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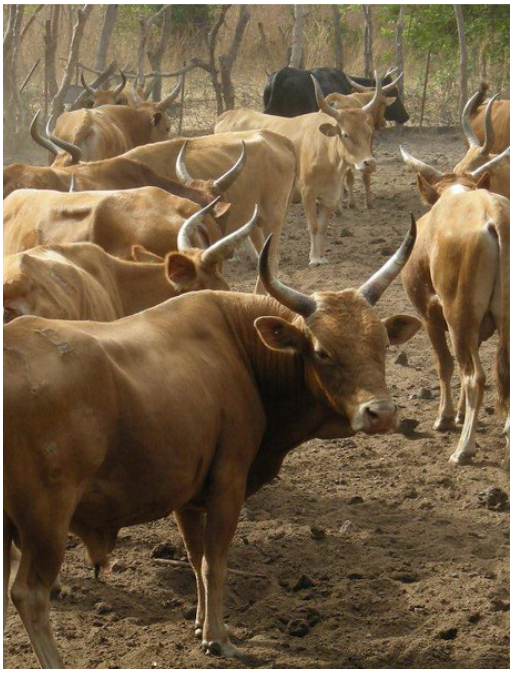
System dynamics modelling of the cattle value chain in Nigeria



CGIAR RESEARCH PROGRAM ON Livestock

System dynamics modelling of the cattle value chain in Nigeria

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Acronyms and abbreviations

CLD	Causal loop diagram
Hg	hectogram
KIIs	Key informant interviews
SD	System dynamics

Executive summary

The interactions among complex sets of feedback loops (circular causal connections) between the production, trade and financial performance govern the cattle value chain in Nigeria. This paper aims to identify the key feedback loops influencing the structure and behaviour of trade dynamics in Nigeria's cattle value chain. We deployed a qualitative system dynamics (SD) model to highlight the loop sets containing the feedback loops. Results showed that most of the feedback loops are upstream-focused; these feedback loops revolve around economic and bioeconomic factors. The feedback loops include the price that cattle wholesalers (assemblers) are willing to pay for cattle, the proportion of producers' cattle supply to assemblers, the delay in the maturation of heifers into productive cows, and abattoirs' carcass inventory levels. Our findings suggest two countervailing strategies that producers can adopt to curtail potential exploitation by cattle wholesalers (assemblers): (i) regulating the supply of cattle to other distribution channels other than wholesalers through online marketing platforms; and (ii) regulating the timing and proportion of sales, which requires investments (including financing options) that will boost producers' capacities related to cattle inventory management and marketing.

1 Introduction

The prominence of beef consumption among the Nigerian consumers makes cattle an important livestock in Nigeria (Gambo 2020). Among livestock-rearing households in pastoral areas and where there is high engagement in cattle production in the sub-humid and semi-arid ecological zones, possession of cattle is seen as a guarantee for secured food supply (Kubkomawa et al. 2017). Cattle are used throughout the country in important ceremonies like marriages and funerals. However, an analysis of the trend of cattle imports, exports, and production from 2005 to 2019 showed that domestic production is unable to meet the growing demand in-country (FAO 2019; Odoemena Walters and Kleemann 2020).

About 99% of Nigeria's cattle population is managed in smallholder and pastoral systems using indigenous production methods (Suleiman, Jackson and Rushton 2015), which has implications of scarce supply and higher prices of cattle. Yet, there seem to be no viable alternatives for meeting demand domestically (Kubkomawa 2017). Cattle trade is the largest market across Nigeria, with live cattle marketed through movements from the northern regions in Nigeria to final consumers in the southernmost parts of the country. The long spatial distance between the production area and major consumption areas influences the transportation cost, which contributes to higher marketing costs (Kubkomawa 2017; Kubkomawa et al. 2018).

According to Kubkomawa (2017), the structure of the cattle market influences the performance of the value chain. This structure is determined by the trade flows, which is complex when the dynamic flows of cattle among different heterogeneous chain actors are considered (Bigras-Poulin et al. 2006). The inefficiencies of the cattle market affect the supply of beef, which, in turn, shapes the structure of the cattle market (Emokaro and Egbodion 2014). A complex set of feedback loops governs the interaction among different sectors (production, trade, and performance) of the value chain, which dictates how the sector evolves. This paper uses a systems thinking approach to identify the feedback loops influencing the structure and behaviour of trade dynamics in Nigeria's cattle value chain. This objective is achieved by answering two research questions: (i) what are the feedback loops influencing the structure and behaviour of cattle trade flows? and (ii) at which nodes of the cattle value chain are these feedback loops located?

