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African swine fever control and market integration in Ugandan peri-urban smallholder pig value chains: An ex-ante impact assessment of interventions and their interaction

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ABSTRACT

Pig production in peri-urban smallholder value chains in Uganda is severely constrained by impact of disease, particularly African swine fever (ASF), and the economic consequences of an inefficient pig value chain. Interventions in the form of biosecurity to control ASF disease outbreaks and pig business hub models to better link smallholder farmers to pig markets have the potential to address the constraints. However, there is a dearth of evidence of the effects of the interventions on performance and distribution of outcomes along the pig value chain. An ex-ante impact assessment utilising System Dynamics model was used to assess the impact of the interventions in peri-urban pig value chains in Masaka district. The results showed that although implementation of biosecurity interventions results in reduction of ASF outbreaks, it also leads to a 6.3% reduction in farmer profit margins per year but more than 7% increase in other value chain actors' margins. The pig business hub intervention alone results in positive margins for all value chain actors but minimal reduction in ASF outbreaks. When biosecurity and the pig business hub interventions are implemented together, the interaction effects of the interventions result in positive outcomes for both the control of ASF and improvement in farmers' margins. Farmers may therefore be unwilling to adopt biosecurity practices if implemented alone to control ASF outbreaks unless there is a corresponding financial incentive to compensate for the high costs. This has implications for policy or developing institutions to facilitate cost sharing arrangement among chain actors and/or third party subsidy to provide incentives for producers to adopt biosecurity measures.

1. Introduction

Pig production in Uganda is largely an activity of smallholder farmers. Eighty percent of pig farmers are smallholders, each holding an inventory of 1–5 pigs at any given time (Ouma et al., 2015). Opportunities to expand production are severely constrained by two factors, namely the impact of disease, particularly African swine fever (ASF), and the economic consequences of an inefficient pig value chain arising, in part, through lack of market power for producers. The situation is further complicated by factors such as poor husbandry practices and lack of knowledge of disease control measures (Dione et al., 2014). It is possible to design in-principle interventions to address such challenges. However, such efforts too often ignore the fact that the interactions between interventions and factors are likely to be critical; unanticipated interactions may negate or reinforce the effects of an intervention. The anticipated benefits of a disease control strategy, for example, may be negated if the responsible actors, mainly the smallholder farmers, cannot cover costs of adoption because of the structure of the market.

ASF is a highly contagious haemorrhagic disease of pigs caused by a DNA virus of the *Asfarviridae* family and is easily spread over broad geographical areas through the movement of infected pigs or contaminated pork and pork products. Mortality rate as perceived by smallholder farmers in Uganda is currently 20.8% (Dione et al., 2014) and can be as high as 100% in a naïve pig population. There is currently no curative treatment or effective vaccine for the disease. Biosecurity is the main option for prevention and control of outbreaks. ASF biosecurity protocols have been developed by the FAO (2010) and

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implemented in a number of countries such as Nigeria, with reported success in the control of outbreaks in production systems (Fasina et al., 2011). Barongo et al. (2016) show that enhancing biosecurity measures on farms within a fortnight of an ASF outbreak can significantly reduce the likelihood of the disease in a herd by as much as 74%. However, most biosecurity measures are not implemented in most smallholder pig farms and other nodes of the pig value chain in Uganda (Nantima et al., 2015a; Dione et al., 2015). The widespread occurrence of ASF outbreaks shows gaps in control measures (Atuhairwe et al., 2013). The situation is different for more commercial oriented medium and large-holder pig farmers that generally invest in biosecurity measures to minimise disease outbreak occurrences.

Since most pig production in Uganda is an activity of poor smallholder farmers, responsibility for implementing disease control measures at farm level will largely rest with them. However, it is typical of smallholder pig farmers in Uganda, as in much of East Africa, that they mostly lack voice and bargaining power as they individually sell their pigs to middlemen. Transactions are based on visual estimates of weight, done by the traders. This often results in low price offers even in the absence of disease outbreaks. The price offers are further depressed during ASF outbreaks due to panic sales as reported by Ouma et al. (2017) and Dione et al. (2016). Previous studies focussing on the dairy value chain in East Africa have tested business hub models, a series of linkages of farmer collectives with dedicated input and output markets, and found them effective in improving smallholder dairy farmers' incomes (Rao et al., 2016). Their application to the pig value chain in East Africa is yet to be evaluated.

Specifically, in the case of disease control, interventions in the form of biosecurity interventions to control ASF disease outbreaks and pig business hub models to better link smallholder farmers to pig markets have the potential to resolve a number of constraints. However, there is a dearth of evidence of the effects of such interventions on performance and distribution of outcomes in the pig value chain and on the way in which individual interventions might interact.

Most ex-ante assessment methodologies lack capability of capturing such interactive effects and quantifying their distributional impacts along value chain nodes. The System Dynamics model overcomes this constraint as it is able to capture interactions, feedback, and causality within value chain components (Sterman, 2000). System Dynamics has been applied in ex-ante and ex-post impact assessments in various agricultural and agribusiness sectors, for example, Rich et al. (2011), McRoberts et al. (2013), Hamza et al. (2014), Naziri et al. (2015), and Dizyee et al. (2017). We conducted an ex-ante impact assessment utilizing a System Dynamics model to assess the interacting effects and distributional impacts of biosecurity interventions to control ASF disease outbreaks and pig business hub models in Masaka peri-urban smallholder pig value chains. Such an assessment will enable evidence-based decision making on initiatives likely to be effective in ASF control and profitable for the smallholder pig farmers and value chain actors.

2. Description of the peri-urban pig value chain

The study analyses the peri-urban smallholder pig value chains of Masaka district based on typical production and marketing parameters agreed through consultation with local farmers and traders. Masaka district has the highest pig population density in Uganda with more than 50 heads of pigs per km^2 (Uganda Bureau of Statistics, 2009). Most of the pork consumption occurs in peri-urban Masaka. Demand for pork is reported to be highest during Christmas and Easter holidays. Pig trading in peri-urban Masaka is significant, with smallholder farmers selling pigs for slaughter to a variety of intermediaries (live pig traders, collectors, and butchers) through uncoordinated spot-market transactions, based on oral agreements. Pig trading involves collection of pigs from individual pig farmers and bulking for sale or slaughter.

Most of the farmers, about 68% are smallholders having 1–3 sows or 1–4 growers. They sell on average 1–2 growers at a time when in need of finance to local intermediaries working within larger traders' business networks (tables A.1 and A.2). The live pig traders and butchers within Masaka town dominate the trading node and each handles about 20–30 pigs per day. The traders are largely vertically integrated, performing several functions in the value chain under single ownership (Ouma et al., 2017). They are involved in the retail nodes of the value chain, operating pork butcheries and pork joints while also carrying out pig slaughter functions (table A.3).[1] The main pork trading town is Saza in Masaka Municipality and has the highest number of pork joints in Greater Masaka region. Pig supplies are from within the peri-urban as well as neighbouring rural locations. During periods of ASF outbreaks pigs are scarce and transaction costs increase as supplies are obtained from neighbouring districts.

3. Material and methods

3.1. Data sources

3.1.1. Pig value chain assessments

Pig value chain assessment surveys were conducted in Masaka district in 2012–2013 covering all value chain actors; pig farmers, pig traders, collectors, butchers, retailers, and consumers. A random sample of 150 pig value chain actors were covered. The samples were drawn from lists of each value chain actor category prepared by local council authorities from 7 sub-counties in Masaka district. Survey tools were developed to capture information on characteristics of the actors, in particular variable costs, prices of pigs and pork and margins to different value chain actors, quantities of inputs and intermediate inputs purchased, cost, origin, supplier types, transaction characteristics, value addition, geographic destination of the pigs and pork products, and types of buyers.

