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Conceptual issues and methods for analysis

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Abstract

Livestock value chains present a multitude of challenges in the analysis of resilience given their multidimensional role in livelihoods and complexities associated with their biological aspects of production. This paper discusses these challenges at length and provides some guidance on methodological and operational modalities to tease out these nuances that better inform public policy and the choice of technical and policy interventions. Specific advice on models, data, and applications is provided.

Keywords: livestock, value chain, resilience, systems thinking, economic models.

JEL codes: C61, C63, O13, O19, O21, Q01, Q10, Q18.

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Introduction

Strengthening agrifood value chains (AFVC) in developing and conflict-affected countries can be an essential lever of change that contributes to ending poverty while maintaining and restoring food systems economies. Because AFVC are complex – including primary production, intermediaries, domestic transport networks, and households – and involve many interlinked actors, a shock in any component can spread rapidly throughout systems. Natural hazards, pests, conflict, and violence can negatively impact AFVC even when some progress has been made, making sustained progress even more difficult.

The concept of resilience highlights how the well-being of some elements of a system or an entire system can be affected by shocks. Applying this concept to agrifood value chains means maintaining the capacity of value chains to continue to function in the face of shocks, when stable access to markets by farms and businesses (essential for employment and income), and the availability and accessibility of nutritious food by consumers are most critical (Tendall *et al.*, 2015). The COVID-19 pandemic and the war in Ukraine, which have led to sharp increases in food insecurity and malnutrition and left the fragilities of national agrifood systems exposed, have demonstrated the importance of increasing the resilience of agrifood value chains (Acosta *et al*. 2021a; FAO, 2023a).

Livestock is an important component of livelihoods globally, with over 1 billion people engaged in livestock production. However, the complexities of livestock value chains often pose a challenge for development assistance, notwithstanding the efforts of international organizations such as the International Livestock Research Institute and FAO – despite contributing up to 40 percent of agricultural GDP, livestock receive only a small proportion of aid funding (World Bank, 2009). The image of developing country livestock farmers using only traditional technologies and buying few external inputs persists in policy debates (Sheahan and Barrett, 2017), but there is considerably heterogeneity within livestock production systems, ranging from small-scale backyard holdings for own consumption, large cattle herd sizes held by pastoralism operating under transhumance systems, diversified crop-livestock system, and intensive feeding of poultry and small ruminants. Each of these, and their corresponding value chains, have different dimensions of resilience against shocks that remain poorly understood or articulated. This is particularly true in conflict zones where livestock play a critical, if sometimes the only, income generation role and where conflict often originates from shocks affecting the livestock economy (de Haan *et al.*, 2016; FAO, 2023b).

Exploring points of intersection between livestock value chains and resilience is thus crucial, and particularly for developing and emergency country contexts, where vulnerability to shocks is higher and food and nutrition security is already precarious. In this paper, we first review the various characteristics and guiding principles that govern livestock systems and value chains, using this as a basis to set the stage regarding the prospective social and economic impacts of different shocks at value chain level. We further explore how different characteristics along the value chain accentuate or mitigate their impact. We then explore the state-of-the art in the assessment of livestock value chains to better understand where and how shocks to livestock value chains can be measured and their limitations. We then propose a couple of approaches to enhance our ability to measure shocks in livestock value chains, with an aim to better understand the nature of resilience at different value chain nodes to aid in development programming and intervention.

Characteristics of livestock value chains

The analysis of livestock value chains poses specific complexities that are not readily apparent in other agricultural products. A critical difference involves the unique biophysical aspects associated with livestock production. With ruminant production, in particular, there are long biological lags between production and final marketing that have ramifications in terms of the types of decisions taken by producers and their effects on markets downstream. While there are some parallels with livestock and certain agricultural products with similar production lags (e.g. tree crops or forest products), at different points in the livestock life cycle, livestock can serve different uses and values to producers, whether for own-consumption or production, trade, and/or the generation of new stock. As both a capital stock and a source of revenue through slaughter, farmers need to manage an appropriate mix of animals of different ages and sexes to optimize their income (Jarvis, 1974) or, in the case of pastoral producers, their income and social status. Poultry products, given their shorter cycle, act differently than ruminant products, but their production and marketing behaviour more resembles horticultural products than staple commodities.

In developing countries, livestock also serve a variety of multidimensional livelihoods features for producers that go beyond a source of revenue from sales of live animals (Herrero *et al*., 2013). In pastoral societies, livestock serve as a source of wealth and status within communities. Losses of livestock from drought or conflict in such societies often have profound impacts on social dynamics, with the movement of former pastoralists to more sedentary crop-livestock systems a source of tension and social deprivation (McKune and Silva, 2013; de Haan *et al.,* 2016). Livestock produce a range of by-products such as manure or draught labour used in crop production, while income can also be generated from hides and skins in addition to animals or meat. As a source of petty cash (particularly poultry or small ruminants), livestock can smooth income shocks and provide a source of revenue for idiosyncratic household demands such as festivals or the payment of school fees. Finally, livestock have a pronounced gender dimension, both in terms of the types of livestock reared by men and women and control over the assets and inputs required for their maintenance. While livestock can help to enhance a household's food security profile, there can be significant disparities in the ability of women to access inputs and markets (Herrero *et al*., 2013).