The findings provide foundational understanding of the feedback loops governing the cattle value chain in Nigeria and provide practical strategies that can be adopted to improve the performance of the sector and inform the national dialogue on Nigeria's cattle industry (Kubkomawa et al. 2018). The remaining sections of the paper cover a description of the system dynamics (SD) model and the data in Section 2; a synthesis of the feedback loops in Section 3; and the conclusion and next steps in Section 4.

2 Qualitative system dynamics modelling of Nigeria's cattle value chain

2.1 Material and methods

We deployed the system dynamics (SD) modelling technique to highlight the complex set of feedback loops governing the cattle value chain in Nigeria. The SD modelling approach has been used to map the feedback structure and conduct ex-ante impact assessment in the livestock (territorial and aquatic) sector in past decades. This include application of SD to model impact of (i) foot-and-mouth disease (FMD) on cattle herds and international trade in Botswana (Dizyee et al. 2017) and Namibia (Naziri, Rich and Bennett 2015); (ii) African swine fever (ASF) and market hubs on peri-urban pig value chains in Uganda (Ouma et al. 2018); (iii) artificial insemination and market hubs in dairy value chains in Tanzania (Dizyee et al. 2019) and Nicaragua (Lie et al. 2018); (iv) animal disease and herd management in goat value chains in Mozambique (Hamza et al. 2014); (v) sustainable intensification of beef systems in Indonesia (Dahlanuddin et al. 2017); (vi) inter-country trade patterns and competitiveness of beef export from Burkina Faso to Ghana (Rich and Wane 2021); and (vii) aquatic disease management in salmon industry in Norway (Hamza et al. 2014).

SD models can be both qualitative and quantitative. Qualitative SD models can generate insights on the feedback structure that governs the system and policy leverage points (e.g. see Baker et al. 2017 and Berends et al. 2021), whereas quantitative SD models provide insights on what could happen under different scenarios that provides useful analytical tools to policymakers to test the likely impact of different policy options on livestock systems and value chains. In the paper, we focus on the qualitative SD model to highlight key feedback loops that govern the cattle value chain in Nigeria. The model consists of eight modules that represent the main actors in the value chain: producers, live cattle marketers, abattoirs, butchers, cattle wholesalers (assemblers), supermarkets/cold stores, and consumers (households). The interaction of the materials and price information flows between the modules are illustrated in Figure 1.

