mode, the manifest variables are considered to be forming the latent variables (Figure 2). In other words, the latent variables cause the manifest variables. The latent variables age, hpai experience(HPAI), farmer experience (EXP) and sex all relate to their indicators in a formative way. Unlike the reflective mode, the manifest variables/indicators in this case are uncorrelated as they do not measure the same underlying aspect but rather form it.

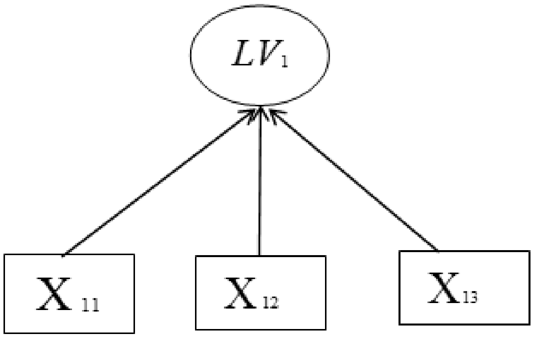

Figure 2. Formative block of a path model

All the relationships are modelled as linear relationships represented by:

$$LV_j = \lambda_{0,j} + \lambda_{jk}X_{jk} + \varepsilon_j \tag{2}$$

Where, λ_0 is the intercept term, λ_{jk} is the loading and ε_{jk} is accounts for the residuals

Regression specification

The linear relationships are formed by a standard regression method that is, the conditional expected values of the response variables (manifest or latent) are explained in terms of the predictor variables. This logic is represented by:

Reflective:

$$E(X_{jk}|LV_j) = \lambda_{jk} + \lambda_{jk}LV_j \tag{3}$$

Formative:

$$E(X_j|LV_{jk}) = \lambda_{0j} + \lambda_{jk}X_j \tag{4}$$

3.4.2 Structural model

The structural model focuses on the relationships between the LVs. Dependent LVs are referred to as endogenous while independent LVs are referred to as exogenous.

Aspects of the structural model include:

1. Linear relationships - All the relationships in the inner model are treated as linear relationships
$$LV_j = \beta_0 + \sum_{i \to j} \beta_{ji} LV_i + \varepsilon_j \tag{5}$$
   Where:
   The subscript i of LV_i refers to all the latent variables that are supposed to predict LV_j,
   β_{ji} are the path coefficients which explain the strength and direction between the exogenous variables LV_j and the endogenous variables LV_i,
   β_0 is the intercept and ε_j represents the error term.
   The arrow between i and j shows that the latent variables LV_i predict LV_j

2. Recursive model - Paths formed by the arrows in the structural model cannot form a loop.

3. Regression specification - Linear relationships in the structural model are formed by a standard regression method. That is
$$E(LV_j|LV_i) = \beta_{0i} + \sum_{i \to j} \beta_{ji} LV_i \tag{6}$$
   The assumption here is that the latent variable LV_j is uncorrelated with the error term ε_j

3.4.3 Weight relations

Latent variables cannot be directly measured and are therefore estimated as a linear combination of their respective manifest variables. This estimate is known as a score denoted by Y_j :

$$L\hat{V} = Y_j = \sum_k W_{jk} X_{jk} \tag{7}$$

3.4.4 PLS-PM Algorithm Overview

The PLS algorithm involves three stages:

- Calculate weights that will estimate the LV scores
- Path coefficients estimation in the inner model
- Calculate outer model loadings

First stage : Calculate weights that will estimate the LV scores

The first stage is an iterative process whose end goal is to compute the "weight relations". The PLS algorithm is as follows:

- Start: Assignment of initial arbitrary outer weights
- First step: Get the external estimation of LVs
- Second step: Compute inner weights
- Third step: Internal approximation of LVs
- Fourth step: Update outer weights Repeat first to fourth step until the outer weights converge.

Start: Assignment of initial arbitrary outer weights

Arbitrary values are initially assigned to the outer weights.

First step: Get the external estimation of LVs

Here, each latent variable is expressed as a weighted sum of its respective indicators. The standardized latent variables are expressed as:

$$Y_j = \sum_k W_{jk} X_{jk} \tag{8}$$

Second step: Compute inner weights

This step focuses on the relationships in the inner model. The scores of the latent variables are re- generated as a linear combination of its associated latent variables. This is denoted by:

$$Z_j = \sum_{i \leftrightarrow j} e_{ij} Y_i \tag{9}$$

Where:
e_{ij} are the inner weights since we are now focusing on the inner model.
The double arrow between i and j shows that there is a relationship between latent variables LV_j and LV_i and regardless of the type of relationship whether predictor or dependent

the LV_i should be taken into account while calculating Z_j

Various methods are used to calculate the inner weights:

Centroid scheme: This method uses the sign direction as the inner weights. The inner weights are defined as:

$$e_{ji} = \begin{bmatrix} sign[cor(Y_j, Y_i)] & LV_j, LV_i \ \ adjacents \\ 0 & otherwise \end{bmatrix} \tag{10}$$

Factor scheme: Unlike the centroid scheme, the factor scheme takes into account both the sign direction and strength of the path. The correlation coefficients are used as the inner weights. The inner weights are defined as:

$$e_{ji} = \begin{bmatrix} cor(Y_j, Y_i) & LV_j, LV_i \ \ adjacents \\ 0 & otherwise \end{bmatrix} \tag{11}$$

Path scheme: Latent variables are categorized as predictors and predictands. A Latent variable is a predictor when it determines another LV or predictands when determined by another LV. If a latent variable is a predictand then inner weight is the correlation coefficient between the two latent variables else for latent variables that are predictors of another latent variable the inner weights are regression coefficients of the multiple regression of predictor LVs.

Third step: Internal approximation of LVs

Using the inner weights estimated in step 2, we update the internal approximation as:

$$Z_j = \sum_{i \leftrightarrow j} e_{ij} Y_i \tag{12}$$

Fourth step: Update outer weights

After completion of the approximation of internal weights, the outer weights are re-assessed with regards to the internal weights. Mode A: For reflective blocks, the outer weights are calculated as a simple regression for each indicator:

$$\hat{\omega}_{jk} = (Y_j^{'}Y_j)^{-1} + Y_j^{'}X_{jk} \tag{13}$$

Mode B: For the formative blocks, the outer weights are calculated as a multiple regression:

$$\hat{\omega}_j = (X_j^{'}X_j)^{-1} + X_j^{'}Y_j \tag{14}$$

Check for convergence

Convergence is assessed by comparing the outer weights of every step with the outer weights of the previous step.