The surveys were conducted by staff of the International Livestock Research Institute (ILRI) in collaboration with the Masaka district local government. The survey instruments were administered by qualified and trained enumerators using in-person questionnaire interviews. Qualitative focus group discussion data from 600 randomly selected pig farmers were also used to complement the producer level data. Results from these assessments were used to parameterise the System Dynamics model. Literature review on pig biosecurity interventions applied in Uganda (Barongo et al., 2016) and elsewhere in sub-Saharan Africa (Fasina et al., 2011) were also used in model parameterisation.

3.1.2. Group model building

A participatory group model building (GMB) approach following Vennix (Vennix, 1996) was applied to design a qualitative peri-urban pig value chain model. Such model building is an effective approach to involve stakeholders from diverse disciplinary backgrounds in the modelling process to reach consensus and increase stakeholders' commitment to the outcome of GMB (Vennix, 1996; Andersen and Richardson, 1997). Twelve experts from different disciplines in the pig value chain, comprising economists, gender researchers, mathematicians and epidemiologists participated in the GMB. The participants had detailed knowledge of the study region through their direct engagement with local communities.

3.2. The model structure

System dynamics (SD) is a methodology that studies the dynamic interactions and feedback effects among a set of variables that comprise a system (Sterman, 2000). The model structure applied in the study relies on concepts from Sterman (2000), and the general value chain structure is based on Kaplinsky and Morris (2001) and Ouma et al.

[1] Pork joints are common pork eateries in Uganda serving roasted or fried pork. Many people socialise and watch football matches in such joints.

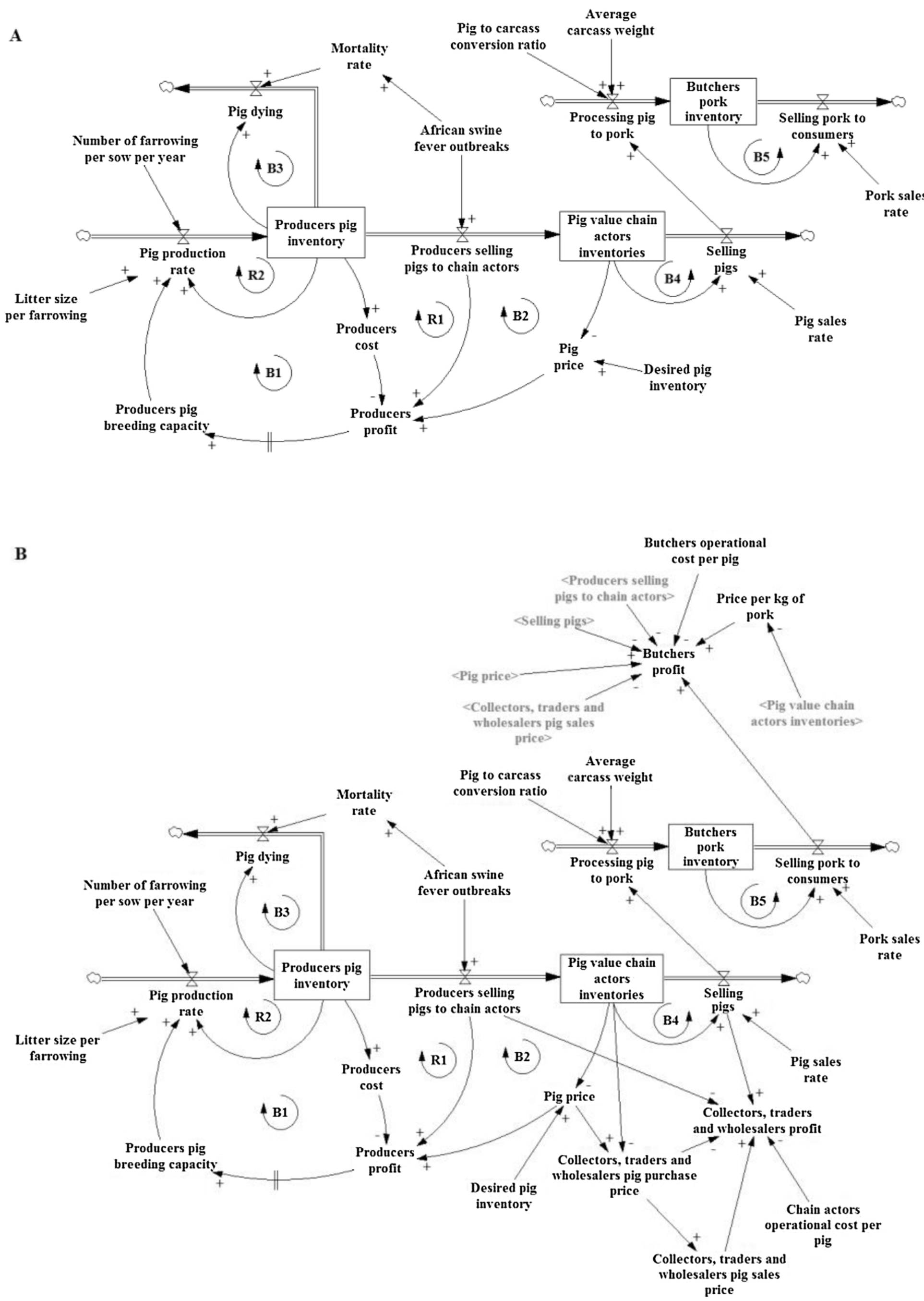

Fig. 1. A-Portrayal of pig value chain model structure; B- chain actors profit model structure.

(2015). The model includes two main sectors: pig production and trading. The System Dynamics model is portrayed in Fig. 1A. The main feedback loops and stocks in the system are highlighted. The central concepts of SD are stocks, flows and feedback loops. Stocks are accumulation of goods, services, or information (e.g. pig population in a farm). Flows change over time (e.g. number of pigs born or sold over time). Feedback loops are circular connections that govern flows (Sterman 2000). We used iThink/Stella software[2] to construct the quantitative value chain model and Vensim to construct the stock and flow diagram in Fig. 1.

Each stock (rectangular shape boxes) in Fig. 1A represents value chain actors' inventories of pig or pork. The thick arrows that connect one stock to another are flows. Flows facilitate movement of pigs from producers to value chain actors (and among chain actors) and pork to consumers over time. Flow of producers selling pigs to value chain actors represents number of pigs producers sell to different chain actors over time; flow of pig production rate represents number of new born piglets over time; flow of selling pig represents number of pigs value chain actors sell over time; and flow of selling pork to consumers represent volume of pork sold to consumers over time. The thin arrows that connect different model elements together are connectors. These connectors facilitate information flow among model sectors. Connectors are used to construct feedback loops and causal relationships among model elements.