2.1.1 Model description

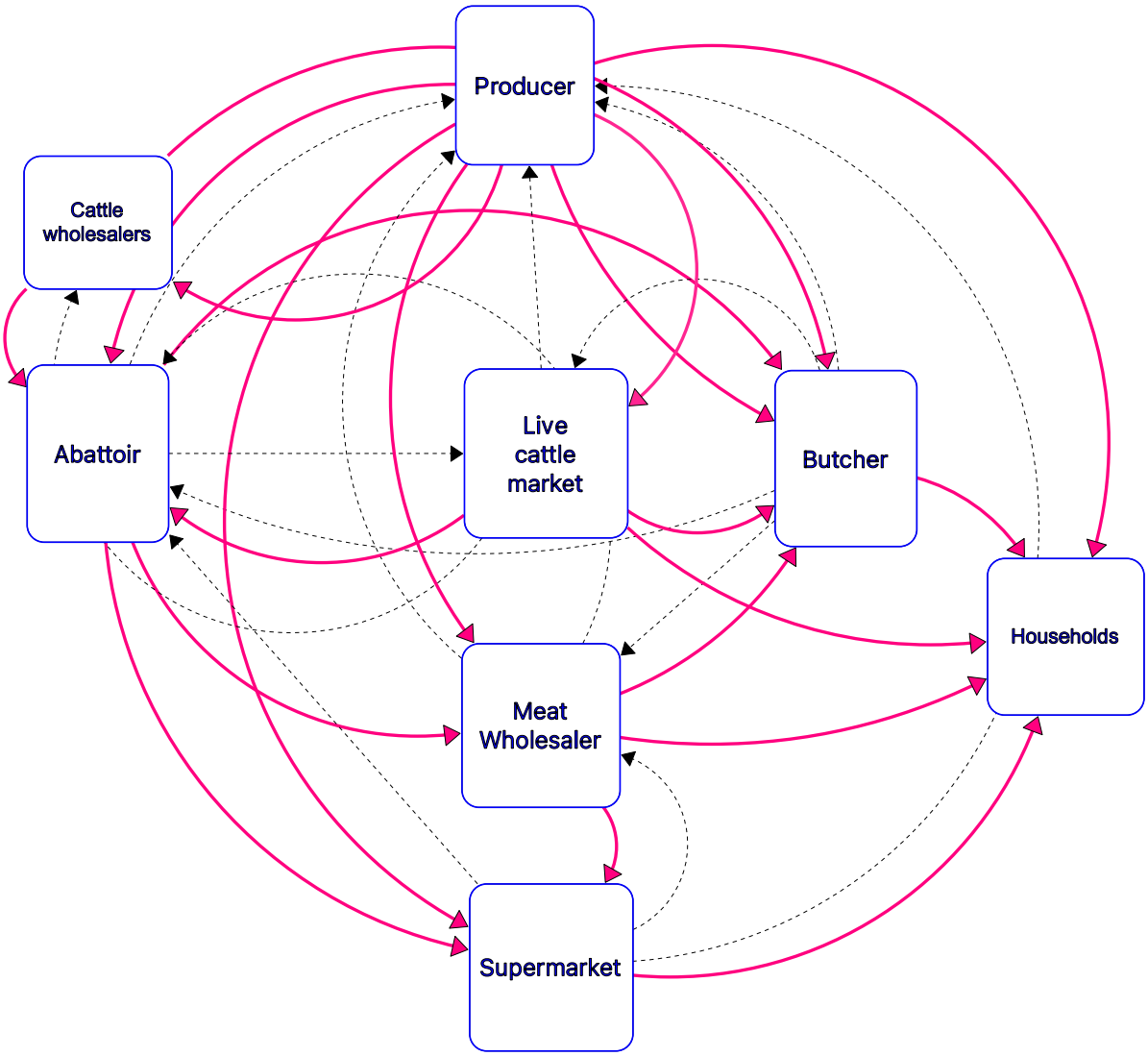
In the production module, the key parameter interactions focus on production flow and variables, maturation period, cattle (bulls and cows) sales to different distribution channels, and the feedback loops that govern cattle supply and demand based on market. A condition for evolutionary equilibrium is specified for the baseline using a sex ratio of 0.5:0.5 for bulls and heifer births (Roche, Lee and Berry 2006). The maturation period for a heifer to give birth to its first calf is set at four years (Kubkomawa 2017). The number of cattle at the farm level is depleted by the deaths, which is influenced by an annual mortality rate of 5%, specified based on projected deaths for the extensive production system in the African Sustainable Livestock 2050 report (FAO 2017).

The model considers an annual supply and demand of cattle and beef. Producers have four different channels to sell their live cattle: directly to households (including corporate firms), live cattle markets, abattoirs, butchers, cattle wholesalers (assemblers), and supermarkets/cold stores. The live cattle markets have one source of inflow (i.e. from the producer) and three outflows (i.e. butcher, households and wholesalers). Cattle assemblers buy cattle from producers

and live cattle markets and sell to other chain actors on the live cattle markets, or directly to abattoirs, butchers and supermarkets. The abattoirs buy live cattle from local producers, live cattle markets, and assemblers, slaughter the cattle, and sell the carcasses with their by-products (including hides and offal) to supermarkets and butchers. A one-week cattle holding period at the abattoirs is assumed for the baseline.

A carcass conversion weight of 1,034 hg per animal[1] (i.e. 103.4 kg per animal) is applied to estimate the quantity of fresh meat sold by the abattoirs. The number of hides and offal obtainable from an animal's carcass is determined using the average weight of offal and hides per animal determined based on gathered primary data. The average offal weight is specified as a triangular distribution with 23 kg, 30 kg, and 35 kg being the minimum, mean, and maximum offal weight per animal, respectively. Triangular distribution of 17 kg, 22 kg and 27kg being minimum, mean, and a maximum of extracted hide weight per animal is specified in the model.

Figure 1: Module interaction and information flows in the Nigeria cattle value chain.



Note: black dotted links are for information flow, and red links represent materials flow.

The butcher module receives cattle supply from local producers and the live cattle market, and fresh beef supplies from the abattoir and wholesaler modules. The outflows from the butcher module (i.e. fresh beef and its by-products) go to households, food vendors and restaurants. Based on the primary data, 80% of meat from the butchery is sold directly to

1 https://knoema.com/atlas/Nigeria/topics/Agriculture/Live-Stock-Production-Yield/Carcass-weight-of-cattle-and-buffaloes - :~:text=In 2019, carcass weight of,1,034 hg%2Fan in 2019

households and the remaining goes to food vendors and restaurants. The solid arrows in Figure 1 represent material flow and dashed arrows represent information flow among different chain actors (modules), respectively.