Second stage: Path coefficients estimation in the inner model

In the second stage of the PLS-PM algorithm, the structural coefficients are estimated through Ordinary Least Squares multiple regressions among the estimated *LV* scores:

$$Y_j = \sum_{\leftrightarrow} \hat{\beta}_{ji} Y_i \tag{15}$$

Third stage: Calculate the outer model loadings

In the last stage of the PLS-PM algorithm, loadings are computed as the correlations between the the LVs and each respective indicator.

4 Results and discussion

4.1 Model development

The model consists of the constructs (LVs): Farm characteristics, HPAI history on farm, social status of farmer, sex and age of farmer which are associated with blocks of manifest variables that explain them (Table 1). The path diagram of the final model is illustrated in figure 3. The ellipses represent the latent variables (LVs) , rectangular boxes represent the manifest variables (MVs) and the arrows represent the relationship between the latent and manifest variables - formative or reflective depending on the cause-effect relationship between LVs and MVs- In this case, the indicators associated with social status of the farmer (sst), farm characteristics (Fam) and bio-security (Bio) are reflective while those associated with sex, age, experience of farmer(exp) and HPAI history are all formative.

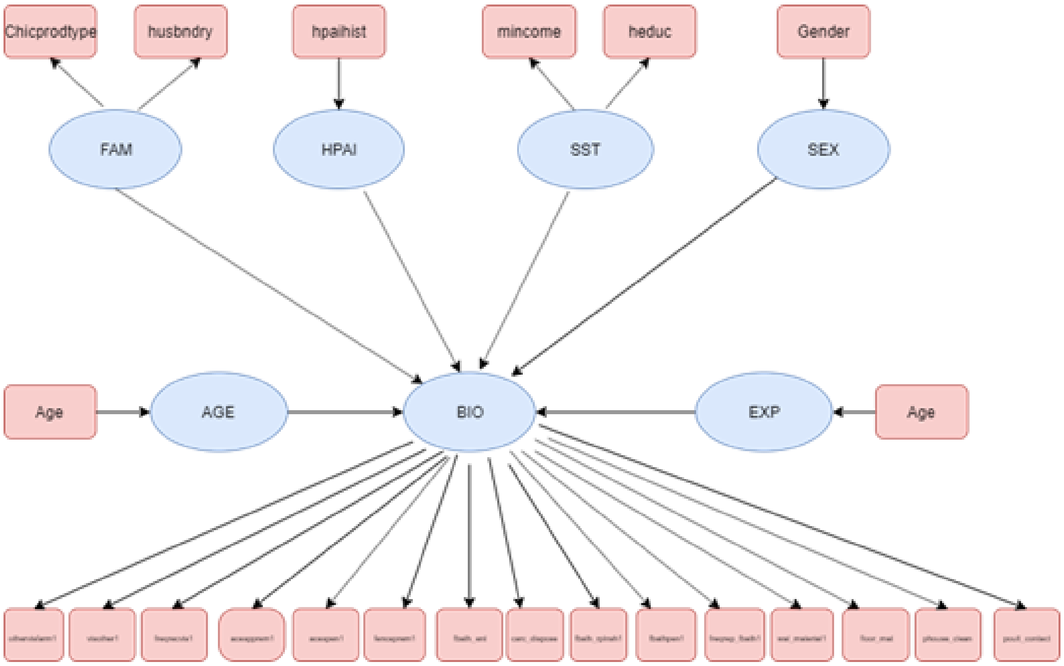

Figure 3. Path diagram of the final model

Latent Variable	**Manifest variable**
Farm characteristics	Production type meat/eggs
	Husbandry
Age	Age of farmer
Sex	Gender of farmer
Social status	Main source of income
	Level of education
Farmer experience	How long has the farm been producing chickens/eggs
Hpai experience	HPAI history on farm- Infected, not infected
Bio-security	Do the owners or workers of other poultry farms visit your farm?
	Do you or your workers visit other poultry farms in the area?
	How frequently do you receive visitors in your farm?
	Can the visitors easily access poultry premises?
	Can visitors easily access your poultry pen?
	Is there a fence and gate around the poultry premises?
	Is there a footbath at the entrance to your farm?
	How frequently do you replenish the disinfectant used in the footbath to the farm (weeks)
	Is there a footbath at the entrance of each pen?
	How frequently do you replenish the disinfectant used in the footbath to the pens in weeks?
	What materials are the walls of your poultry houses build with?
	What materials is the floor of your poultry house build with?
	How clean is the poultry house (looking for evidence for faeces around)
	Is there a possibility of poultry coming into direct contact with other birds/animals?
	How are carcasses disposed of?

Table 1. List of latent and manifest variables in the data

4.2 Constructing the bio-security score

The survey collected data on up to 20 bio-security variables by farm. Of the 20, 15 were used in the analysis. Table 2 presents all the manifest variables in the bio-security block and their loadings and communalities. Figure 4 shows that the variables on borrowing farm equipment (otherborimp1), roof material of poultry house (roof_mat) and mode of selling broilers (sel_broil) all have a negative relationship with the bio-security latent variable they represent. Variables on mode of selling layers (sel_splayers) and considerations while replacing stock (consider_rplstoc) had loadings below 0.3 as evident in table 2. Consequently, these 5 variables were dropped as they did not conform to the unidimensionality requirement of PLS-PM as evident in figure 4 and table 2.

A score ranging between 0 and 4 was allocated to each bio-security variable - a choice that represented the highest bio-security level that could be achieved for that variable was given a score of 4 while that which represented the lowest was given a score of 0 (Table 9). The ultimate score that a respondent got for a variable depended on the choice he/she gave and the observation made by the enumerators (in cases where the questions required visual inspection). Principal component analysis was used to get a set of uncorrelated components that explain the most variation. The first component, since it explains the most variation, was multiplied by each of the scores. The overall index was generated by summing up all the scores generated for a farm. Values above the mean were assigned bio-security index 1 while those below the mean were assigned 0.