Feedback loops regulate flows through causal relations among model elements. The label R and B denote a self-reinforcing (or positive) and a self-balancing (or negative) feedback loop, respectively. In a reinforcing feedback loop, the larger population leads to more births,

[2] iThink/Stella software is provided by isee systems https://www.iseesystems.com/ Vensim is provided by Ventana systems http://vensim.com/

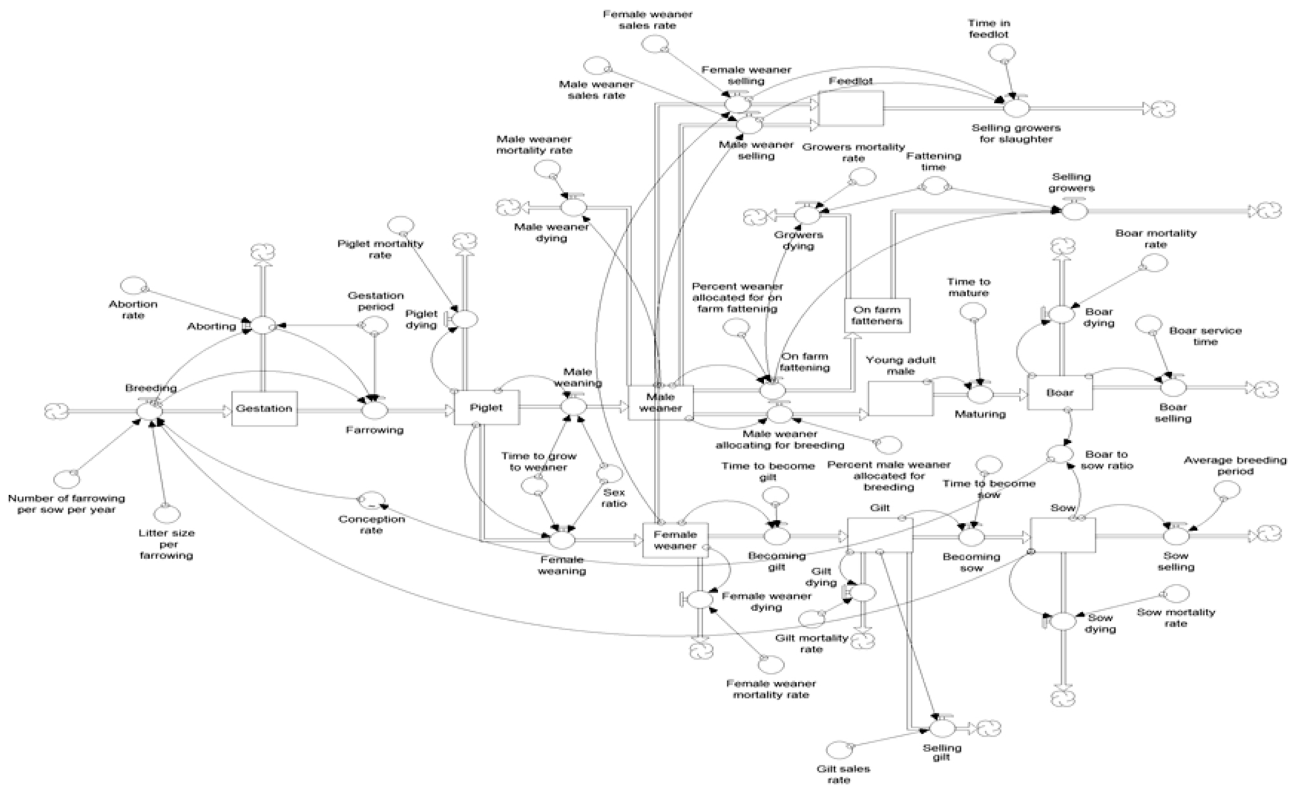

Fig. 2. Pig production sector for peri-urban value chain in Masaka district (adapted from Sterman (2000).

which in turn results in higher population. In contrast, in a balancing feedback loop, higher population leads to higher deaths than what it would normally be, which in turn limits population growth (Sterman, 2000). The sign (//) denotes delays in the system. In Fig. 1A, the pig production and marketing chains are governed by multiple feedback loops, including the following:

Reinforcing loop 1 (R1) governs the investment in producers pig breeding capacity. An increase in producers profit motivates investment in pig breeding capacity (i.e. retaining more female weaners and gilts for breeding purpose to increase pig breeding and supply in the subsequent periods, and vice versa), which in turn, after some time lag, increases pig production. Higher pig production leads to more pig sales to value chain actors which further increase producers' profit. This leads to more investment in producers' pig breeding capacity. This is a reinforcing feedback loop because the system reinforces itself.

R2 governs sows breeding rate. The higher the number of breeding sows leads to higher pig production rate. This leads to further increase, albeit after some time lag – biological delay, breeding sow population.

Balancing loop 1 (B1) balances producers pig breeding capacity. Higher pig population at producers' inventories increases total production cost, which in turn lowers producers' profit. This in turn discourages investment in producers breeding pig capacity (i.e. producers sell more female weaners and gilts as means to reduce breeding and pig production in the subsequent periods), which limits pig production rate, which in turn lowers producers production cost in the subsequent periods. This is a balancing loop because the system self-corrects itself.

B2 provides market signals about pig inventory and desired inventory ratio. When there is more supply of pigs to the market, pig inventory increases which leads to lowering pig price. Lower pig price reduces producers' profit and investment in producers breeding pig capacity. This in turn leads to lower pig production and pig supply to the market, which lowers pig inventory in the subsequent periods. This feedback loop is particularly dominant during ASF outbreaks because producers oversupply market with pigs which markedly depress pig prices. In our model, ASF is a key driver of changes in price, an ASF outbreak changes producers selling behaviour (panic sale) which reduces pig price and depletes producers pig inventory. Shortly after an ASF outbreak pig price begins to increase due to limited pig supply to the market as producers replenish their breeding stock and biological time lag to produce pigs and commence supplying the market.

B3 regulates the outflow of deaths from producers' pig inventories. Higher pig population in producers' inventories increases number of pig deaths over time (i.e. in absolute terms). That is, given a constant background (i.e. not ASF-related) mortality rate, the number of deaths changes in proportion to the population ('inventory'). In a similar way, B4 and B5 regulate the outflow of selling pigs and selling pork to consumers, respectively.

Fig. 1–B shows aggregated model structure of modelling profit for other value chain actors (collectors, traders, wholesalers, and butchers). We present a simple portrait of the model structure of value chain actors profit to keep the presentation of Fig. 1 simple. Variable *pig price* represents producers pig price which is the same as collectors pig purchase price (and other chain actors who buy directly a portion of their pig supply from producers). In a similar vein, traders pig purchase price (e.g., the portion of traders pig supply sourced from collectors) is equal to collectors pig purchase price (i.e. producers *pig price*) plus collectors operational cost per pig and profit margin. We applied the same approach for pig purchase and sales price for other chain actors. However, we did not present the detailed model structure to avoid an overly complex presentation of Fig. 1B.