The proportion of cattle sold to the distribution channels is influenced by the price offered by the focal chain actor. Based on the survey data, the proportion of cattle supplied to the different channels reduces by an average of 2% for every change in the offering price of the recipient chain actor. The initial producer price of the animal is the average cattle price (i.e. NGN213,333) obtained from the survey data. The annual demand for live cattle is estimated using the product of the annual per capita consumption for beef and the total population divided by the carcass conversion weight. The unit cattle price for assemblers and live cattle markets are set as NGN350,000 and NGN400,000, respectively.

The proportion of cattle that are directly sold to households is the difference after deducting the sum of the proportion sold to abattoirs and butchers. The desired level of inventory of each actor is specified as the first-order exponential smoothing of the total number of cattle sold to the distribution channels from the previous year. The sales of fresh beef from the previous year(t) are used to forecast the demand for the next year(t+1). The quotient of the inventory levels and the forecasted demand determine the effect of demand on price. The initial unit price for beef per kg sold at the abattoir, beef wholesalers, butchers, and supermarkets are set at NGN1,250, NGN1,520, NGN1,660, and NGN1,850, respectively.

2.1.2 Data

A mix of primary and secondary data was used in this study. Before the field surveys, statistics retrieved from actuarial databases (FAO 2019) were analysed to understand the general trends of demand, production, and trade of live cattle and beef in Nigeria. This analysis informed the initial characterization of value chain actors, major consumer products and consumer types, geographical clusters of demand and supply, and end markets for cattle and beef products. Primary data were collected from a range of value chain actors: consumers, supermarkets/cold stores, butcher, abattoirs and slaughterhouse operators, wholesalers of live cattle, live cattle traders (assemblers), and producers. Data was collected using market observations, targeted consumer surveys and key informant (individual and group) interviews (KIIs). Data gathered covered estimates of consumer demand for specific beef products and cuts and provided information about factors of supply, market access, and production.

Questionnaires were developed to obtain relevant information from the value chain actors. Data collection was conducted in three administrative states in Nigeria: Lagos State in the Southwest, Abuja Federal Capital Territory in the North Central, and Kano State in the Northwestern geopolitical zones. These states were selected based on their status as major sites of production (Kano) and demand (Lagos, Kano and Abuja). Also, the selected states represented areas geographically close to (Kano), far away from (Lagos) and mid-point to major sites of cattle production in Nigeria. Within the three states, specific sites were selected to span the geographical coverage, population sizes, ethnicities and income levels represented by the state. The major meat retail and wholesale markets within the identified sites were targeted for trader and consumer interviews. Ten consumers and two butchers/retailers were interviewed in each retail market. One interview was conducted for each value chain actor (i.e. wholesale live animal dealerships, live cattle traders, supermarket/cold store operators, abattoir/slaughterhouse operators, butchers, and cattle farmers) in each site. Although the sites had been purposively selected for relevance to either cattle production, beef demand, or both, some sites were missing one or more of the value chain actors and most outside Kano did not include cattle farmers.

To obtain consensus figures, where relevant, wide ranges or trend averages, actors were interviewed in groups (e.g. several butchers or live cattle traders) rather than as a single respondent. A snowballing technique was applied to select value chain actors. The surveys in Kano and Abuja covered eight retail and 10 wholesale meat markets and six abattoirs, supermarkets, and producers. The Lagos KIIs was administered in three local government areas: Ojo (Ojo) Agege/Ojodu/Ikeja (Agege), and Somolu/Gbagada/Bariga (Bariga), which are the 6th, 9th, and 11th largest of the 20 local government areas in Lagos by population, and together account for 10% of the state's population. The surveys were conducted between December 2019 and March 2020. Data gathered from these study areas were consolidated using averaging and distribution schemes for variables with two or more than two different values, respectively. Also, secondary data were extracted from reports, journal articles, and archival databases to augment the primary data. The

same data consolidation scheme was applied to the extracted secondary data. However, the highest priority was given to published official data with current years (between 1 to 3 years) (FAO 2019).

