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A systems thinking approach to understand the drivers of change in backyard poultry farming system

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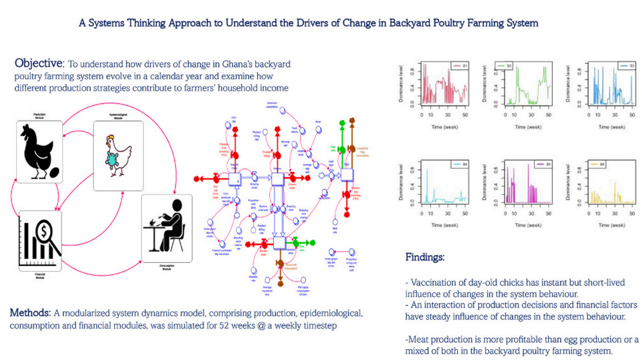
HIGHLIGHTS

- Drivers of change evolve in complex systems.
- Understanding the evolution of drivers of change helps to localize interventions.
- Backyard poultry system focused on meat production is profitable.
- Vaccination of birds has a strong but short-lived impact on backyard poultry farming systems

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Drivers of change in farming systems are not static, they evolve. Yet, there is an underlying assumption in the literature that drivers of change are static.
OBJECTIVE: This paper seeks to understand how drivers of change in Ghana's backyard poultry farming system evolve within a calendar year and examine how different production strategies contribute to the incomes of farm households.
METHODS: A system dynamics model, comprising production, financial, consumption, and epidemiological modules, was developed, validated, and simulated for a 52-week period using a weekly timestep.
RESULTS AND CONCLUSIONS: Results of the loops that matter analysis showed that from the onset of the poultry production, disease prevention at different growth stages of the chicken (especially for day-old chicks) via vaccination is a critical driver of change that has a high but short-lived dominance. Beyond the grower stage, the changes in the unit price of eggs have a relatively higher and longer influence on production dynamics than changes in the unit price of poultry meat. Moreover, the results suggest that a focus only on meat production is the most profitable strategy compared to production strategies that focus only on egg production or a mix of egg and meat production.
SIGNIFICANCE: The findings of this paper extend the literature on drivers of change in the farming system by stressing the need to assess how these drivers evolve. The application of the loops that matter analysis in system dynamics modelling provides a framework for analysing the evolution of drivers of change in farming system.

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1. Introduction

Ghana's poultry industry has been on a decline, with total volume of meat production decreasing annually over for the past two decades. In contrast, there has been an increase in poultry meat consumption in Ghana over the same period (Asante-Addo & Weible, 2019). Since 2010, chicken has become the most produced meat in Ghana, overtaking beef and pork, yet the demand for poultry meat exceeds local supply (Adzitey, 2013; Etuah et al., 2020; Yevu and Onumah, 2021). Although imported chicken contributes a substantial percentage of supply in Ghana, the current policy that applies 20% tariffs on all poultry product imports has been criticised as too low, thereby promoting the influx of cheaper imports that has become one of the impediments to the development of the poultry sector in Ghana (Butler, 2016; Etuah et al., 2020). In addition, diseases that cause high mortality and morbidity rates in poultry flocks, poor management decisions by poultry farmers, and unavailability of poultry feed have also been identified as factors inhibiting the development of Ghana's poultry sector (Banson et al., 2015).

The backyard production system is the most common poultry production system in rural areas in Ghana. Revenues earned from this production system provide additional household income and occasionally, satisfy the nutritional needs of farm households, especially during festive occasions (Anang et al., 2013; Butler, 2016; Yevu and Onumah, 2021). However, the farm management practices adopted in the backyard poultry production system are criticised as being sub-optimal (Adusei-Bonsu et al., 2021; Kunadu et al., 2020). For instance, although the use of termites as poultry feed has been linked to some common poultry diseases, the practice still persists in the Northern, Upper East, Upper West, and Volta regions in Ghana (Boafo et al., 2019). Overall, adopted management practices and production strategies are driven by different socio-economic and epidemiological factors (Banson et al., 2015). As noted by García-Martínez et al. (2009), farmers' adaptability to socio-economic drivers and internal household economic factors have contributed to the observed changes in farming systems.

These drivers of change in farming systems are not static, they evolve. Yet, there is an underlying assumption in the literature of static drivers of change (Anang et al., 2013). Understanding how the drivers of change in a farming system evolve can spearhead the formulation of effective strategies to solve systemic problems in farming systems (García-Martínez et al., 2009). This study seeks to understand how farm-level drivers of change in the backyard poultry production system evolve within a calendar year and examines how different production strategies contribute to farm household income in Ghana. A systems dynamics modelling approach was adopted to answer two research questions. (i) What are the dominant drivers of change in the backyard poultry production system, and how do these drivers evolve over time? (ii) How do different production strategies (i.e., meat production, egg production, or mix production strategies) impact the household incomes of chicken-owning households?

The remaining sections of the paper are structured as follows. Section 2 covers a description of the System Dynamics model used for the analysis. The study's results are presented and discussed in Section 3, and the conclusions drawn from the key findings are presented in Section 4.

2. Methodology

System Dynamics (SD) modelling has become a useful tool for understanding the drivers of change in livestock farming systems (García-Martínez et al., 2009). The approach has also been used extensively to

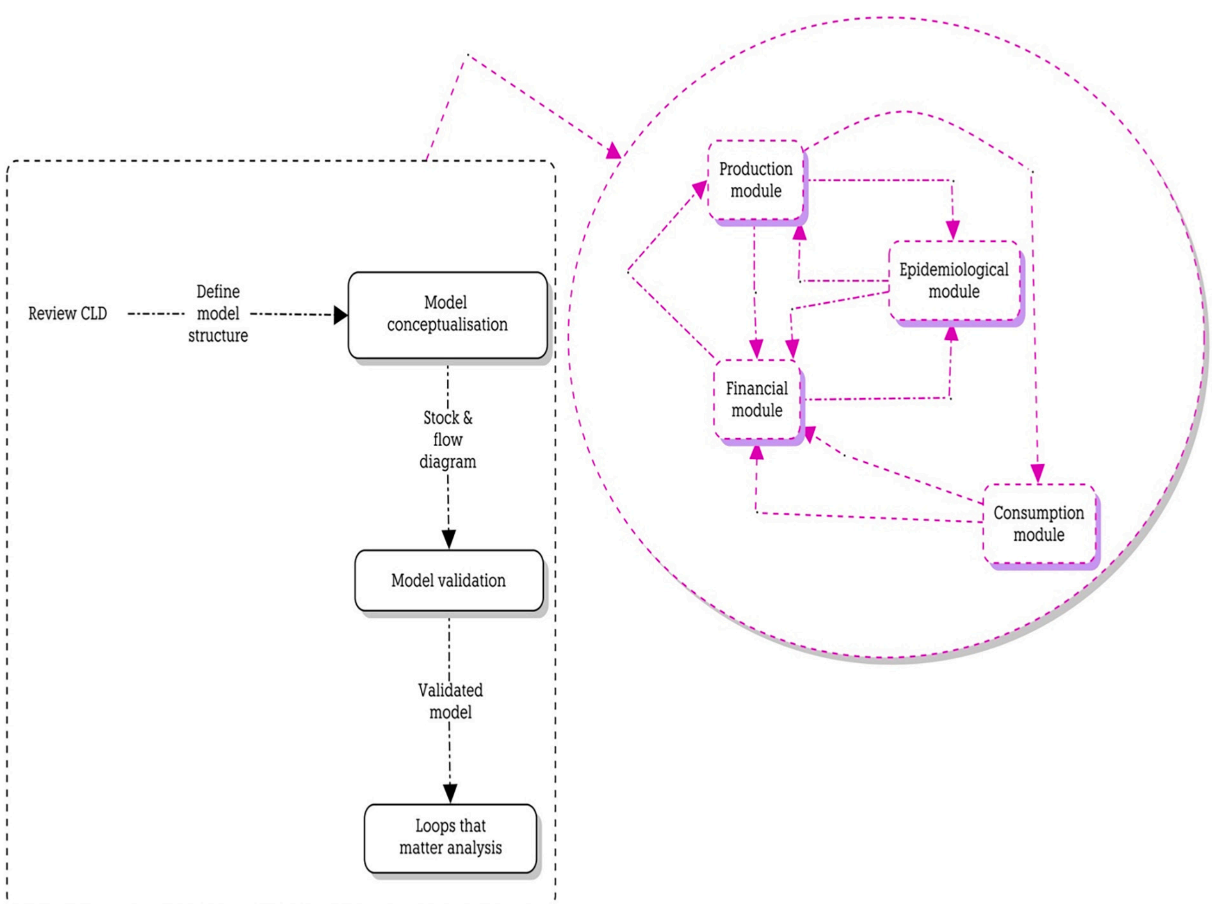

Fig. 1. The modelling process.

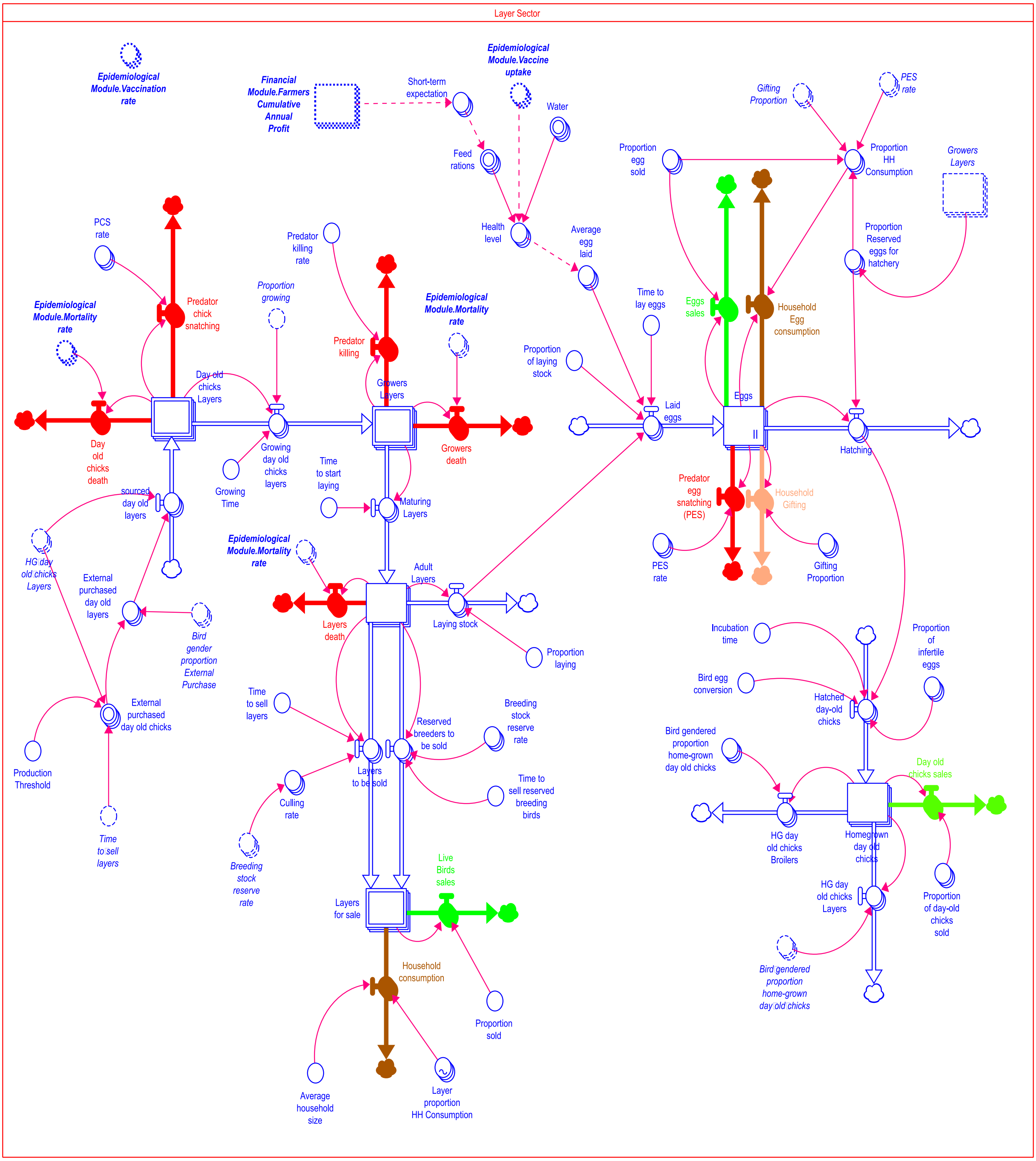

Fig. 2. The layer sector in the production module- at disaggregated farm level.