3.2.1. Pig production sector

The production sector was constructed based on the livestock model in Sterman (2000). Based on the GMB exercise, the sector was further disaggregated to differentiate the pig population based on age and sex. Further details on the separate fattening process of growers was also included.[3] The disaggregated pig production sector is presented in

[3] Production process that involves purchase of weaners for fattening and sale for slaughter

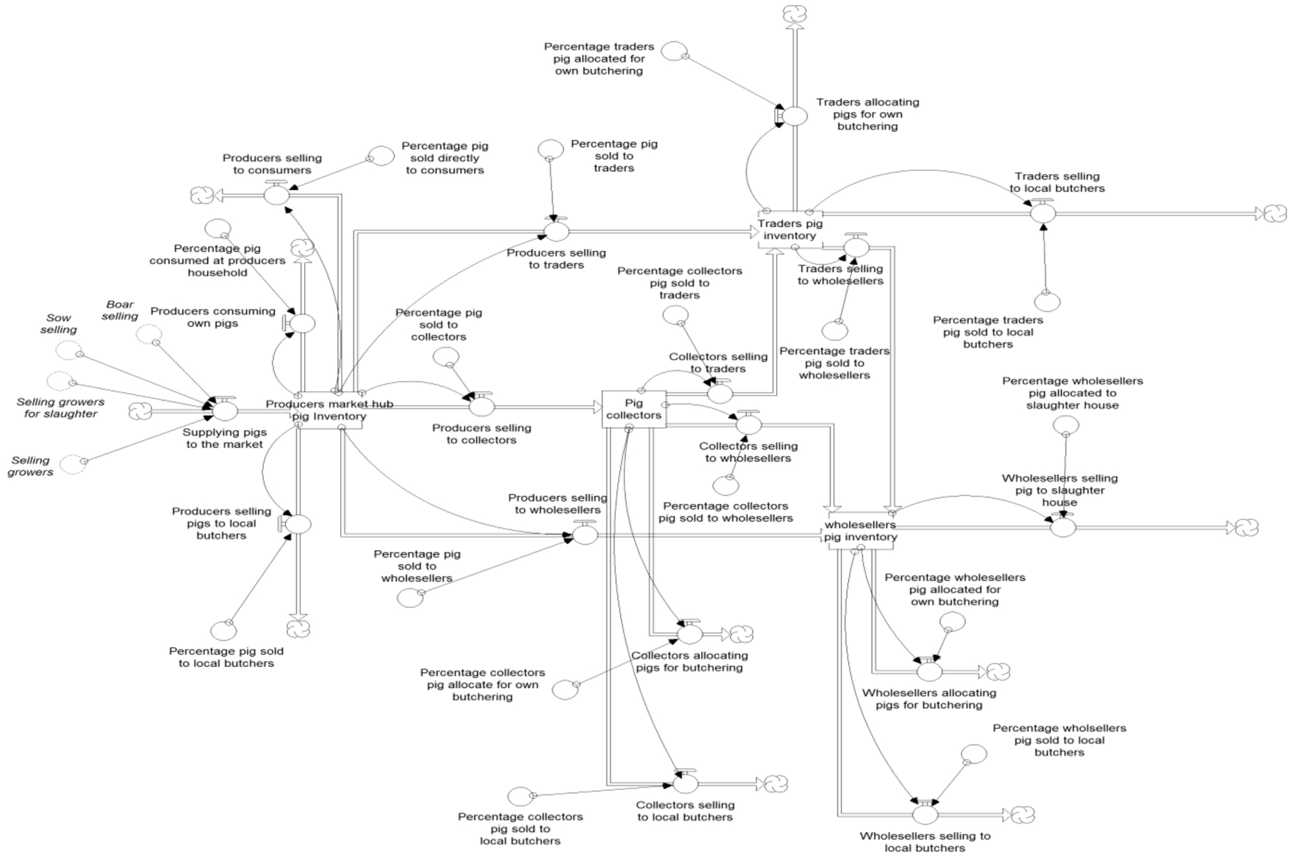

Fig. 3. Live pig value chain.

Fig. 2. The GMB process enabled identification of chain actors (collectors, traders, wholesalers, local butchers, processors, centralized pig slaughter house, and other urban butchers) involved in live pig and pork value chains.

3.2.2. *Pig trading sector*

The trading channels among identified chain actors were mapped and quantified. Fig. 3 shows live pig value chain and trading channels beyond the farm gate. Some chain actors, at local rural market level, such as producers, collectors, traders, and wholesalers trade both live pig and pork. That is, they sell a percent of their pig inventory as live pig to other chain actors, butcher a portion of their inventory to sell as pork, and trade the remaining pigs to local butchers for processing at local rural butcheries. Pig slaughter at local actor level (rural markets) is basic. Pigs are slaughtered and sold with limited product differentiation. The premium price for pork without back fat is 20% higher than with fat. Aside from that, the value of all pork cuts is the same. The scenario is different in Kampala market where product differentiation is evident in some of the urban butcheries and supermarkets that sell differentiated pork cuts including processed products. Product differentiation in Kampala market is beyond the scope of our study.

A model structure to transform live pigs to meat in the peri-urban markets is presented in Fig. 4. The chain actors such as local butchers in peri-urban areas process carcass to bone-in and deboned pork and by-products. There is only one regulated pig slaughterhouse for pigs in Uganda, located in Kampala city. The slaughter house differentiates carcass to different meat cuts and by-products. Almost all of slaughter house outputs go to modern urban butchers (in Kampala region) where different meat cuts are priced differently.

3.2.3. *African swine fever model*

We modelled ASF to be introduced randomly into the model once a year (assumed based on past outbreaks). Once ASF outbreak occurs, both mortality increases and producers panic sales behaviour occurs over a period of one month which leads to a substantial reduction in producers pig inventory. Panic sales behaviour is producers risk mitigation strategy to reduce the likelihood of pigs dying in their farm or getting culled by veterinary authorities. A month after the outbreak, we assume the outbreak is over and producers begin replenishing their pig stock in which each household recommence pig production by purchasing a sow. Replenishing pig inventory occurs over a month of time after ASF outbreak is over.

The investment in biosecurity occurs in week 104 to the end of the simulation. Biosecurity control reduces the likelihood of ASF outbreaks rather than reducing mortality directly. In different words, if ASF outbreak occurs, there is no treatment to cure infected pigs to control the outbreak or reduce mortality or control producers panic sale behaviour. The recommended best practice to control the disease once an outbreak occurs is culling – by slaughtering and burying – all pigs in the affected farms once the district veterinary authorities impose a quarantine. The producers therefore take advantage of the time lag between detecting an ASF outbreak and quarantine notice by district veterinary authorities to sell off their pigs (panic sales) or slaughter to sell the meat or consume at home.

3.3. *Model simulation scenarios*

The constructed value chain model was used to run four scenarios through simulations over a 15 year and 30 year period to predict changes in pig mortalities and gross margins accruing to pig farmers and other value chain actors as a result of the ASF and pig business hub interventions relative to the current baseline situation. The details of the four scenarios are as follows:

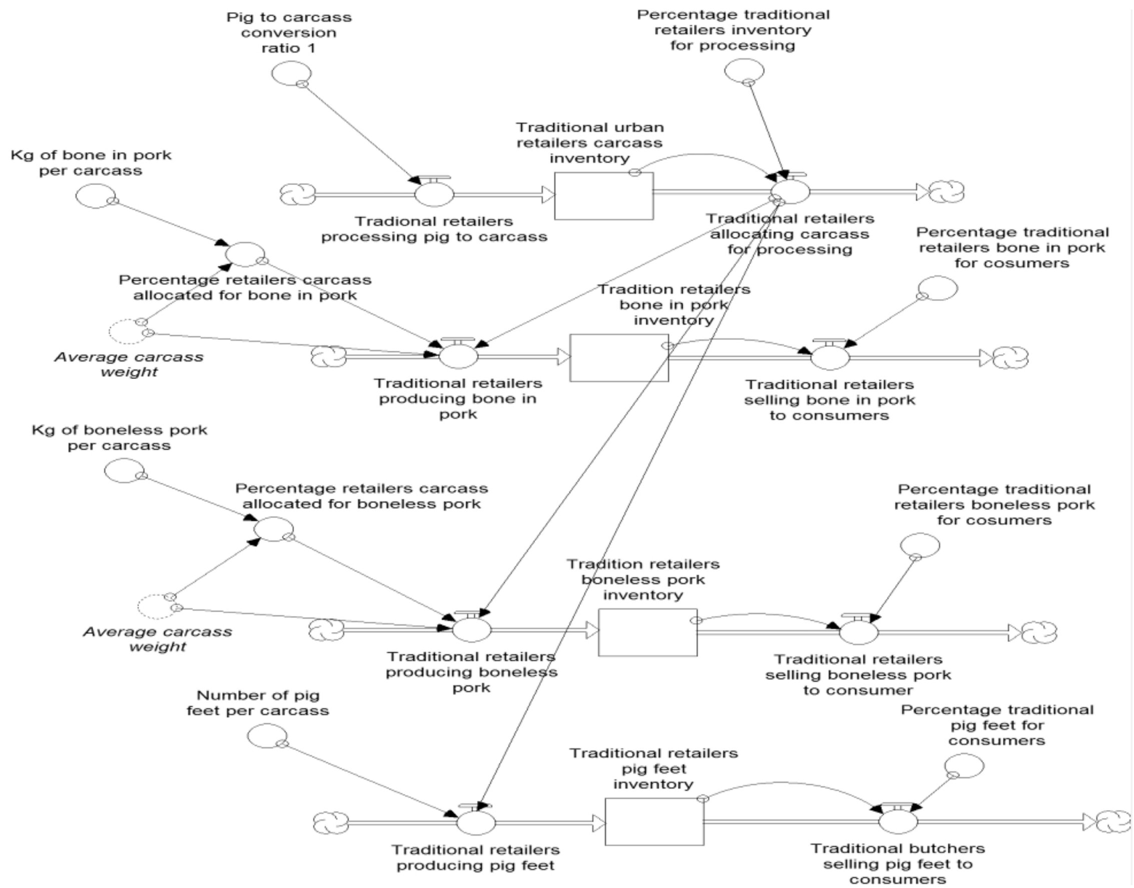

Fig. 4. Pig processing model for butchers in peri-urban market.

3.3.1. Baseline scenario

The baseline scenario presents the status quo of peri-urban pig value chains in Masaka district. In the baseline scenario, the model is parameterised based on data from the pig value chain assessment survey. The results of the baseline scenario is used as a benchmark to compare alternative scenarios. Tables 1A, 1B and 2 show the parameters, per cent product flow through different channels, and initial values used in the production and trading sectors, respectively.

Table 1A
Pig value chain baseline parameters.

Parameter	Benchmarking survey figures (2011–2012)	Time unit
Time to grow to become weaner	8	Weeks
Fattening time (time to mature to become grower)	26	Weeks
Average carcass weight	55	Kg of pork/carcass
Grower mortality rate	0.02	1/week
Male weaners sales rate	0.79	1/week
Percent of weaners allocated for fattening on-farm	0.10	1/week
Average breeding period	104	Week
Gestation period	15.5	Week
Abortion rate	0.05	1/week
Litter size per farrowing	8	Piglets/farrowing
Number of farrowing per sow per year	2	Farrowing/pig/year

3.3.2. Implementation of ASF biosecurity interventions in the production sector to control ASF outbreaks

In this scenario, we look at the effect of implementation of biosecurity interventions in the production sector to control ASF outbreaks. The target is to reduce mortality rates due to ASF from the current 20.8% to zero (Dione et al., 2014). The effects of ASF in the value chain are introduced through increased mortality, home slaughter and panic selling. The biosecurity practices are in line with FAO (2010) recommendations and have been adapted for smallholder piggery settings in Uganda (Nantima et al., 2015b). These include:

(a) Erection of fence and gate, control and monitoring of physical barrier, enforcement of change of footwear and clothing, and restricting the entry of vehicles or dipping of tyres in case of necessary entrance
(b) Daily sweeping, routine washing of the pen with copious amount of water, thorough washing with soap, water and brush to ensure that no visible dirt is seen on the surface of building and materials, dry cleaning of all material that are not water resistant.
(c) Usage of appropriate disinfectant to sanitize washed and dry-cleaned materials.
(d) Reporting to the veterinary office in case of disease outbreak
(e) Quarantine and prompt disposal of dead animals
(f) Regular deworming of pigs
(g) Boiling of swill before feeding to pigs

The cost of the biosecurity practices is estimated at Uganda Shillings 2625 per grower (pig ready for slaughter with a weight of about 30Kg carcass weight) per week. The biosecurity estimates are provided in Table 3A With improved biosecurity implementation, the pigs have better body condition and farmers are able to bargain for about 5%

Table 1B
Per cent product flow through various chain actors.

Chain actors	Producers	Collectors	Traders	Wholesalers	Butchers**	Slaughter house****
Producers		30%	5%	3%	62%	
Collectors**			20%	70%	10%	
Traders				30%	70%	
Wholesalers					40%	60%
Butchers***						

* This includes all pigs allocated for butchering – i.e. butchered by various actors or sold to local butchers.
** This table indicates that collectors trade 20%, 70% and 10% of their product to traders, wholesalers and butchers, respectively.
*** Butchers trade all their products and by-products to final consumers.
**** Only wholesalers trade pigs to slaughterhouse in Kampala (beyond the scope of this study).

Table 2
Initial price and cost used in model runs.

Parameter	Producers	Collectors	Traders	Wholesalers	Butchers
Average price per pig	158164	160360	189900	291180	195000
Average cost per pig	116717	41468	20215	65597	90000

higher price.

3.3.3. *Implementation of the pig business hub model to enhance linkages to input and output markets for better pig incomes*

The pig business hub model links pig producer collectives to dedicated input suppliers and output markets. This scenario assesses the effect of the pig business hub model on ASF control and pig incomes. The pigs are marketed collectively and collected by traders from pig collection centres. This has an effect of minimising ASF outbreaks and spread as traders are not allowed to collect pigs on-farm. The farmers are also able to negotiate with input suppliers and pig traders for better input and pig prices due to bulk sales and purchases. At baseline, the average producer price per grower is about 150,000 Uganda Shillings. With the pig business hub the farmers are able to bargain for a 24% higher price. The cost parameters associated with the pig business hub model include land rate payment to the municipal council associated with the pig collection centre, ante-mortem pig inspection fees and pig loading into transport equipment. The cost is estimated at 68,540 Uganda Shillings per week. The detailed cost breakdown are provided in Table 3B.

3.3.4. *Implementation of ASF biosecurity and pig business hub model*

In this scenario, we look at the effects of implementing both biosecurity interventions to control ASF and the pig business hub model to better link pig producer collectives to input suppliers and pig markets. With combined biosecurity and the pig business hub, farmers are able to bargain for 30% higher pig price.

3.3.5. *Sensitivity analysis*

Sensitivity analyses of the model results have been conducted in order to assess sensitivity of the estimates to +/− 10% change in higher price bargains associated with the interventions and +/− 10% change in the cost of the interventions. A uniform distribution has been used to conduct 100-runs per scenario for 15 and 30 years simulation. Results of the sensitivity analysis are provided as supplementary data.

4. Results

The analysis compared three intervention strategies with the *status quo*: application of ASF biosecurity measures, modification of the pig supply chain through development of business hubs and a combination of both interventions. The results of the scenarios analysed are presented in Figs. 5 and 6 and Tables 4–6. In all the figures, trend 1 represents the baseline scenario, trend 2 represents the ASF biosecurity scenario, and trend 3 represents the pig business hub scenario, while trend 4 represents the combination of ASF biosecurity and pig business hub scenarios.