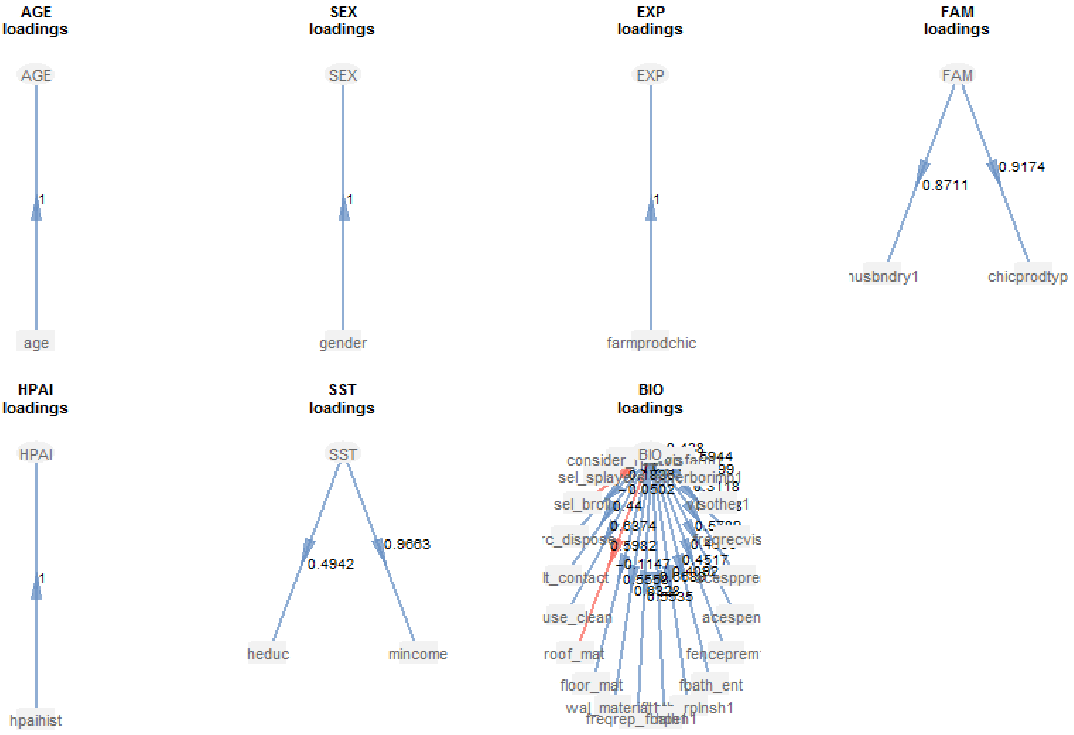

Figure 4. Initial loadings of manifest variables

Manifest variable	Latent variable	Loading	Communality
othervisfarm1	BIO	0.438	0.192
otherborimp1	BIO	-0.594	0.353
visother1	BIO	0.58	0.336
freqrecvis1	BIO	0.312	0.097
acespprem1	BIO	0.515	0.265
acespen1	BIO	0.579	0.335
fenceprem1	BIO	0.461	0.212
fbath_ent	BIO	0.452	0.204
fbath_rplnsh1	BIO	0.409	0.167
fbathpen1	BIO	0.669	0.447
freqrep_fbath1	BIO	0.553	0.306
wal_material1	BIO	0.633	0.4
floor_mat	BIO	0.556	0.309
roof_mat	BIO	-0.115	0.013
phouse_clean	BIO	0.598	0.358
poult_contact	BIO	0.637	0.406
carc_dispose	BIO	0.44	0.194
sel_broil	BIO	-0.05	0.003
sel_splayers	BIO	0.184	0.034
consider_rplstoc	BIO	0.047	0.002

Table 2. Initial loadings and communalities of the biosecurity block manifest variables

4.2.1 Distributions of bio-security indicators

Figure 5 presents the distributions of the bio-security indicators. Most farmers had a bio-security score of 4 with regard to poultry housing. This means that majority of the farmers' poultry houses were built with cement which was regarded as the best score for that measure due to the ease of cleaning. However, most farmers had a moderate score 2 for cleanliness of the poultry house. In terms disposal of carcasses, if the farmers had a foot bath at the entrance of the pen and if the farmers' poultry had contact with other birds, most farmers had a moderate to good bio-security score. It is prominent that most farmers did not replenish foot bath disinfectant at the entrance of the pen and did not have a foot bath in place at the entrance of the farm.

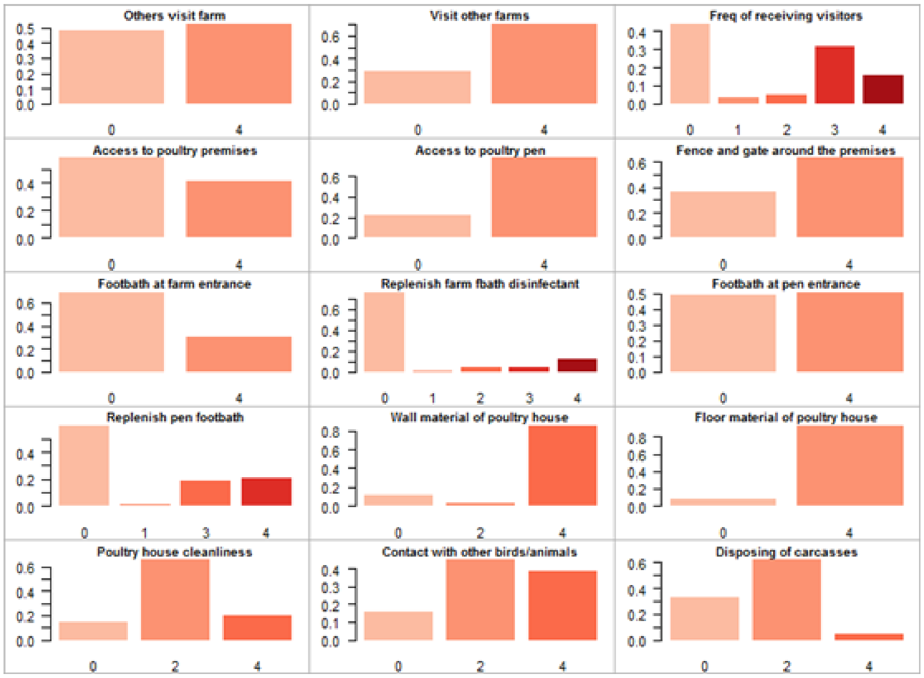

Figure 5. Distributions of bio-security indicators

Correlations were further performed on the bio-security measures using PCA to check if the indicators optimally represented bio-security. Correlations of the bio-security practises in the bio block are presented in figure 5. It can be seen from figure 5 that all the indicators are clustered on the right which is a clear indication of positive correlation between the practices. The measures are therefore a good reflection of bio-security.