capture the dynamic interactions of variables, and the feedback effects of these interactions in livestock systems (Dahlanuddin et al., 2017), and to facilitate ex-ante impact assessment that enables practitioners to ascertain and anticipate the impacts of strategies and interventions (Aboah et al., 2019; Rich and Wane, 2021). Therefore, SD modelling approach was adopted to understand how drivers of change in Ghana's backyard poultry production system evolve within a production cycle.

The modelling process is shown in Fig. 1. Stock and flow diagrams (SFD) were developed based on a causal loop diagram generated from a group model building process with stakeholders. The model was developed to run for a 52-week period with a weekly time step, using an exhaustive iteration of 1000 runs in the Stella Architect® software. The time zero was assumed to coincide with the start of the calendar year. Data for the model parameterization were retrieved from the literature,

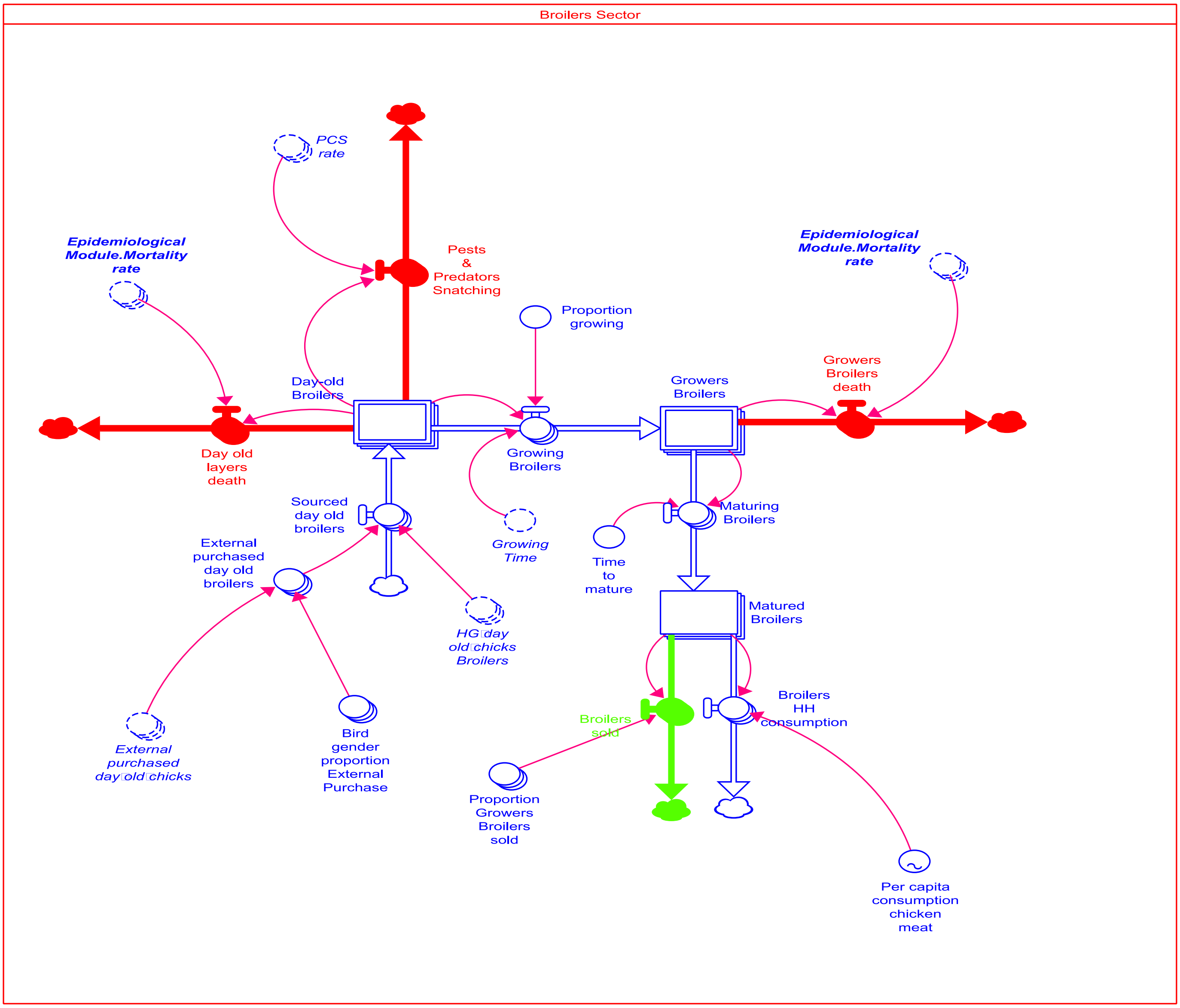

Fig. 3. The broiler sector in the production module- at disaggregated farm level.

stakeholder engagements, and expert elicitation.

2.1. Model description

The SD model was segmented into four interacting modules as shown in Fig. 1. The modules comprised production and financial modules at a disaggregated farm level, and the epidemiological and consumption modules at an aggregated regional level. This four-component model depicted the backyard poultry production system in the Northern region of Ghana which was derived from the causal loop diagram generated from a group model building process.

2.1.1. Production module

Figs. 2 and 3 show the variable interactions in the two sectors (i.e., egg production and bird production for live animal sales or chicken meat consumption[1]) within the production module. Unlike commercial poultry production that typically commences with stocks of day-old chicks, backyard poultry production usually commenced with growing layers (four on average) that are often received as gifts from relatives to serve as start-up capital for economic activities. Subsequently, farm households may purchase day-old chicks from established hatcheries in the region when the reserved breeding stocks are sold. Based on information elicited from stakeholders, a production capacity threshold of 20 birds was set for each farmer household. This condition restricted the production system from exceeding the typical production capacity of a

[1] In Figs. 2 and 3, egg production sector is labelled as "layer" sector, and live sales/ chicken meat production sector is labelled as "broiler" sector.The overlapping words in Figs. 2,3, and, 4 are "ghost icons" of variables in the model. Ghost icons are used to show that the original variable (and the value) in the model influences more than one variable. Ghost icons are used primarily to improve the legibility and comprehensibility of a model.

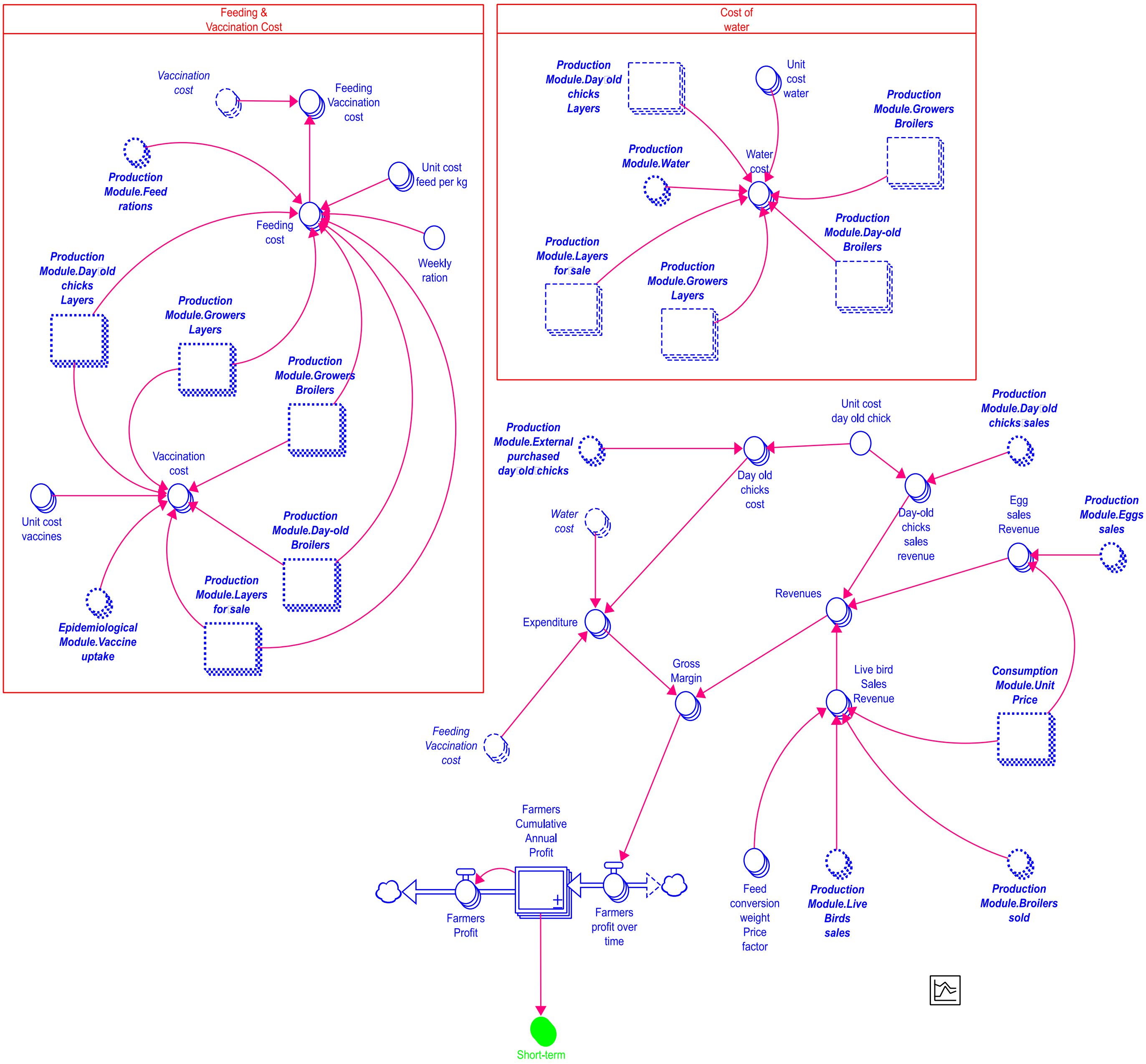

Fig. 4. Financial module - disaggregated level.

backyard poultry system. The number of day-old chicks procured from external hatcheries for subsequent production activities was contingent on the condition that home-grown day-old chicks are lower in number than the threshold of production capacity assumed in the model.