Primary data were collected by local enumerators fluent in the local languages spoken at the study sites, who received training on the survey tools and relevant research ethics issues. Interviews were administered upon participants providing informed consent. This study received ethics clearance from the Institutional Research Ethics Committee (IREC) of ILRI, with approval number ILRI-IREC2019-44.

3 Results: syntheses of the loop sets

Table 1 shows a summary of the loop sets and the key issues highlighted in the feedback loops. In total, 24 loop sets[2] that contain the feedback loops were synthesized. Out of the 24 loop sets, only four loop sets contain more than two feedback loops; five loop sets have two feedback loops, and 15 loop sets contain only one feedback loop. When the loop sets are categorized based on the value chain position[3] results in Table 1 show that the loop sets concerning trade flow issues relating to the upstream, midstream, and downstream ends of the cattle value chain are five, nine, and ten sets, respectively. A disaggregation of the number of the loop sets in each value chain position indicates that four out of the five upstream-focused loop sets have more than two feedback loops, and one upstream-focused loop set has one feedback loop. Out of the nine midstream-focused loop sets only one had more than two feedback loops; two midstream-focused loop sets contain two feedback loops; and six midstream-focused loop sets have one feedback loops. Out of the ten downstream-focused loop sets, seven loop sets have only one feedback loop, and three loop sets have two feedback loops. The disaggregation of the loop sets based on the value chain position and the total number of feedback loops suggest that the feedback loop driving trade dynamics in the cattle value chain are upstream-focused.

At the producer level, the quantity of cattle that producers are willing to sell (loop set 1) is crucial for the continuity of the value chain activities. The feedback loop revolving around the changes in producer's supply due to changes in price supports the well-known notion that producers keep cattle and only sell when needed as a risk mitigation strategy (Thornton 2010). Also, the delay in the maturation of heifers (loop set 5) is another important feedback loop because as more heifers grow into adult cows, the number of cattle on the farm increases. Thus, the number of heifer births and the genetic makeup that determine their maturation duration can be critical drivers of the trade dynamics in the cattle value chain. As noted by Odoemena, Walters and Kleemann (2020), the maturation process is a significant driver of the cattle value chain.

Other upstream-focused feedback loops (loop sets 3 and 4) revolve around the cattle supply from assemblers to the live cattle market. As noted by Gambo (2020), the role that middlemen play in cattle marketing is a peculiar structure of Nigeria's cattle trade. Musa et al. (2018) reported that most local producers sell to cattle wholesalers (assemblers), who in turn sell to other value chain actors. Aside from local producers, assemblers buy and sell cattle from the live cattle market. Therefore, with multiple sources of supply of cattle, cattle wholesalers (assemblers) hold a powerful position in determining cattle price in Nigeria's cattle value chain. The role that cattle wholesalers play as the main distributors of live cattle in the value chain (Musa et al. 2018), contributes to the criticality of their asking price as a driver of Nigeria's cattle trade flow dynamics and behaviour.

The presence of so many middlemen is expected to introduce some competition that can benefit the value chain. However, given that the middlemen operate from the same live cattle market and the differences in the cattle price are very minimal among the traders, the involvement of so many middlemen in the cattle value chain limits the volume of direct trading between producers and other chain actors, contributing to inefficiencies in the cattle value chain (Emokaro and Egbodion 2014). As noted by Kubkomawa et al. (2018), the middlemen adopt manipulative marketing

2 Loop sets contain different dominant feedback loops driving changes in the model behaviour.

3 Upstream – feedback loops about live cattle trade flows from the producer, assemblers, and cattle wholesalers on the live cattle market. Midstream – feedback loops concerning carcass, beef, and by-products (i.e., offal and hides) trade flows from the abattoir and beef wholesalers. Downstream – feedback loops concerning beef and by-products trade flows from the supermarket and butchers.

methods which make them key beneficiaries of the inefficiencies in the cattle value chain. The findings suggest that the cattle market arrangement creates a weak linkage between producers and other value chain actors (Musa et al. 2018), which supports the dominance of cattle wholesalers in the chain. Also, the level of inventories held by abattoirs play an important role in the trade dynamics as evident by loop set 2.