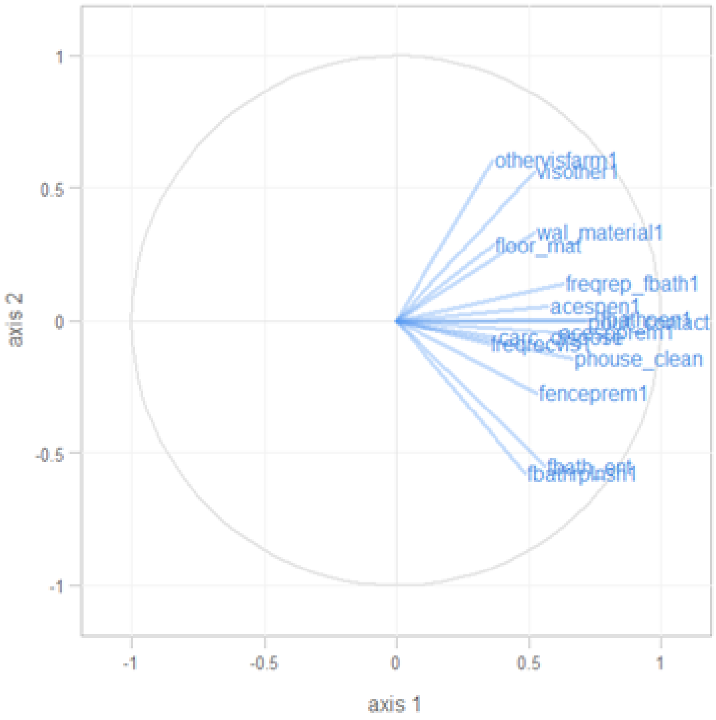

Figure 6. Correlations of manifest variables integrating the bio-security block of indicators

4.3 Demographic characteristics

The sample included a total of 82 respondents. Of the 82 participants, $(62\%, n = 49)$ of them were males. Majority $(75\%, n = 62)$ regarded poultry farming as their main source of income. Most of the farmers interviewed kept layers only $(83\%, n = 64)$. Other types of poultry kept included broilers only $(14\%, n = 11)$ and both layers and broilers $(2\%, n = 2)$. The number of chickens kept by ranged between 15 and 40,000 with a median of 1150. Most of the respondents $(87\%, n = 65)$ had never used HPAI vaccines. Conversely, $39\% (n = 30)$ and $94\% (n = 72)$ had used vaccines to control fowl and gumboro cholera diseases respectively.

4.4 Model diagnostics

4.4.1 Outer model

Unidimensionality

All the reflective manifest variables- FAM, SST, BIO- are in one dimension and belong to one and only one latent variable. This is evident in figure 7. Both the Croncbach's alphas and the Dillon-Goldstein's rhos are greater than 0.7 as required by PLS-PM (Table 3) except social status(SST) . The DG.rho is considered as the best measure of unidimensionality, using DG.rho all the indicators within the blocks conform to the unidimensionality requirement. Regarding the eigen-analysis, the first eigenvalues are much more larger than 1, while the second eigenvalues are smaller than 1, which is a good indication that variables in each block are in a uni-dimensional space.

	Mode	MVs	C.alpha	DG.rho	eig.1st	eig.2nd
AGE	B	1	1	1	1	0
SEX	B	1	1	1	1	0
EXP	B	1	1	1	1	0
FAM	A	2	0.752895	0.890034	1.603714	0.396286
HPAI	B	1	1	1	1	0
SST	A	2	0.404681	0.770618	1.253668	0.746332
BIO	A	15	0.828294	0.862611	4.617165	1.649305

Table 3. Unidimensionality of the model

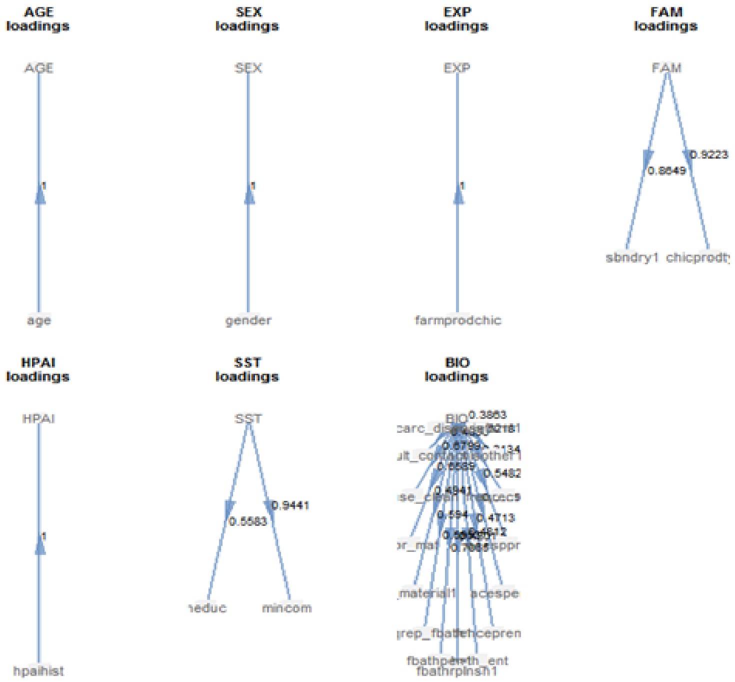

Figure 7. Adjusted loadings of manifest variables

4.4.2 Loadings and communalities

Loadings above 0.3 for the reflective blocks were allowed in the model. Table 4 shows that all the manifest variables in the BIO, SST and FAM block had loadings above 0.3.