Day-old chicks (captured as stocks in Fig. 2) took five weeks to mature into growing chicks (i.e., outflow from the stock of day-old chick in Fig. 2). Growers (in the egg production sector[2]) took 14 weeks to mature and become productive layers, while birds kept primarily for live sales or meat[3] became ready for the market after eight weeks (Rich, 2007). Although there is a preference for the female chicken, a 50:50 ratio was assumed for the composition of male and female home-grown day-old chicks, reflecting biological realities. Based on elicited information from stakeholders, 10% of eggs were assumed infertile, and 2.5% of the eggs produced were given as gifts to relatives and friends. Mature birds in the egg-production sector) were sold, and day-old chicks were restocked after 24 weeks.

Farm households allocated 80% of produced eggs for home-grown hatching when the total number of growers are below the production capacity threshold. The percentage dropped to 50% when growers in stock exceeded the production capacity threshold. Birds are slaughtered for home consumption (i.e., brown-coloured outflows in Figs. 2 and 3), sold live on the traditional open market (i.e., green-coloured outflows in Figs. 2 and 3), or reserved as breeding stock for a specified period. The reserved breeding stocks continued to produce eggs for sale or on-farm hatching. Although chicks can naturally live for six years, the reserved breeding stocks were later sold on the live market after 52 weeks (Rich, 2007).

Bird deaths in the production module (i.e., red-coloured outflows in

[2] Chickens are reared primarily for their eggs and peripherally for their meat

[3] Chickens are reared primarily for their meat and peripherally for their eggs

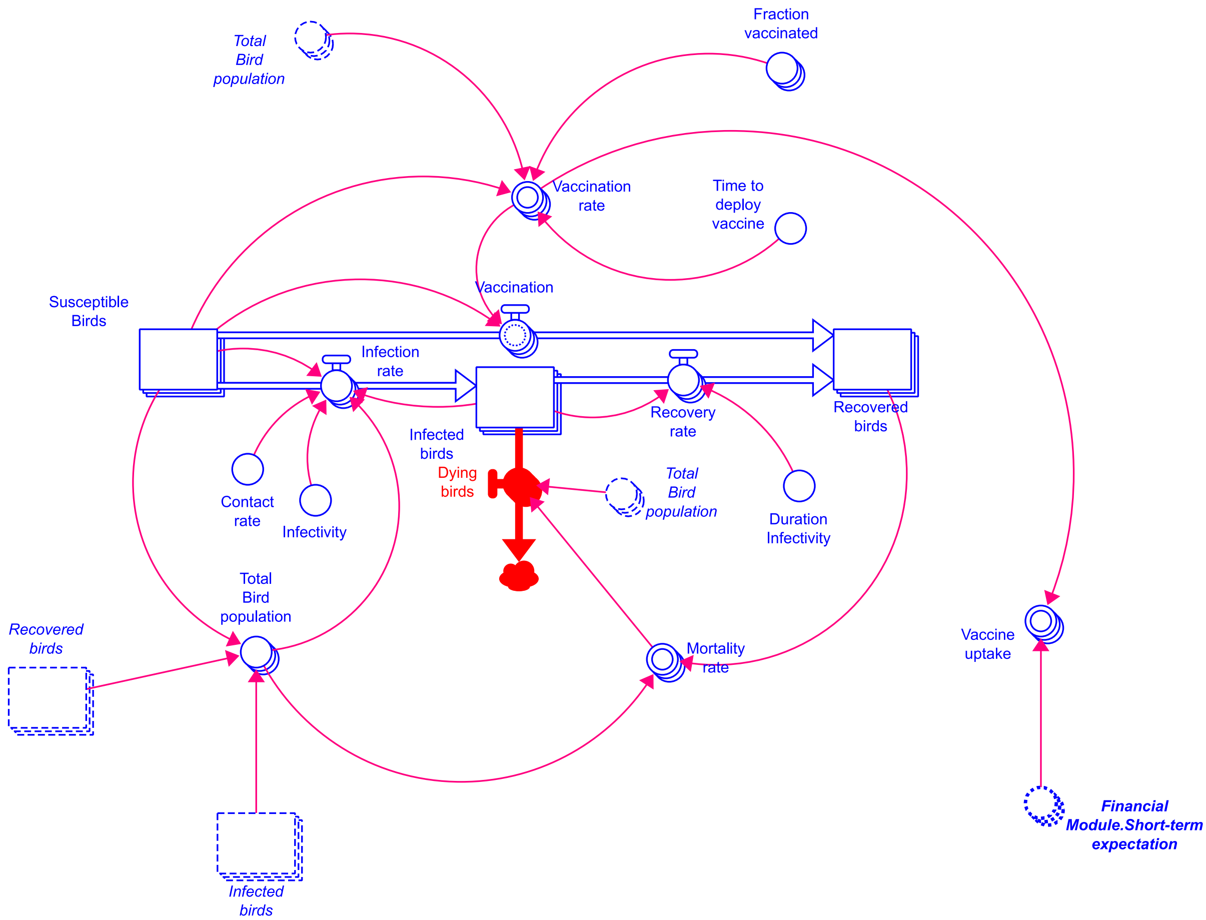

Fig. 5. The epidemiological sector - at an aggregated regional level.

Figs. 2 and 3) were caused by diseases, predators, and pests. The deaths were captured throughout the different stages of growth for the birds (day-old, growers, mature). Similarly, the mortality rate in this model was arrayed to accommodate the potential differences at the various stages of growth. The mortality rate was endogenised in the epidemiological module, which was modelled at an aggregate regional level.

Farm households were classified as good agricultural practices (GAP)-adopting farm households and non-GAP-adopting farm households based on their production decisions. Following a recommended vaccination schedule published by the Food and Agriculture Organization (FAO, 2013), the model considered that GAP-adopting farm households vaccinated the day-old chicks in week 1 with Gumboro vaccine, week 2 with HB1 for Newcastle disease, week 3 with a second Gumboro vaccine, and week 7 with the first fowl pox vaccine. Growers were vaccinated in week 10 with Lasota vaccine against the Newcastle disease. The second vaccine for fowl pox and the third Newcastle disease (Newcavac) were administered in weeks 12 and 16, respectively (Duah et al., 2020). The number for vaccine uptake for the day-old chick and growers was four and three times, respectively. The last vaccination event in the schedule occurred at 16 weeks. Generally, farm households engaged in backyard poultry production are noted to be non-GAP adopters (Adusei-Bonsu et al., 2021). Therefore, the GAP-adopting farm households can be considered as counterfactuals in the model.

A farm household's decision to vaccinate birds was reliant on the expected profit. Farm households engaged in backyard poultry production system are constrained by low levels of access to vaccines which affects the majority of farm households across the study areas (Enahoro et al., 2021). As farmers in the study regions indicated they all accessed vaccines from a limited pool of extension or veterinary officers (Enahoro et al., 2021), an underlying assumption was made in the model of homogenous efficacy of vaccine administration across farm households. However, the feed rations were influenced by the profitability of production activities. The type of feed (quality) and quantity (ration) of feeding in turn influenced the physiological conditions like the weight of the chicken (Duah et al., 2020). GAP-adopting farm households gave more feed rations than the non-GAP-adopting farm households. The feed[4] and water rations given to the birds, and the level of vaccination uptake determined the health level of the birds, which was measured on a dichotomous (low or high) scale. A matured bird for a GAP-adopting farm household laid an average of six (6) eggs per week. Birds for non-GAP adopting farm households laid between 3 to 6 eggs per week. The uncertainty in the number of eggs produced is captured by the triangular distribution (3 (minimum), 4(mode),6(maximum). Also, a 12.75% weight difference was applied to the live bird sold to differentiate between the two health levels considering the different feed conversion rates (Banso et al., 2015). The outputs from the production sector (i.e., the egg and live chicken sold) connected the production sector to the consumption and financial sectors at aggregate regional and disaggregated farm levels, respectively.

2.1.2. Financial module

The financial module, shown in Fig. 4, captured the flow of money (expenditures and revenues) at the disaggregated farm level, and the

[4] Based on feed formulation specification from Maridav (a commercial feed concentrate seller in Ghana), the feed ration is estimated using the guidelines, 10,000 birds will feed 1 ton (1000 kg) of feed per day. The optimal feeding ration is estimated to be 0.1 kg of feed per day per bird. Hence, the weekly feed ration for a bird is 0.7 kg).

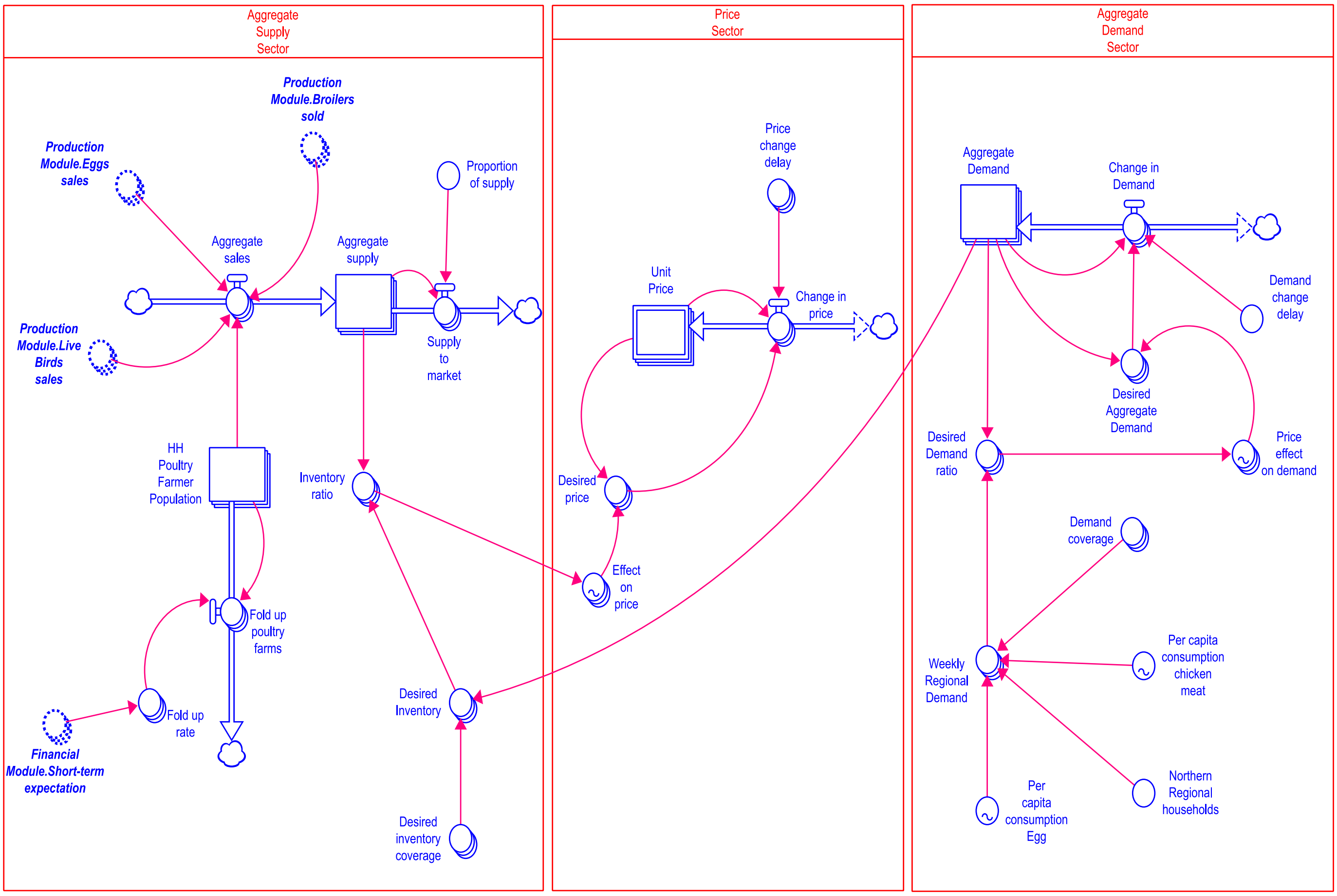

Fig. 6. Consumption sector - at an aggregate regional level.

estimation of profitability. The sales of eggs and live birds were the main sources of revenue. The total production cost consisted of feeding, water and vaccination costs, and the cost of purchasing day-old chicks. The unit price of the commercial feed for the chicken at different stages of growth was estimated using the market prices of feeds obtained from the website of the Ghana Accra Poultry Farmers' Association.