Loop set	No of reinforcing feedback loop	No of balancing feedback loop	Total number of feedback loops	Main issues highlighted by the feedback loops
1 ♠	2	4	6	(i) Cattle that producers are willing to sell, and changes in producers' cattle price (ii) the effect of producers' supply to assemblers on producers' inventory
2 ▽	2	4	6	(i) the effect of abattoirs' beef supply to beef wholesalers on abattoirs' inventory levels (ii) Abattoirs' carcass price
3 ♠	2	4	6	(i) Cattle sold on the live cattle market, and changes in cattle price in the live cattle market. (ii) Cattle supplies to abattoirs from the live cattle market
4 ♠	2	4	6	(i) Changes in assemblers' cattle price (ii) Cattle that assemblers sell to the live cattle market
5 ♠	1	4	5	(i) Delay in heifer birth and maturation (ii) Death of cows on the farm
6 ▽	-	1	1	Beef wholesalers' inventory levels
7 ◆	1	1	2	Changes in supermarkets' beef price
8 ▽	1	1	2	Changes in abattoirs' cattle purchase price
9 ◆	1	1	2	Changes in butcher price for beef
10 ▽	1	1	2	Changes in beef wholesaler' beef price
11 ▽	-	1	1	Abattoirs' offal for sale
12 ♠	-	1	1	Producers' sale of bulls
13 ◆	-	1	1	The effect of beef sales on butchers' inventory
14 ◆	-	2	2	Butchers' self-processed carcass on inventory
15 ▽	-	1	1	Abattoirs' sale of offal to butchers
16 ◆	-	1	1	Supermarkets' sale of offal
17 ▽	-	1	1	Beef wholesalers' offal sales to supermarkets
18 ▽	-	1	1	The effect of abattoirs' slaughtering rate on cattle purchase
19 ▽	-	1	1	The quantity of beef sold by beef wholesalers
20 ◆	-	1	1	The effect of butchers' slaughtering rate on cattle purchase
21 ◆	-	1	1	Butchers' offal sales
22 ◆	-	1	1	The effect of beef sales on supermarkets' inventory levels
23 ◆	-	1	1	The effect of supermarkets' slaughtering rate on cattle purchase
24 ◆	-	1	1	Supermarkets' processed carcass for sale

Loop setNo of reinforcing feedback loop No of balancing feedback loop Total number of feedback loops Main issues highlighted by the feedback loops

Note: ♠ upstream-focused
▽ midstream-focused
◆ downstream-focused

4 Conclusion and next steps

This paper sought to identify the feedback loops driving the trade dynamics in Nigeria's cattle value chain. The findings suggest that the key feedback loops that govern Nigeria's cattle value chain are upstream-focused. These feedback loops are economic (i.e. producers' price, assemblers' purchase price, and the proportion of producers' supply to assemblers) and bioeconomic (maturation period of heifers, and producers' sale of cattle) in nature. The feedback loops revolving around producers' cattle supply to cattle assemblers, the assemblers' cattle price, and the cattle supply from assemblers to the live cattle markets suggest a potential power play or exploitation of producers. However, the presence of the other feedback loops unveils countervailing strategies that can be adopted at the producer and abattoir levels to limit the power of cattle wholesalers.

For the producer, two strategies can be adopted:

1. Regulating the distribution channels by reducing the supply of cattle to assemblers and live cattle markets, and subsequently increasing supply to abattoirs and butchers. Most of the cattle trade between producers, live cattle markets and assemblers are conducted under a spot market arrangement. However, abattoirs reach contractual agreements with cattle wholesalers operating in the live cattle markets. Thus, one way to increase supply is to establish producer supply contracts with abattoirs.

2. Regulating the timing and proportion of cattle sales to limit or curtail the arbitrage technique that cattle wholesalers adopt. An online auction or marketplace like Nigeria's Livestock247 serves as a virtual spot market that offers farmers an alternative and efficient way to reach other actors aside from the cattle wholesalers. Yet, its effectiveness to curtail the power play in the cattle value chain is hinged on the type of actors that buy directly from producers, and the volumes of purchases.

The feedback loop revolving around the changes in the inventory levels for abattoirs suggest that effective management of inventories via the establishment of cold chains can be a crucial factor in shaping the cattle trade dynamics. However, there is a need for an economic feasibility analysis to determine the trade-off of establishing a cold chain. Also, the feedback loop on the delay in the maturation period for heifer highlights the possible impact that the type of cattle breed will have on the trade dynamics, which is a potential area for future research.

Our paper reports results based on qualitative SD model. Currently a preliminary quantitative model is under validation process to give empirical evidence on the strength of feedback loop sets highlighted in this paper. Next steps include further parameterization and validation of the quantitative SD model to provide empirical evidence of the driving factors that govern cattle value chain in Nigeria to support increasing efficiency and effectiveness for policies that aim to improve the socio-economic and livelihood condition of cattle producers and other value chain actors.

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