name	block	weight	loading	communality	redundancy
age	AGE	1	1	1	0
gender	SEX	1	1	1	0
farmprodchic	EXP	1	1	1	0
chicprodtype	FAM	0.627184	0.921429	0.84903	0
husbndry1	FAM	0.48739	0.86603	0.750008	0
hpaihist	HPAI	1	1	1	0
mincome	SST	0.855745	0.943011	0.889269	0
heduc	SST	0.344014	0.561089	0.314821	0
othervisfarm1	BIO	0.084935	0.38389	0.147371	0.055172
visother1	BIO	0.105536	0.519667	0.270054	0.101101
freqrecvis1	BIO	0.060527	0.302689	0.091621	0.0343
name	block	weight	loading	communality	redundancy
acespprem1	BIO	0.102536	0.556732	0.30995	0.116037
acespen1	BIO	0.171768	0.585773	0.34313	0.128459
fenceprem1	BIO	0.059906	0.46836	0.219361	0.082123
fbath_ent	BIO	0.087378	0.516152	0.266413	0.099738
fbath_rplnsh1	BIO	0.117566	0.489066	0.239186	0.089545
fbathpen1	BIO	0.097069	0.720699	0.519407	0.194453
freqrep_fbath1	BIO	0.132643	0.608903	0.370762	0.138804
wal_material1	BIO	0.16244	0.590773	0.349012	0.130661
floor_mat	BIO	0.173277	0.476567	0.227116	0.085027
phouse_clean	BIO	0.152921	0.649835	0.422285	0.158093
poult_contact	BIO	0.125972	0.683547	0.467237	0.174922
carc_dispose	BIO	0.191027	0.477023	0.227551	0.085189

Table 4. Loadings and communalities

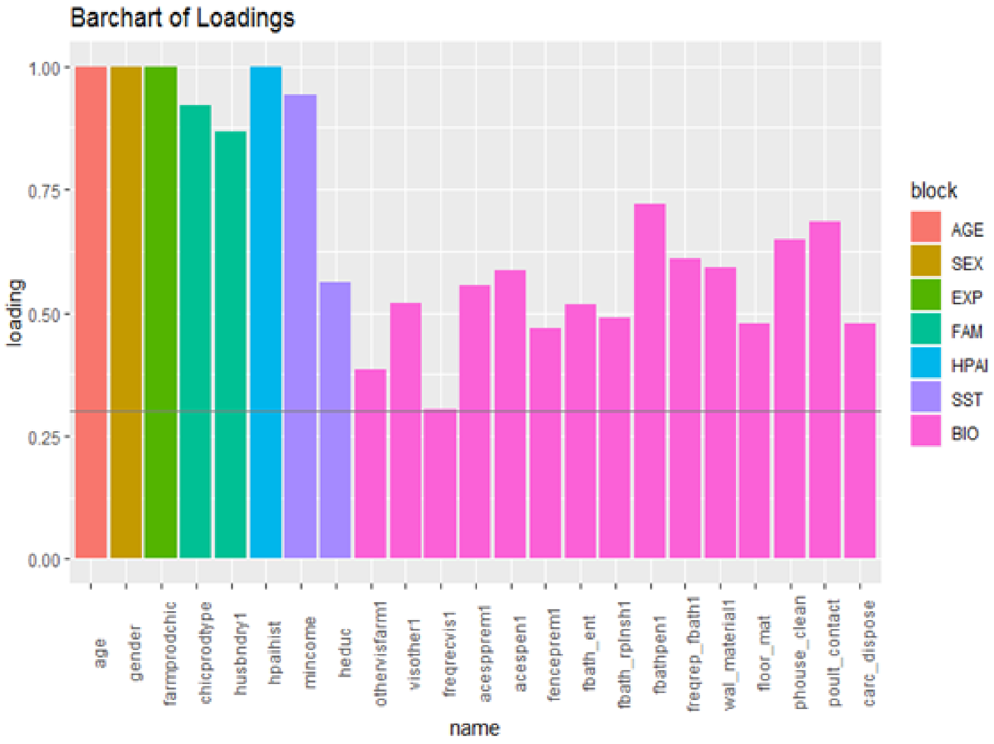

Figure 8. Barchart of loadings

4.4.3 Cross loadings

A manifest variable should not load highly on a construct it doesn't belong to. It's loading should only be high for the construct it is supposed to measure. As evident in table 4, none of the manifest variables loaded highly on constructs other than the ones they were intended to measure.