The feedback effect from the consumption module to the price for eggs and live chicken from was highlighted in the estimation of the total revenue from the financial sector. The net income, estimated in Eq. (1), was used as a measure of farmers' household income.

$$\text{Net income} = \sum P_{(ij)}\, Q_{(ij)} - \sum \text{Exp}_{(ij)} \quad (1)$$

Where $P_{(ij)}$ is the selling price of egg and poultry meat; $Q_{(ij)}$ is the quantity sold.

$\text{Exp}_{(ij)}$ is the total production cost; ij is egg and poultry meat, respectively.

In the backyard poultry system, the birds were raised on a free-range, and poultry bans were often makeshift coops. As such, only variable costs were captured as expenditures; with no fixed cost was accounted for in the profit estimations.

2.1.3. *Epidemiological module*

The idea of an integrated epidemiological-economic model was captured by the feedback that existed in how producers responded to disease outbreaks (Rich, 2007). The epidemiological module, shown in Fig. 5, emphasised the role that vaccination played in the reduction of mortality rate at the various stages of growth for the local chicken. Following the SIR (susceptible-infected-recovered) model, arrayed stocks were used to represent the various stages of growth for susceptible birds, infected birds, and recovered birds. The SIR model relied on the assumption that; no natural death occurred, there was no latent period for infection, chickens acquired lifetime immunity after recovery from infection, and the total population was constant (Cooper et al., 2020; Weiss, 2013).

The initial population of the stock of susceptible birds was the total bird population. The initial bird population at an aggregate level was estimated as the product of the number of farm households engaged in local poultry production (GSS, 2014) and the average flock size. The vaccination rate, expressed as a proportion of susceptible birds that have recovered due to vaccination, influences the vaccination uptake in the production sector. Due to the low vaccination rate in the backyard poultry system, it was assumed based on expert elicitation that 1% of the farm households on aggregate vaccinated their birds and the time to deploy the vaccine was 1 week. Sensitivity analysis exploring impacts of vaccination rates deviating to +5% from the assumed 1% vaccination rate showed that the mortality rates and the number of birds that recover from disease decrease and increase respectively. Results of the sensitivity analysis are presented in Appendix A.

The recovery rate was estimated as the quotient of the population of infected birds and the duration of infectivity. The duration of infectivity, which represented the average duration that the birds are infectious, was 16 weeks because the last vaccines were taken in the 16th week. The main output from the epidemiological sector that sent feedback to the production sector was the mortality rate, which was endogenised based on the recovery rate, the infected birds, and the total bird population at an aggregate level.

2.1.4. *Consumption module*

The consumption module, presented in Fig. 6, encompassed the aggregate supply and demand for egg and chicken at the regional level, and how these factors influenced the unit price of egg and chicken. Following Whelan et al. (2001), the unit price of egg and live chicken was endogenised. The unit price was modelled using an initial value of Ghana Cedis (GHS) 0.6 per egg and GHS 35 per live chicken, at an annual price change delay because the prices usually changed after the peak seasons at Christmas. The supply was estimated as an aggregation of egg and live chicken produced by farming households from the production sector.

Given the perishability of the poultry products, a weekly desired inventory coverage was specified. The influence of inventory levels on price (i.e., effect on price) was estimated as the ratio of inventory to desired inventory. The total demand for egg and live chicken was influenced by the regional demand and the demands from other regions. The model considered two peak periods for the consumption of poultry products – weeks 16 and 52, which captured the spike in demand during Easter and Christmas festivities. During these periods, the per capita consumption increased from a weekly average of one to three eggs. According to GSS (2014), the per capita consumption of eggs for the Northern region was 12, translating to one egg per month. However, the model considered at least a weekly consumption of eggs to prevent the simulated demand from running down to zero. When supply exceeded demand, the inventory ratio was high, hence the effect of price decreased. The model accommodated the potential switch from the consumption of local chicken meat using the unit price of imported chicken products as the determining factor for consumers to switch out.

2.2. Loops that matter analysis

The loops that matter method supported an empirical determination of dominant feedback loops (Schoenberg et al., 2020; Eberlein and Schoenberg, 2020), which are the key drivers of change in the model behaviour. The loops that matter method produced three metrics – link score, loop score, and the relative loop score. Link score is the contribution of change from one variable to another variable at a particular time. Loop score is the product of all link scores in a feedback loop at a point in time. The normalised loop score, which measured a loop's contribution to changes in all variables in a model, was the relative loop score (Eberlein and Schoenberg, 2020). The link score (LS) was estimated as in Eq. (2) below.

$$\text{Ls}\ (x.\rightarrow z) = [\Delta_x{}^z/\Delta_Z].sign\ [\Delta_x{}^z/\Delta_x] \tag{2}$$

Where Δ_Z is a change in variable z from time $_{(t)}$ to time $_{(t+1)}$. Δ_x represented the change in the variable x for time$_{(t)}$, and Δ_x^z is the change in variable z concerning variable x. $[\Delta_x^z/\Delta_Z]$ estimated the magnitude of the link score, and sign $[\Delta_x^z/\Delta_x]$ represented the polarity of the link score.

2.3. Model validation

Following the logical sequence of model validation suggested by Barlas (1996), the structure of material and information flows in the model were first validated by a reference group. Due to the restriction of in-person gatherings necessitated by the COVID'19 pandemic and in force during the data collection phase of the study, a virtual model structure validation procedure was executed by a three-member research team comprising of a convenor, facilitator (note taker), and modeller with a reference group.[5] The stock and flow diagrams (SFDs) were presented to the reference group using the storytelling feature of the STELLA Architect ® software. The storytelling feature allowed for a kiosk-style presentation of variable interactions in the SFDs of each module. The reference group provided inputs on each set of variables presented, and the modeller revised the model structure in real time based on these inputs.

The model was afterwards subjected to a structure-oriented behaviour test. Extreme-condition tests were performed by altering the initial number of growers (layers), an average number of egg produced, and average flock size for the estimation of total bird population to zero. The first and third extreme condition tests resulted in a non-occurrence of production activities, generating a "divide by 0 computing error". The second extreme-condition test resulted in the following: no egg production, no home-grown day-old chicks, and the externally purchased day-old chicks were equal to the production capacity threshold. The test results implied that production activities discontinued when there were no layers or no egg production; hence, farmer households needed to keep buying day-old chicks from external hatcheries to ensure continuity of production activities.

Sensitivity analysis was further conducted by altering the frequency of egg production and the proportion of infertile eggs produced. Results of the sensitivity analysis focused on the total number of eggs and home-grown day-old chicks produced. Fig. 7 indicates that an increase in the frequency of egg produced from weekly to twice every week resulted in an increase in the total number of eggs and home-grown day-old chicks produced. An increase in the proportion of infertile eggs resulted in a decrease in the total number of eggs and day-old chicks produced, as shown in Fig. 7. Therefore, the results exuded confidence in the model behaviour.

In addition, a within-group analysis was performed using the *t*-test to determine the statistical significance of the differences in the income earned by the two farm households.

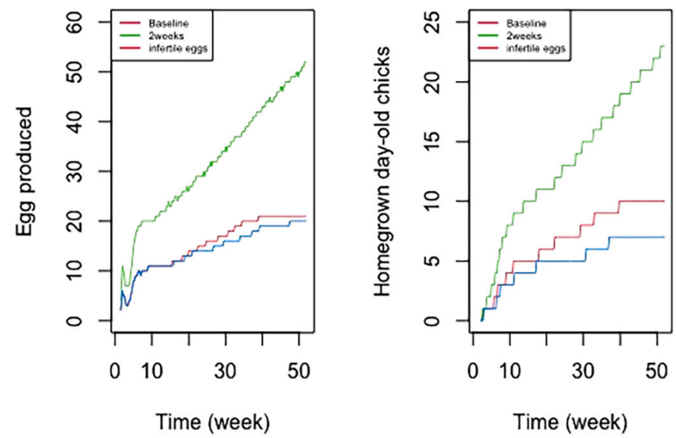

Fig. 7. Eggs and day-old chicks produced when frequency of egg production and. Proportion of infertile eggs increase.

3. Results and discussion

The Loops That Matter feature of the STELLA Architect® software enables a quantitative identification and ranking of the dominant feedback loops that drive the system's dynamic behaviour. Results on how these dominant feedback loops evolve are presented and discussed in Sub-section 3.1. The results representing the effect on the farm household's income of three production strategies (based on the proportion of day-old chicks purchased) are presented and discussed in Sub-section 3.2,

[5] The reference group comprised of two members from the non-governmental organizations involved in the implementation of project interventions in the backyard poultry production system in Ghana, one private sector player (retailer of poultry products), a Director from the Regional Agricultural Ministry an Agribusiness Expert, and an Epidemiologist from the development-focused University in the region.

Table 1
Loop sets and the focal issues of the feedback loops.