Fig. 5 shows pig population in the peri-urban value chain under different scenarios. In scenario 1 (baseline) the population of pigs fluctuates greatly, due to disease outbreaks. After ASF outbreaks there is a time lag in supply as farmers restock pigs to rebuild their breeding stock inventory. In all three intervention scenarios, pig population increases. In scenario 2 (biosecurity implementation) pig population

Table 3A
Costs of biosecurity items (unit of 5 pig growers per year).

Item	Unit cost (Ug Shs)	Total cost per annum (Ug Shs)
Complete fencing of the piggery including installation of a gate for controlled access	288,000 for 15 years	19,200
Construction of a foot bath	35,500 for 5 years	7100
Isolation pen for incoming pigs	402,000 for 20 years	20,100
Labor for burying pigs – assuming a mortality rate 20.8% (Dione et al., 2014), and a herd size of 5 pigs (Ouma et al., 2015), then 1 pig is buried.	5000 per pig	5000
Boots and farm clothes (assumption is that the enterprise is managed by family labor – comprising 3 members (husband, wife child)	90,000 per year	90,000
Cost of farm disinfectant per annum – at the rate of 5Lts per month	2.4 Lts of disinfectant per year @Ug Sh 19300 per Lt	46,320
Water for diluting disinfectant	24 Lts @Ug Sh 300 per year	7200
Hand and body washing facilities – 1 Lt of hand disinfectant every month	10,000 per month	120,000
Hand and body washing facilities – 2 bars of soap every month for washing farm boots/clothes	8000 per month	96,000
Air time for communicating with the veterinary officers to communicate disease outbreaks	1000 per month	12,000
Veterinary care – advisory services	29,040 per grower/year	145,200
Deworming of pigs	23,000 per year	23,000
Heating of swill to feed pigs	Bunch of firewood for 2 days = 2000. 25% allocated to burning swill	91,250
Total		682,370

Table 3B
Costs of a pig business hub.

Item	Unit cost (Ug Shs)	Total cost per week (Ug Shs)
Land rate payment to the municipal council for the collection centre	Daily fixed payment of Ug Sh 5000 per day for 22 days a month = Ug Sh 1,320,000 per annum	25,384.6
Ex-ante pig inspection fees	Ug Sh 154,000 per month = Ug Sh 1,848,000 per annum. Inspection fee per pig @Ug Sh 1000	35,538.5
Transport and loading & offloading pigs into transport equipment	Ug Sh 33,000 per month = Ug Sh 396,000 per annum. Assuming about 40 pigs per week in the hub collection point	7,615.4
Total		68,538.5

increase compared to the baseline due to reduced frequency of ASF outbreaks which reduces pig mortality and panic selling. This in turn stabilizes pig population and supply. In scenario 3 (pig business hub model), the pig population and supplies rise even higher than scenario 2, triggered by the price incentive associated with the business hub but this tappers off over time due to limited capacity for further expansion. The combination of both biosecurity intervention and pig business hub (scenario 4) results in the highest pig supply due to reduction in pig mortalities and price incentive.

Table 6 shows the reduction of pig mortality rate under the intervention scenarios relative to baseline. Combined pig market hub and biosecurity intervention leads to the lowest pig mortality rate (about 18% less than the baseline mortality figure), followed by biosecurity (13–14% less than baseline) and pig market hub (about 7% less than baseline).

Changes in pig supply as a result of the implementation of biosecurity intervention (scenario 2) and pig business hub (scenario 3) influence the price of pigs which in turn affects gross margins and cumulative profits of different value chain actors (see Tables 4 and 5). Fig. 6 presents the average pig price in the value chain under different scenarios. Higher average prices result from the pig business hub and the coupling of the biosecurity and ASF interventions (scenarios 3 and 4, respectively). This has a positive effect on producers and other chain actors' margin. The costs associated with the biosecurity intervention reduces the margins, especially for producers since all the implementation costs are borne by producers. The other value chain actors are the main beneficiaries of the biosecurity and pig business hub intervention as it ensures stable supply of pigs in the market.

Tables 4 and 5 summarizes the financial performance of the different value chains actors under each scenario relative to the baseline scenario using 15 year and 30 year simulation time horizon, respectively. Producers lose out from scenario 2, by 6.3% to 2.7% lower gross margins per year relative to baseline due to the high investment cost of biosecurity to control ASF. The butchers, traders, collectors and the wholesalers on the other hand, all benefit by about 3.5–9.2% higher gross margins per year compared to baseline. The higher margins to the

Table 4
Average annual% change of value chain actors' cumulative profit relative to baseline (based on 15 year model run).

Scenario	Pig value chain actors				
	Producers	Butchers	Traders	Collectors	Wholesalers
Scenario 2 Vs 1	−6.3	7.1	9.2	7.6	7.0
Scenario 3 Vs 1	8.4	4.7	8.1	6.6	3.5
Scenario 4 vs. 1	3.7	12.7	20.9	16.9	10.0

Notes.
Scenario 1: baseline.
Scenario 2: ASF biosecurity implementation.
Scenario 3: Pig business hub.
Scenario 4: coupling of ASF biosecurity and pig business hub intervention.

Table 5
Average annual% change of value chain actors' cumulative profit relative to baseline (based on 30 year model run).

Scenario	Pig value chain actors				
	Producers	Butchers	Traders	Collectors	Wholesalers
Scenario 2 Vs 1	−2.7	3.5	4.4	3.8	3.5
Scenario 3 Vs 1	4.3	2.0	3.5	2.9	1.3
Scenario 4 vs. 1	3.6	7.1	11.6	9.6	5.7

Notes.
Scenario 1: baseline.
Scenario 2: ASF biosecurity implementation.
Scenario 3: Pig business hub.
Scenario 4: coupling of ASF biosecurity and pig business hub intervention.

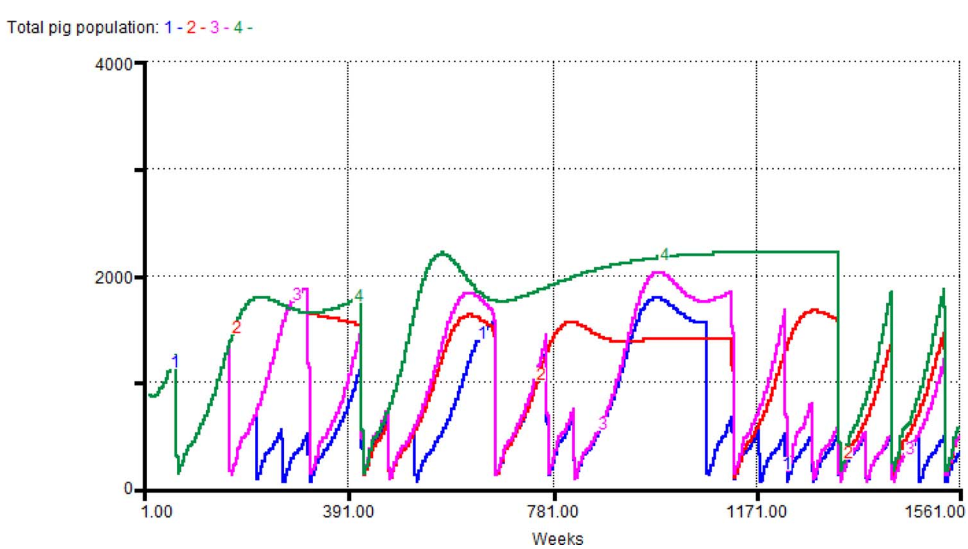

Fig. 5. Pig population under different scenarios.