name	block	AGE	SEX	EXP	FAM	HPAI	SST	BIO
age	AGE	1	0.168946	0.142781	-0.19459	-0.05561	-0.02335	0.169282
gender	SEX	0.168946	1	-0.02128	-0.06234	-0.04477	0.064949	0.218445
farmprodchic	EXP	0.142781	-0.02128	1	-0.03728	-0.0263	0.078709	0.043549
chicprodtype	FAM	-0.17063	-0.05008	-0.02997	0.921429	0.178458	0.186114	-0.49033
husbndry1	FAM	-0.17969	-0.06345	-0.03792	0.86603	-0.07308	0.091578	-0.38104
hpaihist	HPAI	-0.05561	-0.04477	-0.0263	0.076307	1	-0.03695	-0.03166
mincome	SST	0.007518	0.088101	0.099536	0.208868	-0.02899	0.943011	-0.36482
heduc	SST	-0.08656	-0.03036	-0.0188	-0.05051	-0.0353	0.561089	-0.14669
othervisfarm1	BIO	0.06209	0.1853	0.106703	-0.06401	0.1019	-0.1387	0.38389
visother1	BIO	0.124413	0.124941	0.07098	-0.33962	0.145412	-0.05063	0.519667
freqrecvis1	BIO	0.062281	0.033271	0.087895	-0.13536	0.038851	-0.0442	0.302689
acespprem1	BIO	0.109779	0.23091	-0.09434	-0.18835	-0.07622	-0.03824	0.556732
acespen1	BIO	0.111499	0.103162	0.058922	-0.45799	-0.01638	-0.17194	0.585773
fenceprem1	BIO	0.016468	0.013429	-0.14504	-0.272	0.054423	-0.21844	0.46836
fbath_ent	BIO	0.039161	0.152618	-0.07084	-0.16864	-0.02699	-0.15149	0.516152
fbath_rplnsh1	BIO	0.051445	0.261606	-0.05568	-0.12497	-0.11778	-0.12953	0.489066
fbathpen1	BIO	-0.02813	0.059676	0.107907	-0.24756	-0.00536	-0.12753	0.720699
freqrep_fbath1	BIO	0.038652	0.141987	0.102339	-0.2088	-0.08317	-0.13541	0.608903
wal_material1	BIO	0.045609	0.077833	0.047046	-0.27733	0.002136	-0.42438	0.590773
floor_mat	BIO	0.153684	0.054823	0.032501	-0.38609	0.063897	-0.36475	0.476567
phouse_clean	BIO	0.157273	-0.01627	-0.00733	-0.38423	-0.11597	-0.18507	0.649835
poult_contact	BIO	0.040482	0.12042	-0.03558	-0.34426	0.005993	-0.21104	0.683547
carc_dispose	BIO	0.212847	0.218628	0.057227	-0.1794	-0.09072	-0.26429	0.477023

Table 5. Cross loadings

4.5 Inner model

4.5.1 Path coefficients

Path matrix

The zeros in the diagonal imply no relationship while the value one shows that the column has an effect on the row associated with it for instance age, sex , exp, fam, hpai, sst all have an impact on bio.

$$\begin{bmatrix} & AGE & SEX & EXP & FAM & HPAI & SST & BIO \\ AGE & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ SEX & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ EXP & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ FAM & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ HPAI & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ SST & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ BIO & 1 & 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix} \qquad (16)$$

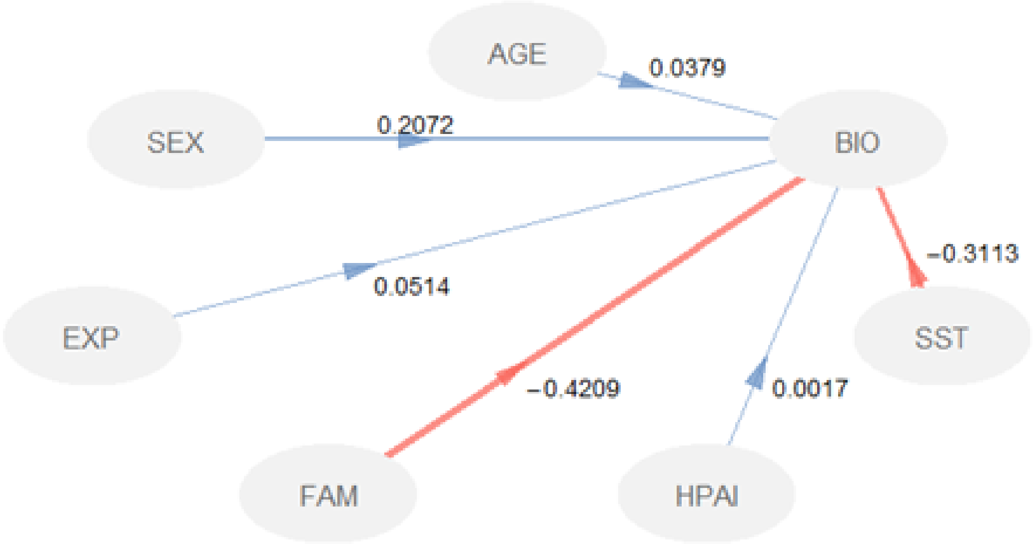

Figure 9. Inner model with path coefficients

4.5.2 Structural regressions

The results of the structural regressions are presented in table 6. Farm characteristics (FAM) and social status (SST) have a negative relationship with bio-security (BIO). A unit increase in SST results in a 0.311 decrease in bio-security. Similarly, a unit increase in farm characteristics leads to a 0.421 decrease in bio-security. It is evident that sex (p = 0.0291), farm characteristics (p = 0.00003) and social status (p = 0.00132) all significantly influenced bio-security. Using males as the reference group, female farmers had a higher bio-security implementation of 0.2 units compared to their male counterparts. Females are therefore better at implementing the bio-security measures than males. Age is expected to influence adoption but that was not the case. Highest level of education was significant as expected since the higher the level of education the higher the chances of understanding and implementing the measures. Main source of income equally significantly influenced bio-security. It is expected that experience in poultry farming directly translates to adoption but the results proved otherwise.

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	-2.58E-16	0.09133276	-2.82E-15	1.00
AGE	0.0379	0.09539016	0.397	0.693
SEX	0.207	0.09315489	2.22	0.0291
EXP	0.0514	0.09276735	0.554	0.581
FAM	-0.421	0.09469005	-4.45	0.00003
HPAI	0.00169	0.09184647	0.0184	0.985
SST	-0.311	0.09328753	-3.34	0.00132

Table 6. Structural regressions results

4.5.3 Inner model summary

36.8 %(Table 7) of the variation in the bio-security score is explained by the exogenous latent variables in the model. The AVE parameter in table 7 shows that 79.9% , 60.1% and 29.3% of the variance in FAM, SST and BIO latent variables respectively is explained from their manifest variables.