Loop set	Nº reinforcing feedback loops	Nº of balancing feedback loop	No of feedback loops describing 80% of model behaviour	Main issues highlighted by the dominant feedback loops
1♥	4R	10B	2R 4B	How changes in consumer price affects supply, and the consequential feedback on on-farm profitability
2♠	–	16B	5B	(i) The effect of changes of layers sold on layers stock at the farm level, (ii) the delay in the maturing layers, (iii) proportion of reserved breeders sold
3♠	–	16B	5B	(i) Delay in the sales of layers, (ii) effect of day-old chicks' death on day-old chick stock, (iii) egg sales effect on stock of eggs
4◆	1R	2B	1B	How vaccination affects the number of recovered birds (day-old chicks GAP)
5◆	1R	2B	1B	How vaccination affects the number of recovered birds (day-old chicks No GAP)
6◆	1R	2B	1B	How vaccination affects the number of recovered birds (grower chicks GAP)
7◆	1R	2B	1B	How vaccination affects the number of recovered birds (grower chicks No GAP)
8◆	1R	2B	1B	How vaccination affects the number of recovered birds (Broiler chicks GAP)
9◆	1R	2B	1B	How vaccination affects the number of recovered birds (Broiler chicks No GAP)
10▽	1R	2B	1R 1B	Effect of changes in demand on price (egg)
11▽	1R	2B	1R 1B	Effect of changes in demand on price (poultry)
12◆	1R	1B	1B	The effect on the dying birds (day-old chicks GAP), infection, and infection rate
13◆	1R	1B	1B	The effect on the dying birds (day-old chicks No GAP), infection, and infection rate
14◆	1R	1B	1B	The effect on the dying birds (Grower chicks GAP), infection, and infection rate
15◆	1R	1B	1B	The effect on the dying birds (Grower chicks No GAP), infection, and infection rate
16◆	1R	1B	1B	The effect on the dying birds (Broiler Layer chicks GAP), infection, and infection rate
17◆	1R	1B	1B	The effect on the dying birds (Broiler Layer chicks No GAP), infection, and infection rate
18♠	–	2B	1B	Effect of the death of day-old layers on day-old broilers (GAP) and the delay in the growth of broilers
19♠	–	2B	1B	Delay in maturing broilers (GAP) and broilers death
20♠	–	2B	1B	Effect of bird sales on household consumption
21♠	–	2B	1B	Death of day-old chicks (broilers No GAP) & delay in broilers growing (No GAP)
22♠	–	2B	1B	Delay in maturing broilers (No GAP)
23♠	–	2B	1B	Effect of live birds' sales on household consumption (No GAP)
24♠	–	1B	1B	Depletion of broilers stock by sales of broilers (GAP)
25♠	–	1B	1B	Depletion of broilers stock by sales of broilers (No GAP)

♠ Production module.
◆ Epidemiological module.
∇ Consumption module.
♥ Consumption, financial & production module -.

3.1. Drivers of change in the backyard poultry production system

In total 25 loop sets highlighting different dominant feedback loops at different times of the simulation run are shown in Table 1. The dominant feedback loops that influence the dynamic behaviour of the model are those that explain at least 50% of the changes in the system's behaviour (Schoenberg et al., 2020). At a 50% dominance level threshold, 20 loop sets have only one dominant feedback loop, and five loop sets (Loop sets 1,2,3,10, and 11) do not have any dominant feedback loop. A decrease of the dominance level threshold to include all feedback loops that contributed to describing 80% of the changes in the model behaviour yields 40 dominant feedback loops. Details of the main issues addressed in the dominant feedback loops are summarised in Table 1.

Analysis of the dominant feedback loops is presented under each module. The epidemiological module had the highest number of loop sets (i.e., 12 loop sets), followed by the production module with 10 loop sets and the consumption module with 2 loop sets. One loop set contained interactions of consumption, financial and production modules. This loop set contained the highest number of dominant feedback loops

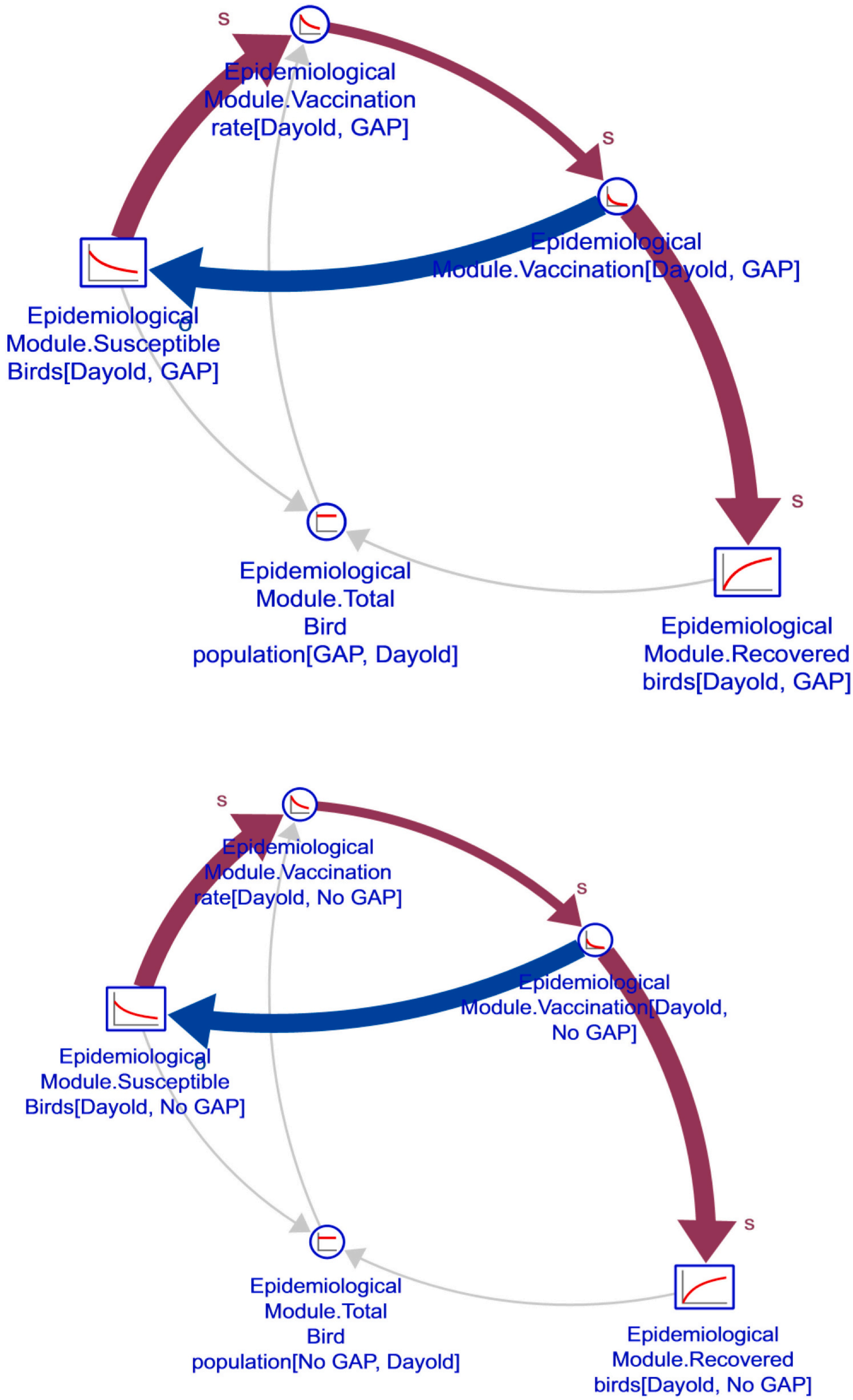

Fig. 8. The generative causal loop diagram for loop sets 4 *(top)* and 5 *(bottom)*.

(i.e., 6 feedback loops). A summary of the dominant feedback loops in loop sets (shown in Table 1) indicates the drivers of change for the backyard poultry production system. Results of the dominant feedback loops at 50% dominance threshold level showed that the epidemiological factors are critical drivers of change in the backyard poultry system in Ghana. Results highlight the potential level of change that vaccination can cause on the production dynamics of the backyard poultry system. Details of the generative causal loop diagram showing the strength of dominance for vaccination is presented in Fig. 8. The results corroborated with the observation that infectious diseases in poultry are key driving forces in backyard poultry production systems in Ghana (Enahoro et al., 2021).

Table 2
Loop score of dominant feedback loops in Loop set 1.

Loop	Shown	$T =$ 52.00	Total 100%	Feedback loop
R1 1 stock 3 variables	R1	24.95%	18.47%	Consumption Module.Change in price[Egg] → Consumption Module.Unit Price[Egg] → Consumption Module.Desired price[Egg] → Consumption Module.Change in price[Egg]
B1 1 stock 2 variables	B1	−17.63%	−13.78%	Consumption Module.Change in price[Egg] → Consumption Module.Unit Price[Egg] → Consumption Module.Change in price[Egg]
B2 1 stock 2 variables	B2	−7.32%	−13.50%	Consumption Module.Supply to market[Egg] → Consumption Module. Aggregate supply[Egg] → Consumption Module.Supply to market[Egg]
R2 1 stock 3 variables	R2	24.95%	13.21%	Consumption Module.Change in price[Poultry] → Consumption Module.Unit Price[Poultry] → Consumption Module.Desired price[Poultry] → Consumption Module.Change in price [Poultry]
B3 1 stock 2 variables	B3	−17.63%	−12.22%	Consumption Module.Change in price[Poultry] → Consumption Module.Unit Price[Poultry] → Consumption Module.Change in price[Poultry]

A → B means a change in A cause change in B.
R – reinforcing feedback loop.
B – balancing feedback loop.

3.1.1. Evolution of drivers of change (E-driver $_{(change)}$)

Trend analysis of the dominant feedback loops was used to determine how the drivers of change evolve in a calendar year. The trend analysis focused on the loop sets with high dominant feedback loop sets (i.e., ≥5 feedback loops); these are loop set 1, 2 and 3. A summary of the cumulative influence level of the feedback loops (denoted by the total loop score) in loop set 1 is presented in Table 2. Fig. 9 shows the trend the influence level of the dominant feedback loops in loop set 1.

Generally, the feedback loop with the highest cumulative influence for loop set 1 was the reinforcing feedback loop revolving around the effect of price changes on the desired price of egg (R1). However, from the onset of simulation run, the balancing feedback loop revolving around changes in the unit price of poultry (B3) initiates the dominance but loses dominance to R1. The balancing feedback loop, B3, drives the dynamics in the backyard poultry production system with a 39.2% dominance level and rises to 64.7%. However, at the end of the entire simulation run (i.e., 52 weeks), B3 has a cumulative influence level (total loop score) of 12.22%. The dominance of the feedback loop (R1) commences after 6.5 weeks continues to the 9th week, and losses dominance to the balancing feedback loop revolving around the supply of egg (B2) on the market till the 22nd week when the feedback loop revolving around the changes in the unit price of egg and desired price (R1) regains dominance. The reinforcing feedback loop revolving around the changes in the unit price of egg (R1) also drives most changes in the model behaviour at the same period but losses dominance after the first year.

Considering the evolution of the dominance level for the feedback loops in loop set 1 (as shown in Fig. 9), results of the trend analysis suggest that the changes in the unit price of egg have higher influence on the changes in behaviour of the backyard production system than the changes in the unit price of live poultry. Indeed, there is ready market for eggs because demand for eggs exceeds supply (Bannor et al., 2021); therefore, egg sales are an important factor contributing to farmers' cashflow (Butler, 2016). Comparatively, the demand for locally produced poultry meat is seasonal due to the presence of cheaper imported chicken. Also, unlike poultry meat that is differentiated based on its origins or production system, the differentiation of eggs on the market is mostly based on the size. Hence, the same unit price of egg from commercially produced birds applies to the eggs from the backyard poultry system. The findings on the dominance of unit price of eggs corroborate with reports by Bannor et al. (2021) that under some contractual agreement between producers and wholesalers in commercial poultry production systems, the price of eggs is sometimes predetermined based on prevailing prices even before mature birds start

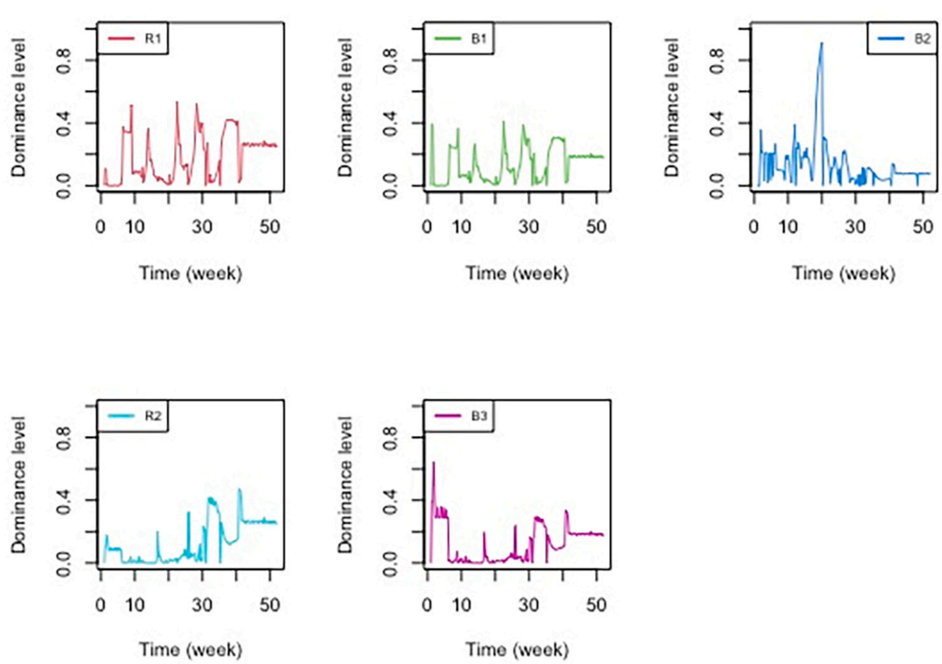

Fig. 9. Trend of the influence level for the dominant feedback loops in loop set 1.