Table 6
Average percentage change in pig mortality rate in intervention policies relative to baseline (over 15 and 30-year).

Scenario	% change in mortality rate	
	15 year model run	30 year model run
Scenario 2 Vs 1	−13.4%	−14.4%
Scenario 3 Vs 1	−6.7%	−6.6%
Scenario 4 vs. 1	−17.9%	−17.7%

Notes.
Scenario 1: baseline.
Scenario 2: ASF biosecurity implementation.
Scenario 3: Pig business hub.
Scenario 4: coupling of ASF biosecurity and pig business hub intervention.

value chain actors, apart from producers, result from stable supply of pigs as a result of implementation of biosecurity practices by farmers, leading to reduction in mortalities and transaction costs.

The business hub (scenario 3) results in positive margins for all value chain actors, including producers (4.7–8.4% per year). The producers benefit from higher prices and stable pig supply due to lower mortalities. The other value chain actors benefit from stable pig supply in the market and economies of scale due to bulk purchases. The combined effects of the two interventions (scenario 4) results in high pig supplies and positive margins for all value chain actors. The producers' margins change positively by about 4% per year relative to baseline. Producers' margin in scenario 4 is lower than scenario 3 due to high costs associated with implementing biosecurity control measures.

For brevity reasons sensitivity analysis result tables are presented in Annex B – tables B.1 to B.12. The results show that producers profit does not change substantially based on changes in pig price bargain associated with improved biosecurity intervention. Similarly, sensitivity analysis of other chain actors (see butchers, traders, collectors, and wholesalers columns in table B.1) do not show substantial variability under different pig price bargains associated with improved biosecurity intervention. This is because almost all costs associated with policy interventions is covered by producers while other chain actors maintain their profit margins. The 30-year model results are slightly less sensitive relative to the 15-year model outputs to changes in price because producers and other value chain actors profit are more stable in the long run. A notable result of sensitivity analysis for scenario 2 (biosecurity) is that even with 10% increase in price premium associated with implementing biosecurity control, producers profit is still lower than the baseline in both 15-year (−2.4%) and 30-year (−0.3%) model results.

Among the intervention scenarios, scenario 4 (pig business hub and implementing biosecurity control) is more sensitive to changes in higher pig price bargain associated with policy interventions (see tables B.5. and B.6.). The reason for this is because scenario 4 combines both scenarios 2 and 3 which combines the associated costs and benefits of both scenarios. Therefore, +/−10 changes in higher pig price bargain associated with policy interventions result in higher magnitude of changes. A notable result of sensitivity analysis of scenario 4 is that under lower pig price bargain associated with policy interventions, producers profit in scenario 4 could possible become lower than producers profit under baseline scenario. This indicates the importance of higher pig price bargain to ensure the feasibility to implement policy interventions specifically biosecurity interventions.

5. Discussion

All the three intervention strategies: application of ASF biosecurity measures, pig business hubs and a combination of both interventions increased pig supplies by smallholders, albeit at different levels. The rise in pig supply leads to an increase in pork supply thereby contributing to stable pork retail prices. Efforts to efficiently increase pig supplies in urban pig value chains are therefore beneficial to consumers.

The findings show that biosecurity interventions applied alone reduced ASF outbreaks but resulted in income losses to pig farmers and profit gains to other value chain actors due to stable pig supply. Similar studies such as Fasina et al. (2011) also show reduction in farmers profits by 9.7% as a result of full implementation of biosecurity practices. Although implementation of farm level biosecurity practices is justified in view of the substantial costs incurred in the event of an ASF outbreak as demonstrated by Babalobi et al. (2007) and Nantima et al. (2015a), without an income or financial incentive to counter the high costs, farmers are unlikely to adopt the practices.

The pig business hub intervention on the other hand if applied alone, increases farmers and other value chain actors' income margins but is not as effective as the biosecurity practices in reducing mortalities due to ASF. As noted by Dione et al. (2016) the highest risk node for spread of ASF disease along the value chain is in the trading activities in market places. Establishment of collective marketing has a potential to significantly reduce the risk to ASF as it will prevent close contact of traders to pig farms, reducing the risk of contamination.

The results show the win-win situation to be a combination of both interventions due to their positive interactions resulting in increased income margins for all the value chain actors and reduced occurrence of

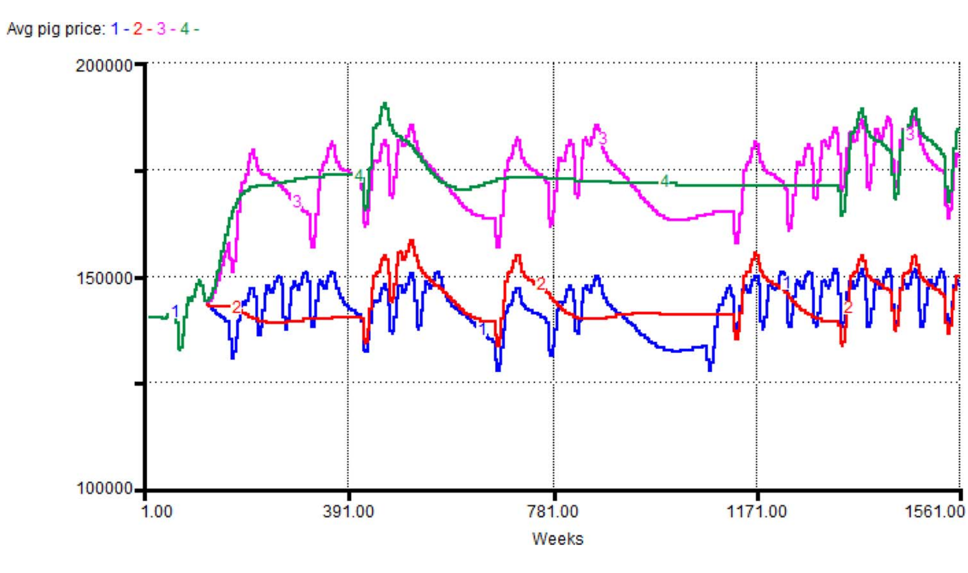

Fig. 6. Average pig price under different scenarios.

ASF outbreaks. However, producers, unlike other chain actors, gain less through combining biosecurity and market hub intervention relative to market hub only intervention (see Tables 4 and 5) due to high costs of implementing biosecurity control measures. This suggests that there must be some cost sharing incentives among producers and other chain actors to make it feasible for producers to adopt biosecurity control measures.

Further effort should also focus on application of biosecurity measures beyond the production node, such as regulations around livestock transport vehicles including vehicle design, cleaning and disinfection of vehicles, entry of vehicles into trading locations, and regulations around slaughter, butchery and pork handling such as disposal of waste, may also significantly contribute in reducing contamination. Such measures can also contribute to ASF control and would be more equitable since the main beneficiaries such as traders and butchers will be responsible for implementation.

Sensitivity analysis results to assess reliability of the estimates show that value chain actors' profit, except producers' profit under pig business hub coupled with biosecurity interventions are not sensitive to +/− 10% changes in higher pig price bargain associated with the interventions and costs of policy interventions. This shows the importance of a price premium associated with policy interventions particularly implementing biosecurity measures. This is because the costs associated with biosecurity, unlike pig business hub, is high. We have conducted sensitivity analysis for other parameters (i.e. production parameters), model outputs were reasonable under all sensitivity tests. However, to save space and avoid overly complex appendices, we only reported sensitivity analysis results for +/− 10% change in higher price bargains associated with the interventions and +/− 10% change in the cost of the interventions.