	Type	R2	Block_Communality	Mean_Redundancy	AVE
AGE	Exogenous	0	1	0	0
SEX	Exogenous	0	1	0	0
EXP	Exogenous	0	1	0	0
FAM	Exogenous	0	0.799354	0	0.799354
HPAI	Exogenous	0	1	0	0
SST	Exogenous	0	0.6015419	0	0.6015419
BIO	Endogenous	0.3681901	0.293889	0.108207	0.293889

Table 7. Inner model summary

4.5.4 Bio-security adoption

Table 8 below shows that majority of the farmers 58(70.73%) did not visit other farms hence attained a good bio-security score of 4. Most farmers also practised good bio-security with regards to segregation on the farm. Of the 82 farmers, 64(78.05%) said that visitors on the farm could not easily access the poultry pen and 52(63.41%) mentioned that they did have a gate around their poultry premises. An overwhelming 76(92.68%) built the floor of their poultry house using cement which is recommended as it is easy to clean. 70(85.37%) of the farmers also built their poultry house walls using cement. Carcass disposal was observed to be the poorest observed bio-security practise. Only 4(4.87%) incinerated dead birds on their farms as is expected to reduce disease transmission to other poultry. The bio-security index generated showed that exactly 50% (n = 41) of the farms had a bio-security index of 1 while the remaining half had a poor bio-security 0.

Bio-security measure	Scoring levels	Number (%) of households				
		0	1	2	3	4
Do the owners or workers of other poultry farms visit your farm?	Yes (0), No (4)	39(47.56)				43(52.44)
Do you or your workers visit other poultry farms in the area?	Yes (0), No (4)	24(29.27)				58(70.73)
How frequently do you receive visitors in your farm?	Once/week (0), once/2 weeks (1), once/month (2), once in a long time (3), never (4)	36(43.9)	3(3.66)	4(4.88)	26(31.71)	13(15.85)
Can the visitors easily access poultry premises?	Yes (0), No (4)	48(58.54)				34(41.46)
Can visitors easily access your poultry pen?	Yes (0), No (4)	18(21.95)				64(78.05)
Is there a fence and gate around the poultry premises?	Yes (0), No (4)	30(36.59)				52(63.41)
Is there a footbath at the entrance to your farm?	Yes (0), No (4)	57(69.51)				25(30.49)
How frequently do you replenish the disinfectant used in the footbath to the farm (weeks)	Daily (4), twice weekly (3), weekly (2), other (0)	63(76.83)	1(1.22)	4(4.88)	4(4.88)	10(12.19)
Is there a footbath at the entrance of each pen?	Yes (0); No (4)	40(48.78)				42(51.22)
How frequently do you replenish the disinfectant used in the footbath to the pens in weeks?	Daily (4), twice weekly (3), weekly (2), other (0)	49(59.76)	1(1.22)		15(18.29)	17(20.73)
What materials are the walls of your poultry houses build with?	Cement/stone (4), off cut/wood planks (2), wire mesh (0)	9(10.98)		3(3.65)		70(85.37)

Table 8. Number and percentage of biosecurity measures by household

Biosecurity measure	Scoring levels	Number (%) of households				
What materials is the floor of your poultry house build with?	Cement (4), earth or other (0)	6(7.32)				76(92.68)
How clean is the poultry house (looking for evidence for faeces around)	Very clean (4), clean (2), dirty (0)	12(14.63)		54(65.85)		16(19.51)
Is there a possibility of poultry coming into direct contact with other birds/animals?	Very unlikely (4), likely (2), very likely (0)	13(15.85)		37(45.12)		32(39.02)
How are carcasses disposed of?	Incinerated (4), buried (2), other (0)	27(32.93)		51(62.2)		4(4.87)

Table 9. Number and percentage of biosecurity measures by household

4.6 Conclusion

Farm and farmer characteristics play a big role in adoption of bio-security practises. This should be taken into account when developing intervention strategies to eliminate the HPAI H5N1. In this project, farm characteristics included the husbandry type on the farm and the type of production(meat, eggs or both) and history of HPAI on farm. Farmer characteristics were age, sex and farming experience. The analysis revealed that sex, husbandry, main source of income and level of education significantly influenced adoption.

4.7 Limitations of study

The PLS-PM methodology does not work with missing data. As a result missing values were replaced with 999 which is a good idea but not the best practice.

4.8 Future Research

Gender differences should be considered during the design phase of the data collection tool. Aspects such as the gender roles in decision making process in households whether females, males or joint decisions were made on the measures greatly influence adoption. It is believed that women are good in following through procedures compared to men.

Investigation of factors influencing implementation should be grouped into adoption on broiler farms and layer farms as management practises vary depending on type of chicken kept.

Bibliography

[Abdu et al.,2010] Abdu P.A., Costard S., Ahmed G.M., Duarte P. and R.Métras, 2010. *Qualitative risk assessment on the transmission of HPAI (H5N1) virus from backyard and medium-scale commercial farms to household free-range poultry in Nigeria.* HPAI Working Paper 29. Washington, DC: IFPRI

[Adene et al.,2006] Adene D.F, Wakawa A.M, Abdu P.A, Lombin L.H, Kazeem H.M, Sa'idu L, Fatihu M.Y, Joannis T, Adeyefa C.A and Obi T.U, 2006. *Clinico-pathological and husbandry features associated with the maiden diagnosis of avian influenza in Nigeria.* Nigerian Veterinary Journal 1:32–38.

[Agwu,2004] Agwu, A. E., 2004. *Factors influencing adoption of improved cowpea production technologies in Nigeria.* Journal of International Agricultural and Extension Education. 11(1), 81-88

[Ahmed,2008] Ahmed I.G., 2008. *Principal activities and situation of avian influenza in Nigeria.* Paper presented at Meeting of Experts of the Steering Committee of the Sub-Regional Mechanism for the Prevention and Control of Highly Pathogenic Avian Influenza, Abidjan 19-24 September 2008, Epidemiology Unit, FDL, Nigeria.

[Alders and Pym,2009] Alders, R.G., Pym, R.A.E.,. 2009 *Village poultry: still important to millions, eight thousand years after domestication.* Worlds Poult. Sci. J. 65,181–190.

[Amass et al.,2006] Amass SF, Baysinger. 2006 *A Swine disease transmission and prevention.* In: Straw BE, Zimmerman JJ, D'Allaire S, Taylor DJ, editors. Diseases of Swine.Ames, Iowa, USA: Blackwell Publishing. pp. 1075–1098.

[Cardona et al.,2007] Carol Cardona, David A. Bunn, Daniel Beltrain – Alcrudo, Walter M. Boyce, David A. Halvorson, Warner, T. Hudson, Christian, Sandrock, Deanna Clifford, Sandy Shanks. 2007. *Avian Flu School Course Guide, Module 4.* The Regents of the University of California, Davis Campus.