Table 3
Loop score of dominant feedback loops in Loop sets 2+.

Loop	Shown	T = 52.00	Total 100%	Feedback loop
B1 1 stock 2 variables	B1	−31.44%	−32.62%	Production Module.Laying stock[GAP] → Production Module.Adult Layers[GAP] → Production Module.Laying stock[GAP]
B2 2 stocks 6 variables	B2	−46.51%	−25.91%	inflow(in macro) → Stock 1(in macro) → delayed input 1(in macro) → Production Module. Layers to be sold[GAP] → Production Module.Adult Layers[GAP] → input(in macro) → inflow(in macro)
B3 2 stocks 6 variables	B3	−3.58%	−14.10%	inflow(in macro) → Stock 1(in macro) → delayed input 1(in macro) → Production Module. Maturing Layers[GAP] → Production Module.Growers Layers[GAP] → input(in macro) → inflow(in macro)
B4 2 stocks 6 variables	B4	−10.87%	−6.54%	inflow(in macro) → Stock 1(in macro) → delayed input 1(in macro) → Production Module. Reserved breeders to be sold [GAP] → Production Module. Adult Layers[GAP] → input(in macro) → inflow(in macro)
B5 1 stock 2 variables	B5	0.00%	−5.80%	Production Module.Layers death[GAP] → Production Module.Adult Layers[GAP] → Production Module.Layers death[GAP]
B6 1 stock 2 variables	B6	−2.51%	−2.77%	Production Module.HG day old chicks Broilers[GAP] → Production Module. Homegrown day old chicks [GAP] → Production Module. HG day old chicks Broilers [GAP]
B7 1 stock 2 variables	B7	0.00%	−2.39%	Production Module.Hatching [GAP] → Production Module. Eggs[GAP] → Production Module.Hatching[GAP]
B8 1 stock 2 variables	B8	−2.58%	−2.35%	Production Module.Day old chicks death[GAP] → Production Module.Day old chicks Layers[GAP] → Production Module.Day old chicks death[GAP]
B9 1 stock 2 variables	B9	0.00%	−2.15%	Production Module.Growers death[GAP] → Production Module.Growers Layers[GAP] → Production Module. Growers death[GAP]

A → B means a change in A cause change in B.
R – reinforcing feedback loop.
B – balancing feedback loop.
+ the same loop scores are represented in Loop set 3 (for non-GAP adopting farmer households).

laying eggs. However, the demand for egg falls when there are relatively cheaper animal protein substitutes like fish are in season or abundance (Butler, 2016).

A summary of the cumulative influence level of the feedback loops in loop sets 2 and 3 is presented in Table 3. Generally, loop sets 2 and 3 have the same influence level, and they capture the drivers of change for GAP-adopting and non-GAP adopting households, respectively. Cumulatively, the balancing feedback loop revolving around the laying stock and adult meat/live sales stock has the highest dominance level (i.e., total loop score of 32.62%). The balancing feedback loop revolving around the delay in the sales of laying stock and delay in the time taken for the laying stock to mature have a loop score of 25.91% and 14.1%, respectively. A generative causal loop diagram of the dominant feedback loop is presented in Fig. 10.

The trend analysis for loop sets 2 is shown in Fig. 11. From the onset of the simulation, changes of the model behaviour are dominated by the balancing feedback loops revolving around the death of laying stock (B5) between the 1st and 2nd weeks. This dominance level declines drastically when the balancing feedback loops revolving around an increase in adult laying stock (B1) gains dominance at 98.60% between the 30th and 40th weeks. Thus, an increase in the number of laying stock producing eggs significantly changes the dynamics in the backyard production system. The next level of dominance is caused by the balancing feedback loop revolving around the delay in the sales of laying stock (B3) between the 6th and 7th week. The feedback loop concerning the delay in the number of laying stock maturing (B2) also drives changes in the production dynamics momentarily from the 7th to the 8th week, and its dominance resurfaces in towards the end of the simulation run. The generative causal loop diagram for loop set 2 is shown in Fig. 12.

The dominance of system behaviour by the feedback loop revolving around the home-grown broilers (B6) around the 30th week shows how proceeds from the early sales of matured birds produced for meat purposes can be instrumental in financing subsequent production activities. The dominance of the feedback loop revolving around the hatching of eggs resurfaces at the 30th week after the first sales of matured birds. The trend analysis of the dominant feedback loops in loop sets 2 and 3 highlight the potential risk that a farm household might encounter when it begins the poultry production with only growers. However, the early sales of matured birds produced for live sales or as meat and the adoption of homegrown hatcheries can help curtail the risk by ensuring production continuity. Therefore, there is a need for a potential research intervention pathway to determine the optimal mix of chicken (at different stages) that is required to start a backyard poultry farm. Results from such research intervention can inform farm households on ways to optimise their revenues from backyard poultry production.

In the literature, the cost of feed, low price of poultry meat and eggs, and high mortality rate ranked as key constraints for layer production (Anang et al., 2013; Yevu and Onumah, 2021). These factors are crucial farm management issues that impact profitability (Butler, 2016; Kusi et al., 2015). Results of this study affirms the conclusions drawn in the literature and show how these drivers evolve. For instance, at the onset of production, the epidemiological drivers are critical, and they can have devasting impact on the profitability of the poultry farm (Enahoro et al., 2021). Afterwards, managerial decisions on the number of matured laying stocks sold and the timing of sales, and the consequential effect on the number of laying stocks reserved to continue reproduction are important. Understanding these dominance cycle can provide vital information required by practitioners to support farmers to improve the backyard poultry production system.

3.2. Contribution of backyard poultry production to household livelihood

Results of the net income earned from the backyard poultry production in a calendar year (i.e., 52 weeks) were compared for the two farm household types: GAP-adopting (the counterfactual) and non-GAP-adopting. Usually, the female chick is preferred due to the reproductive potential to increase the number of birds, and the production of eggs for the farm household. Therefore, the baseline production strategy (strategy 1) considered in this study was a 100% purchase of female day-old chicks from external hatcheries. The effect of two other production strategies on the net income was examined – (i) 1:1 purchase of male and female day-old chicks (strategy 2), and (ii) 100% purchase of male day-old chicks (strategy 3).

Fig. 13 shows the net income levels for all three production strategies. Generally, non-GAP adopting farm households will earn more income than their counterparts who adopt GAP. Results indicate that GAP-adopting farm households will make a loss (GHS -2776.63 on average)

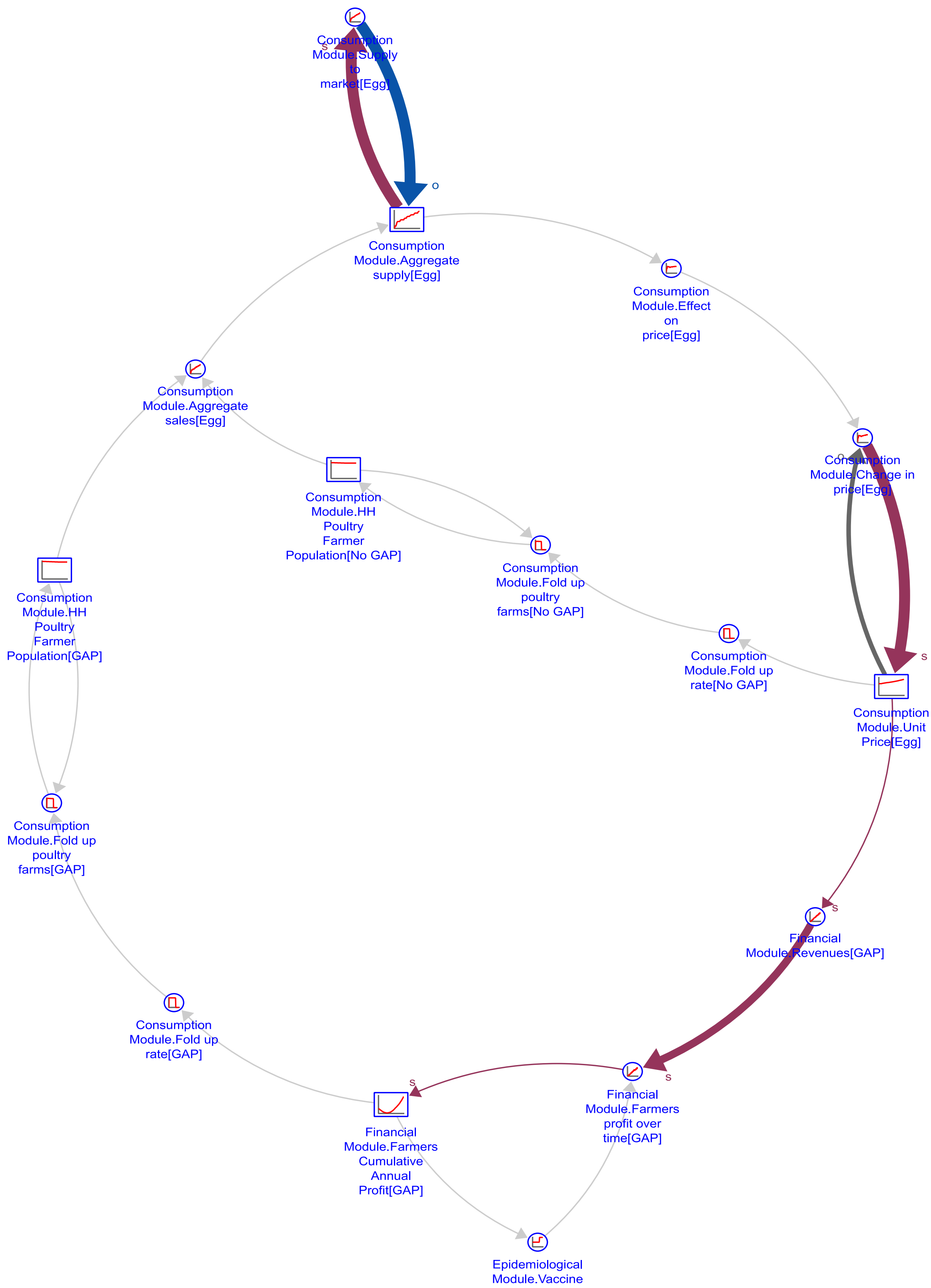

Fig. 10. The generative causal loop diagram for loop set 2.