Application of the System Dynamics model in this study has resulted in robust estimates of the distributional impacts of the ASF biosecurity and business hub interventions along the pig and pork value chain. Most other ex-ante assessment studies utilise cost benefit analysis that focus on one node of the value chain. Such methods are unable to capture interacting effects of interventions and lack the capability to assess causal feedback effects of interventions within a system or along the value chain (e.g. Fasina et al., 2011).

Although the study addresses ASF control in peri-urban value chains, we realise that 45% of the value chains are rural based. Questions on the types of ASF biosecurity measures and incentives that would be effective for such systems need to be addressed. In the rural value chains, extensive systems dominate and pigs are tethered or allowed to free-range, rendering some of the biosecurity practices infeasible.

6. Conclusions

The study analysed the distributional impacts and interacting effects of ASF biosecurity and pig business hub interventions in peri-urban pig value chains in the Masaka district using System Dynamics model. From the analysis, it is clear that smallholder pig farmers are unlikely to take up ASF biosecurity measures if not coupled with an income (financial) incentive to counter the high costs. When coupled with the pig business hub interventions the interaction effects of the interventions result in positive outcomes for both the control of ASF and improvement in producers and all other chain actors margins. The benefits of both scenarios 3 and 4 are positive for all chain actors and are widely distributed along the value chain. This has implications for policy and other efforts to implement actions that incentivise uptake of the desired practices. In a similar vein, model results showed that the return of producers' investment in biosecurity control is not internalized (i.e. producers gain less from combining biosecurity control and market hub relative to market hub only intervention, while other chain actors gain more). This suggests the need of developing institutions to facilitate cost sharing arrangement among chain actors and/or third party subsidy (i.e. government and NGOs) to provide incentives for producers to adopt biosecurity measures.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.prevetmed.2017.12.010.

References

Andersen, D., Richardson, G., 1997. Scripts for group model building. Syst. Dyn. Rev. 13 (2), 107–129.

Atuhairwe, K.D., Ochwo, S., Afayoa, M., M, Arinaitwe, E., Ademun-Okurut, R.A., Okuni, J.B., Nanteza, A., Ayebazibwe, C., Okedi, L., Olaho-Mukani, W., Ojok, L., 2013. Epidemiological overview of African swine fever in Uganda (2001–2012). J. Vet. Med. 9, 263.

Babalobi, O.O., Olugasa, B.O., Oluwayelo, D.O., Ijagbone, I.F., Ayoade, G.O., Agbede, S.A., 2007. Analysis and evaluation of mortality losses of the 2001 African swine fever outbreak in Ibadan Nigeria. Trop. Anim. Health Prod. 39, 533–542.

Barongo, M.B., Bishop, R.P., Fevre, E.M., Knobel, D.L., sematimba, A., 2016. A mathematical model that simulates control options for african swine fever virus (ASFV). PLoS One 11 (7). http://dx.doi.org/10.1371/journal.pone.0158658.

Dione, M., Ouma, E.A., Roesel, K., Kungu, J., Lule, P., Pezo, D., 2014. Participatory assessment of animal health and husbandry practices in smallholder pig production systems in three high poverty districts in Uganda. Prev. Vet. Med. 117, 565–576. http://dx.doi.org/10.1016/j.prevetmed.2014.10.012.

Dione, M.M., Akol, J., Roesel, K., Kungu, J., Ouma, E.A., Wieland, B., Pezo, D., 2015. Risk factors for African swine fever in smallholder pig production systems in Uganda. Transbound. Emerg. Dis. 64 (3), 872–882.

Dione, M.M., Ouma, E., Opio, F., Kawuma, B., Danilo Pezo, D., 2016. Qualitative analysis of the risks and practices associated with the spread of African swine fever within the smallholder pig value chains in Uganda. Prev. Vet. Med. 135, 102–112.

Dizyee, K., Baker, D., Rich, K., 2017. A quantitative value chain analysis of policy options for the beef sector in Botswana. Agric. Syst. 156, 13–24.

FAO, 2010. Good Practices for Biosecurity in the Pig Sector. Issues and Options in Developing and Transition Countries. FAO Animal Production and Health Paper. FAO, OIE, World Bank, Rome.

Fasina, F.O., Lazarus, D.D., Spencer, B.T., Makinde, A.A., Bastos, A.D., 2011. Cost implications of african swine fever in smallholder farrow-to-finish units: economic benefits of disease prevention through biosecurity. Transbound. Emerg. Dis. 59 (3), 244–255.

Hamza, K., Rich, K.M., Wheat, I.D., 2014. A system dynamics approach to sea lice control in Norway. Aquac. Econ. Manag. 18 (4), 344–368.

Kaplinsky, R., Morris, M., 2001. A Handbook for Value Chain Research. IDRC, Ottawa. http://www.ids.ac.uk/ids/global/.

McRoberts, K.C., Nicholson, C.F., Blake, R.W., Tucker, T.W., Díaz-Padilla, G., 2013. Group model building to assess rural dairy cooperative feasibility in south-central Mexico. Int. Food Agribus. Manag. Rev. 16 (3), 55–98.

Nantima, N., Ocaido, M., Ouma, E., Davis, J., Dione, M., Mugisha, A., Okoth, E., Bishop, R., 2015a. Risk factors associated with occurrence of African swine fever (ASF) outbreaks in smallholder pig farms in four districts along the Uganda-Kenya border. Trop. Anim. Health Prod. 47 (3), 589–595.

Nantima, N., Dione, M.M., Brandes-van Dorresteijn, D., Kawuma, B., Smith, J., 2015b. African Swine Fever: Uganda Smallholder Pig Value Chain Capacity Development Training Manual. ILRI Manual 14. ILRI, Nairobi, Kenya. http://hdl.handle.net/10568/56789.

Naziri, D., Rich, K.M., Bennett, B., 2015. Would a commodity-based trade approach improve market access for africa? A case study of the potential of beef exports from communal areas of Namibia. Dev. Policy Rev. 33 (2), 195–219.

Ouma, E.A., Dione, M.M., Lule, P., Pezo, D., Marshall, K., Roesel, K., Mayega, L.,

Kiryabwire, D., Nadiope, G., Jagwe, J., 2015. Smallholder Pig Value Chain Assessment in Uganda: Results from Producer Focus Group Discussions and Key Informant Interviews. ILRI (Research Report), Nairobi, Kenya (150pp).
Ouma, E., Ochieng, J., Pezo, D., 2017. Governance structures in smallholder pig value chains in Uganda: constraints and opportunities for upgrading. Int. Food Agribus. Manag. Rev. 20 (3), 307–319.
Rao, E.J.O., Omondi, I., Karimov, A.A., Baltenweck, I., 2016. Dairy farm households, processor linkages and household income: the case of dairy hub linkages in East Africa. Int. Food Agribus. Manag. Rev. 19 (4), 95–108.
Rich, K.M., Ross, R.B., Baker, D.A., Negassa, A., 2011. Quantifying value chain analysis in the context of livestock systems in developing countries. Food Policy 36 (2), 214–222.
Sterman, J.D., 2000. Business Dynamics: Systems Thinking and Modelling for a Complex World. McGraw Hill (ISBN 0-07-231135-5).
Uganda Bureau of Statistics, 2009. National Livestock Census Report. Uganda Bureau of Statistics (UBOS), Kampala, Uganda.
Vennix, J.A., 1996. Group Model Building: Facilitating Team Learning Using System Dynamics. Wiley (316 pp ISBN 0471953555).