[Costard et al.,2009] Costard S., Porphyre V., Messad S., et al., 2009 *Multivariate analysis of management and biosecurity practices in smallholder pig farms in Madagascar.* Preventive Veterinary Medicine. 92(3):199–209.

[Maduka et al.,2016] C.V. Maduka, I.O. Igbokwe, N.N. Atsanda. 2016. *Appraisal of chicken production with associated biosecurity practices in commercial poultry farms located in Jos, Nigeria* Scientifica, p. 1914692

[De Benedictis et al.,2007b] De Benedictis P, Joannis TM, Lombin LH, Shittu I, Beato MS, Rebonato V, Catolli G and Capua I. 2007b. *Field and laboratory findings of the first incursion of the Asian H5N1 highly pathogenic avian influenza virus in Africa.* Avian Pathology 36(2):115–117.

[Dickenson-Hoyle et al.,2009] Dickenson-Hoyle S and Reenberg A. 2009. *The shrinking globe: Globalization of food systems and the changing geographies of livestock production.* Geografisk Tidsskrift – Danish Journal of Geography 109(1):105 -112.

[Dohoo et al.,2009] Dohoo, I., W. Martin, and H. Stryhn. 2009. *Veterinary Epidemiologic Research.* AVC Inc., Charlottetown, Prince Edward Island.

[FAO,2008] FAO. 2008. *Biosecurity for Highly Pathogenic Avian Influenza.* Issues and Options. Animal Production and Health Paper. Food and Agriculture Organization of the United Nations. Rome.

[Fasanmi et al.,2016] Fasanmi O.G., Ahmed S.S.U., Oladele-Bukola M.O., El-Tahawy A.S., Elbestawy A.R., Fasina F.O.,2016. *An evaluation of biosecurity compliance levels and assessment of associated risk factors for highly pathogenic avian influenza H5N1 infection of live-bird-markets, Nigeria and Egypt.* Acta Trop;164:321–328.

[Gelaude et al.,2014] Gelaude P., Schlepers M., Verlinden M., Laanen M., Dewulf J. 2014. *Biocheck. UGent: A quantitative tool to measure biosecurity at broiler farms and the relationship with technical performances and antimicrobial use.* Poultry Science 93, 2740-2751.

[Gunn et al.,2008] Gunn G. J., Heffernan C., Hall M., McLeod A., Hovi M., 2008. *Measuring and comparing constraints to improved biosecurity amongst GB* *farmers, veterinarians and the auxiliary industries.* Preventive Veterinary Medicine;84(3-4):310–323.

[Jordan,1990] Jordan FTW., 1990. *Poultry Diseases (3rd edition)* English Language Book Society/ Balliere Tindall, 24-28 Oval Road, London. Pp 1- 467.

[Kouam et al.,2018] Kouam, M. K., Moussala, J. O., 2018. *Assessment of Factors Influencing the Implementation of Biosecurity Measures on Pig Farms in the Western Highlands of Cameroon (Central Africa).* Veterinary medicine international, 9173646.

[Martindah et al.,2014] Martindah, E., N. Ilham, and E. Basuno, 2014.*Biosecurity level of poultry production cluster (PPC) in West Java, Indonesia.* International Journal of Poultry Science, 13 (7): p. 408-415.

[Nyaga,2007b] Nyaga, P.N., 2007b. *The structure, marketing and importance of the Commercial and village poultry industry: An analysis of the poultry sector in Kenya. Food and Agriculture Organization of the United Nations. Prevention and Control Strategies of Highly Pathogenic Avian Influenza (HPAI) in Eastern Africa*

[Paul et al.,2011] Paul M, Wongnarkpet S, Gasqui P, Poolkhet C, Thongratsakul S, Ducrot C, Roger FO., 2011 *Risk factors for highly pathogenic avian influenza (HPAI) H5N1 infection in backyard chicken farms, Thailand.* Acta Trop. ;118:209–16.

[Sanchez,2013] Sanchez, G., 2013 *PLS Path Modeling with R*

[Siekkinen et al.,2012] Siekkinen, K. M., J. Heikkilä, N. Tammiranta, and H. Rosengren. 2012.*Measuring the costs of biosecurity on poultry farms: A case study in broiler production in Finland.* Acta Vet. Scand. 54:12.

[Susilowati et al.,2013] Susilowati, S.H., I. Patrick, M. Iqbal and T. Jubb, 2013. *The characteristics of the farm and the farmer that affect the adoption of biosecurity on smallholder poultry farms in Indonesia.* Livestock Research for Rural Development, volume 25 (5)

[Truscott et al.,2007] Truscott J., GarskeT., Chis-ster I., GuitainJ., Pfeiffer D., Snow L., Wilesmith J., Ferguson N. M., Ghani C., 2007. *Control of highly pathogenic*

H5N1 avian influenza outbreak in the GB poultry flock., Proceedings of the Royal Society: Biological Science; 274: 2287-2295.

[Lestari et al.,2012] V. S. Lestari, S. N. Sirajuddin, and K. Kasim. 2012. *Adoption of biosecurity measures by layer small holders,* Journal of the Indonesian Tropical Animal Agriculture, vol.36, no.4, pp.297–302.

[Steenwinkel et al.,2011] Van Steenwinkel, S., S. Ribbens, E. ducheyne, E. Goossens, and J. dewulf. *Assessing biosecurity practices, movements and densities of poultry sites across Belgium, resulting in different farm risk-groups for infectious disease introduction and spread.* Prev. Vet. Med. 98:259–270.

[You et al.,2007] You, L. Z., and X. S. Diao., 2007. *Assessing the potential impact of avian influenza on poultry in West Africa: a spatial equilibrium analysis.* J. Agric. Econ. 58, 348–367.

[Rowlands et al.,2000] Rowlands, G., Musoke, A., Morzaria, S., Nagda, S., Ballingall, K., McKeever, D. 2000. *A statistically derived index for classifying East Coast fever reactions in cattle challenged with Theileria parva under experimental conditions.* Parasitology, 120(4), 371-381. doi:10.1017/S0031182099005600