throughout the year when only female day-old chicks are purchased. Comparatively, non-GAP adopting farm households will make an average loss of GHS -1482.50 but earn a maximum profit of GHS 2099.53 in only 6.75 weeks out of 52 weeks. For production strategy 1, non-GAP adopting farm households will break even after 45.5 weeks. When an equal proportion of male and female chicks are purchased (i.e., Production Strategy 2), GAP-adopting farmer households will make a profit GHS 11.30 on average, with a maximum profit of GHS 6026.36 in

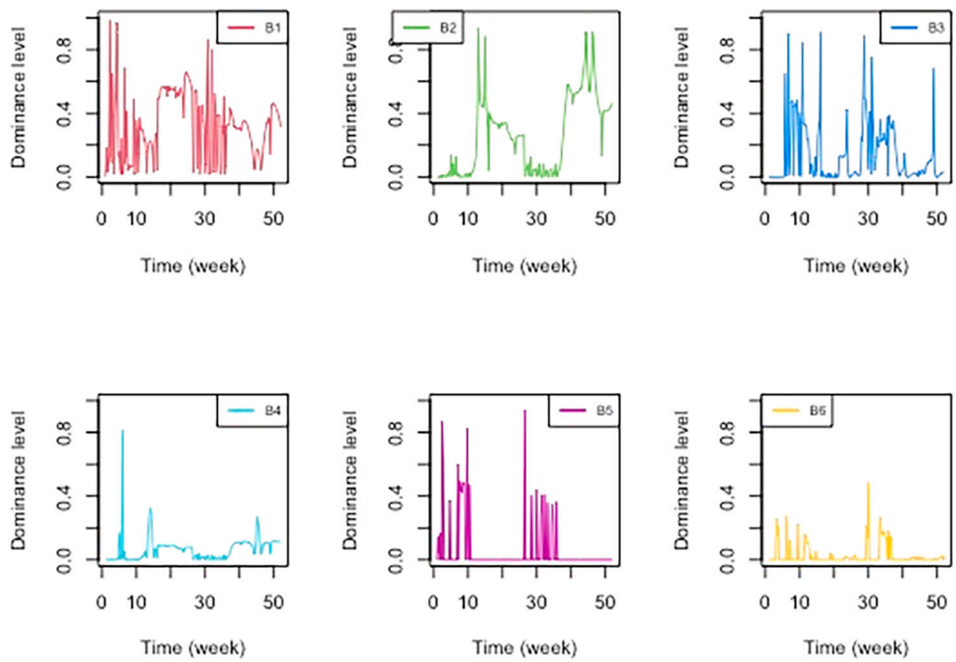

Fig. 11. Trend of the influence level for the dominant feedback loops in loop set 2.

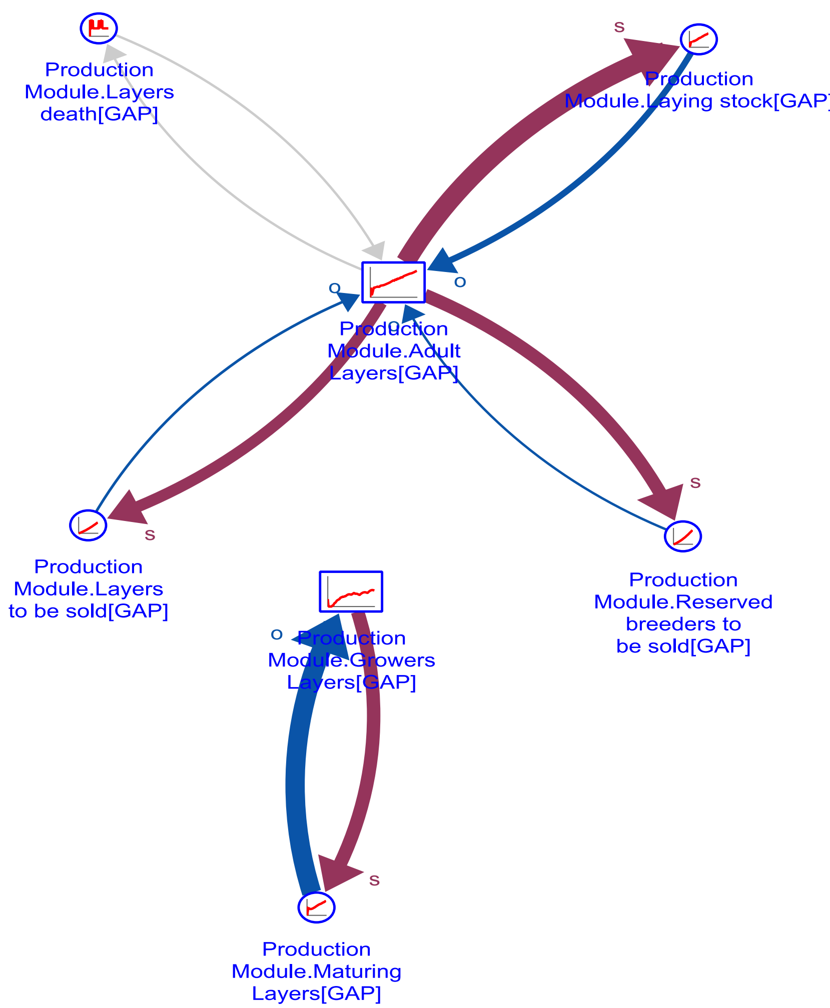

Fig. 12. The generative causal loop diagram for loop sets 2.

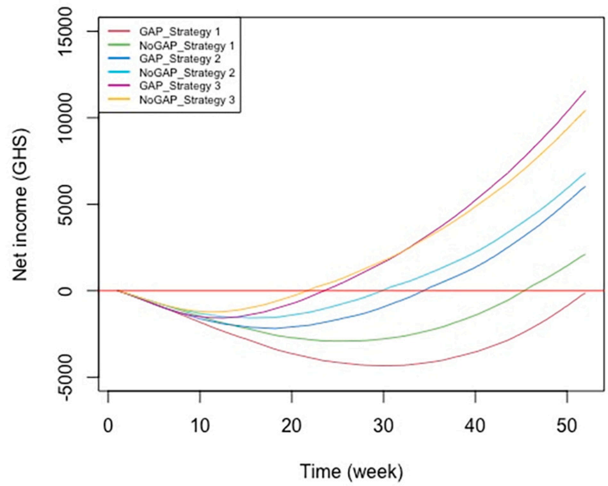

Fig. 13. Comparison of the net income for GAP and non-GAP adopting households.

Table 4
Net income within GAP-adopting farmer household for a production cycle.

	Profitability (GHS)		
	Strategy 1[#]	Strategy 2[+]	Strategy 3[*]
Mean (GHS)	−2776.34	11.33	2260.00
Max (GHS)	0	6026.36	11,1572.59
Min (GHS)	−4331.27	−2182.69	−1577.00
Periods in weeks (<0)	51.00	33.25	22.50
Periods in weeks (>0)	0.00	17.75	28.50
Periods in weeks (=0)	0.25	0.25	0.25

t-test: Paired two samples for means			
	Baseline vs Strategy1	Baseline vs Strategy 2	Strategy 1 vs Strategy 2
Hypothesized Mean Difference	0		
df	334.39	253.41	328.42
t Stat	−15.26	−17.703	−7.24
P-value	2.2e-16**	2.2e-16**	3.3e-12**
95% confidence interval	−3147.09 to −2428.23	−5596.77 to −4476.21	−2860.26 to −1637.404

1:0 ratio of layer to broiler day-old chicks purchased.
+ 0.5:0.5 ratio of layer to broiler day-old chicks purchased.
[*] 0:1 ratio of layer to broiler day-old chicks purchased.

17.75 weeks of the year. For production strategy 2, non-GAP adopting farm household will earn an average of GHS 669.25 with a maximum profit of 6799.16 for 22.25 weeks in the year. While GAP-adopting farm households will break even after 34.5 weeks, non-GAP-adopting farm households will break even after 30 weeks.

For production strategy 3, GAP-adopting farm household will earn an average of GHS 2260 (with a maximum profit of GHS 11,1572.59) for 28.5 weeks in a year, while non-GAP adopting farm household will earn an average of GHS 2216.17, with a maximum profit of GHS 10433.69 for 30.50 weeks in a year. Thus, although GAP-adopting farm households will have a relatively higher net income than non-GAP adopting farm households, the latter will earn profit in more periods than the former. For production strategy 3, GAP-adopting farm households will break even after 23.75 weeks while non-GAP adopting farm households will break even after 21.75 weeks.

Tables 4 and 5 present results on a within-group analysis for the two types of farm households considered in this study. The *t*-test was used to determine whether there was a significant difference in the net income

Table 5
Net income within Non-GAP-adopting farmer household for a production cycle.

	Profitability (GHS)		
	Strategy 1[#]	Strategy 2[+]	Strategy 3[*]
Mean	−1482.50	669.25	2216.17
Max	2099.53	6799.16	10,433.69
Min	−2912.96	−1575.54	−1224.98
Periods in weeks (<0)	44.25	28.75	20.50
Periods in weeks (>0)	6.75	22.25	30.50
Periods in weeks (=0)	0.25	0.25	0.25

t-test: Paired two samples for means			
	Strategy 1[#] vs Strategy 2[+]	Strategy 1[#] vs Strategy 3[*]	Strategy 2[+]vs Strategy 3[*]
Hypothesized Mean Difference	0		
df	320.97	264.03	362.63
t Stat	-11.411	-14.49	-5.35
P-value	2.2e-16**	2.2e-16***	1.58e-07**
95% confidence interval	−2522.72 to −1780.77	−4201.25 to – 3196.09	−2115 to −978.12

1:0 ratio of layer to broiler day-old chicks purchased.
+ 0.5:0.5 ratio of layer to broiler day-old chicks purchased.
[*] 0:1 ratio of layer to broiler day-old chicks purchased.

Table 6
Net income across farmer households for a production cycle.

t-test: Paired two samples for means			
	Strategy 1[#] (GAP vs No GAP)	Strategy 2[+] (GAP vs No GAP)	Strategy 3[*] (GAP vs No GAP)
Hypothesized Mean Difference	0		
df	407.84	407.03	402.21
t Stat	−9.81	−2.89	0.123
P-value	2.2e−16**	0.0039**	0.902
95% confidence interval	−1553 to −1034.66	−1104.29 to −211.54	−66.28 to 749.27

1:0 layer to broiler day-old chicks purchased.
+ 0.5:0.5 layer to broiler day-old chicks purchased.
[*] 0:1 layer to broiler day-old chicks purchased.

earned by each farm household for the three production strategies. Results in Tables 4 and 5 show that there are statistically significant (at *p*-value <0.05) differences in net income earned from the implementation of the different production strategy by both GAP-adopting and non-GAP-adopting farm households.

Production strategy 3 (focusing on live sales/meat production) is the most viable. A comparison of the density plots for the net income earned by the farm households for the three production strategies are presented in Appendix B.

Table 6 shows the results of the t-test for an across-farm household comparison. Results indicate that there is a statistically significant difference in the net income earned by both farm households for production strategies 1 and 2. However, there is no statistically significant difference in the net income earned by both farm households under production strategy 3 as shown by the density plot in Fig. 14.

Generally, production for live sales/ poultry meat and egg production are profitable despite the numerous challenges (Anang et al., 2013). Indeed, there is evidence of technical efficiency in Ghana's poultry industry (Etuah et al., 2020). However, there is a shift from meat production to egg production because of the high production cost in commercial poultry production systems (Etuah et al., 2020; Yevu and Onumah, 2021). Yet due to the relatively low production cost in backyard poultry production, this study's findings suggest that a focus on

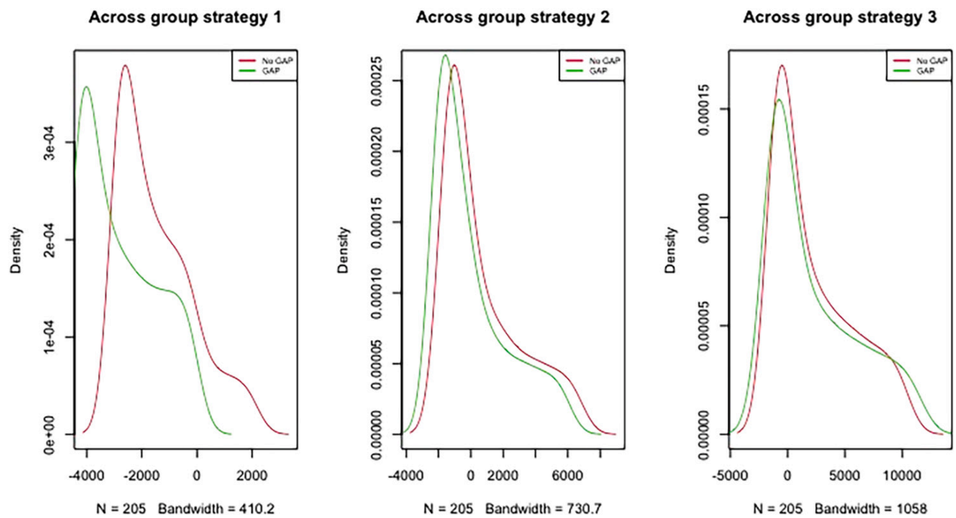

Fig. 14. A comparison of the density plot for the two households under strategy 3.

production oriented towards live bird sales including for meat is the most profitable production strategy. Therefore, given the preference for locally produced poultry meat (Asante-Addo and Weible, 2020), a reduction in the production cost could make meat production a lucrative venture.

Results provide insights into a possible rationale for the production decisions of the non-GAP-adopting farm households. Generally, non-GAP-adopting farm households have a relatively longer financial viability period than GAP-adopting farm households. The results show that GAP-adopting farm household earn higher revenues, yet they will accrue higher feeding and vaccination costs than non-GAP adopting farm households. Also, the underdeveloped system for differentiating live birds and eggs on the traditional market implies that the selling prices offered for chickens and eggs sold by both GAP-adopting and non-GAP adopting farm households are mildly differentiated. Differentiation is done by the size of an egg and the weight (size) of the live birds.

A general preference for locally produced poultry meat with a perception that no antibiotics and hormones are administered to the birds highlights the presence of a viable market (Asante-Addo and Weible, 2020). However, consumers' preference for no antibiotic usage presents the risk of losing the entire birds when there is an outbreak of diseases, as evidenced by the dominant feedback loops in this study. The adoption of biosecurity practices could serve as inexpensive yet effective preventive and mitigative measures against transmissible poultry diseases, that can be adopted by farm households engaged in the backyard poultry production systems (Enahoro et al., 2021). However, the peripheral nature of the economic returns from backyard poultry production in relation to the farm household's income, coupled with the time and other infrastructural (housing) investments required for their successful implementation are key reasons for low adoption of biosecurity measure in backyard poultry production system (Conan et al., 2012). Access to lower cost biosecurity measures as well as appropriate training in poultry husbandry will be required for such practices to become widespread.

4. Conclusion

This study sought to understand how the farm-level drivers of change for Ghana's backyard poultry production system evolve in a calendar year and examine how different production strategies contribute to farmer household income. The paper extends the literature on drivers of change in the farming system by stressing the need to assess how these drivers evolve. The application of the loops that matter analysis in system dynamics modelling provide a framework for analysing the evolution of drivers of change in farming systems.

Practically, the findings offer information relevant to improving the livelihood of farm households engaged in backyard poultry farming. The key findings indicate that from the onset of the poultry production, disease prevention at different growth stages of the chicken (especially for day-old chicks) via vaccination is a critical driver of change that has a high but short-lived dominance. Thus, there is a potential for total loss and discontinuation of production activities following disease outbreak events. As such, the adoption of GAP currently serves as a risk mitigation strategy against total loss, and not necessarily an income-boosting purpose in the backyard production system. However, given the peripheral nature of backyard poultry production, farm households appear to be willing to take the risk by not practicing good husbandry practices.

Beyond the grower stage, the changes in the unit price of eggs have a relatively higher and longer influence on production dynamics than changes in the unit price of poultry. This could be ascribed to the periodic boom and bust of demand for poultry meat especially during festive seasons due to the presence of cheaper imports, juxtaposed to the relatively continuous demand for eggs. Also, the dominance level of the delay in the maturation and sales of laying stock post-grower stage suggest the need for determining the optimal production strategy that provide a financial cushion for farm households.

Generally, farm households that do not practice good farm management practices (in terms of feeding and medication) earn a relatively higher net income than those that do because the unit cost of production is higher than the unit price for poultry meat. This explains the low adoption of good husbandry practices in backyard poultry production systems. Production focused on only egg is not a financially viable strategy for farm households that adopt the requisite farm management practices. A production strategy that targets the sales of lives birds or meat consumption offers a higher financial cushioning for all farm households than a strategy revolved around egg production, with a mid-year break-even point. However, this production strategy does not support an increase in the household consumption of eggs by chicken-owning households. Thus, it may not directly lead to an improvement in the backyard poultry farming system's contribution to the nutritional needs of the farm households. Since the phenomenon of low egg consumption has been attributed to certain traditional beliefs and practices among some people in Northern Ghana, and the perception that the dietary cholesterol in eggs increases the risk of cardiovascular diseases among adult egg consumers (Garti et al., 2020), there is a need for a nutrition advocacy campaign that can sensitize households in the rural areas of the potential benefits of egg consumption especially for children.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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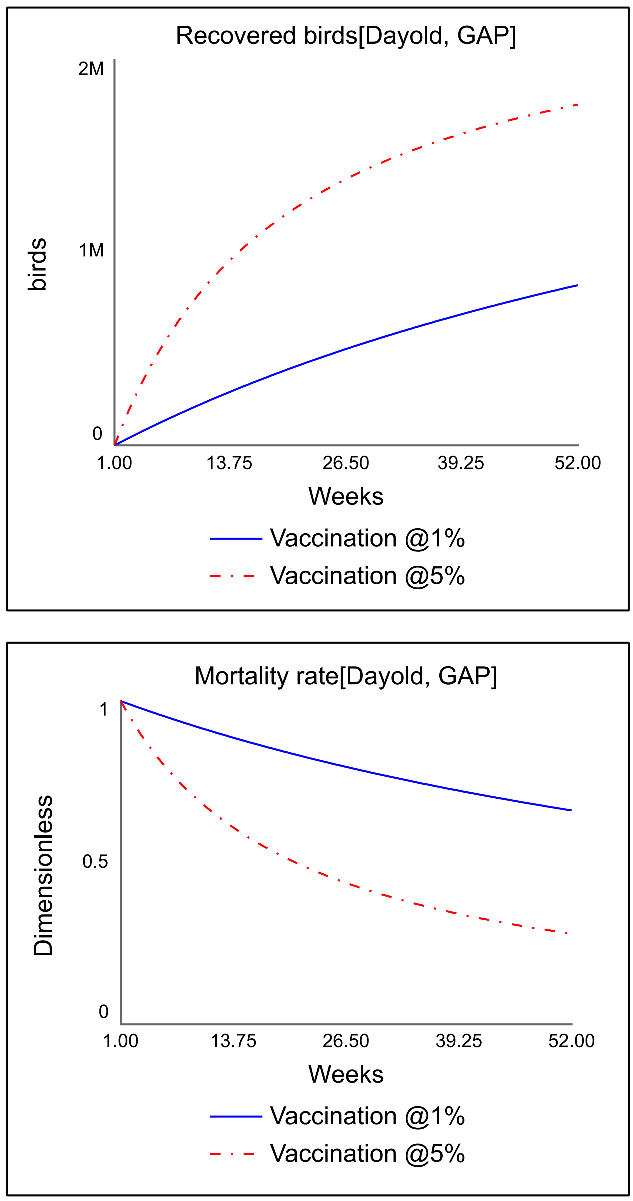
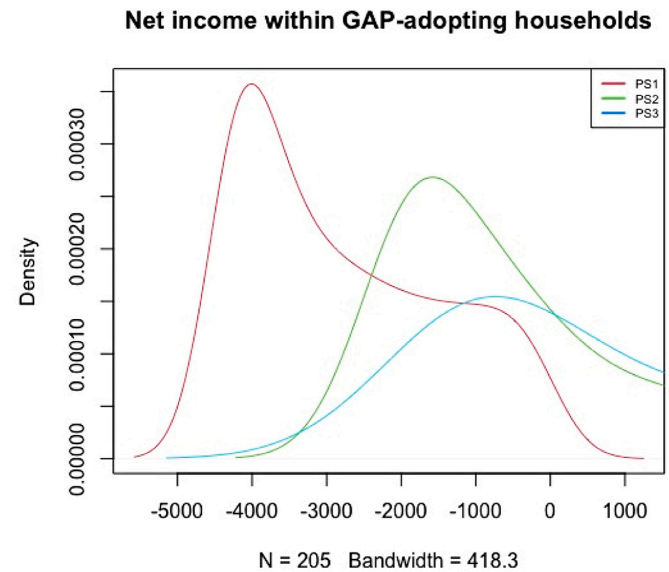
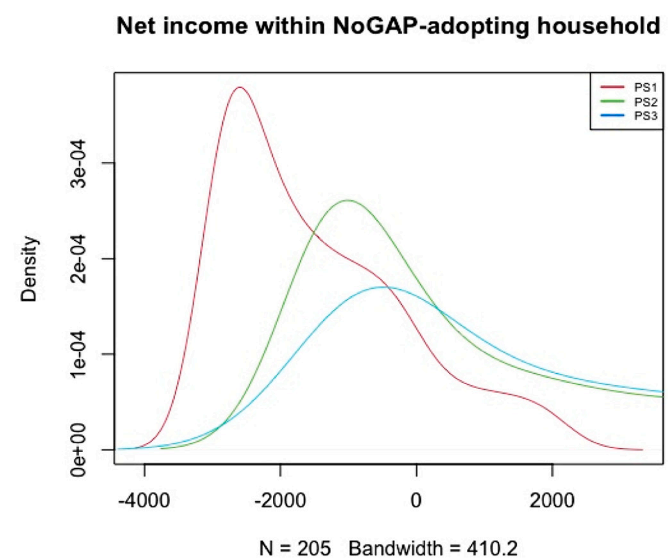
Appendix A



Results of the sensitivity analysis for the assumed vaccination rate.

Appendix B





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