Geographically, a number of livestock systems, particularly pastoral ones, prevail in areas subject to a variety of climatic and conflict-based shocks. These include the Sahel region in West Africa, spanning a zone from Mali eastward to Nigeria and Chad, as well as the Horn of Africa (Somalia, parts of Ethiopia and northern Kenya), Sudan, and specific zones of the Middle East and West Asia (Afghanistan, Yemen). Livestock are often central parts of such conflicts, whether through for example conflicts over land between pastoralists and sedentary agricultural producers or the prevalence of cattle theft, and where climatic and disease shocks accentuate competition for resources. For instance, patterns of transhumance in Mali have trended southward into semi-humid zones that exacerbate competition for grazing land (Ayantunde *et al*., 2014). Conversely, such shocks to pastoralist societies often break down traditional norms of cooperation that mitigated conflicts in the past, while the marginalization of pastoralist societies has further fuelled a rise in extremism and sympathy towards extremist causes (Benjaminsen and Ba, 2009; de Haan *et al*., 2014).

Value chains for livestock in developing countries are diverse and idiosyncratic, with much of this heterogeneity both context and species-specific. Poultry value chains in particular exhibit a greater diversity in the types of governance systems observed, with higher levels of vertical integration and contract farming than larger ruminants but also a range of chains based on the final product traded (broilers, layers, eggs). Formal sector value chains for broilers or layers, like those described by *inter alia* McLeod *et al*. (2009), Sudarman *et al*. (2010), Carron *et al.* (2017), or Indrawan *et al*. (2018), are increasingly tightly coordinated, with a diversity of medium-sized (200–500 birds as reported by Carron *et al*., 2017) or large farms connected to a handful of input suppliers for day-old chicks. In the most modern, formal chains as those described in Indonesia by Indrawan *et al*. (2018) large farms are vertically integrated with processing and distribution functions and products sold to modern supermarkets or high-value outlets (restaurants, hotels). By contrast, more semi-formal types of value chains, such as those found in Nairobi (Alarcon *et al*., 2017) or outside the most formal sectors in Indonesia (Indrawan *et al*., 2018) rely on brokers or traders for downstream distribution. As is common in most livestock value chains, distribution and processing typically have fewer actors handling downstream activities than at farm level. This characteristic was highlighted by Rich *et al*. (2011a) in the context of the impacts on highly pathogenic avian influenza (HPAI) on poultry value chains in four African countries and Indonesia. In particular, such market structures, where traders have monopsony power with farmers and monopoly power in downstream distribution are an added risk factor for disease by depressing the prices received by farmers and their ability (and incentives) to invest in biosecurity practices at farm-level.

Ruminant value chains tend to be less organized and formal for sheep, goats and beef, while formal pig value chains increasingly share many of the same characteristics as those of poultry, particularly in Asia. For instance, while smallholder pig production predominates in Viet Nam, Lapar *et al*. (2018) observed a steady increase in the share of commercially oriented pig producers that is predicted to rise in the future. In Uganda, Ouma *et al*. (2017) found that while value chain relationships in the pig sector are generally characterized by spot market transactions over contractual ones, traders do integrate into other value chain activities to increase their profitability. Ruminant value chains in West Africa often follow traditional transhumance systems, with live animals moving over long distances and downstream activities in animal wholesaling for processing, slaughter, and retail taking place in final destination markets along coastal West Africa (Rich and Wane, 2021). The greater geographic dispersion of transhumance routes in West Africa has brought pastoralists into the value chain performing intermediary functions between farmers and buyers (Ayantunde *et al*., 2014).

In all species, a range of informal and backyard value chains exist in parallel with those found in the formal sector. These value chains are informal, with transactions based on the need for cash to pay for various livelihoods activities (school fees, festivals, petty cash) and part of a general household income diversification strategy. Pastoralist systems deserve special mention in this context, where cattle serve wealth, status, and livelihoods purposes more so than commercial ones. Livestock, particularly poultry, in such settings can also have important sociocultural functions and where the role of women in both raising and receiving income from poultry predominates (Alders *et al*., 2014). These cultural functions are important, particularly in how they shape actor perceptions towards shocks such as diseases and mitigation measures. HPAI control efforts in Egypt and Indonesia were sometimes thwarted by farmers hiding animals from veterinary service culling campaigns, for instance. In addition, livestock value chains are rarely spatially segmented, meaning that backyard, semi-commercial, and commercialized chains all interact across space, while pastoralist systems increasingly interact (and often drive conflict) with sedentary farmers. From a risk perspective, the minimal biosecurity existing on backyard farms can serve as a spatial externality on others and magnify secondary idiosyncratic shocks from an initial covariate one.

The complexities and interconnectedness of actors and functions inherent within the livestock value chain challenge the identification and quantification of impacts of shocks in the livestock sector, whether from conflict, drought, disease, or their interactions in these areas that drive and reinforce each other. The resilience of households in coping with such shocks depends in large part on the role that livestock play in their respective livelihoods and the nature of the shocks encountered. In the context of pastoralist production, for example, Lybbert *et al*. (2004) observe that shocks can be both covariate (affecting all pastoralist) and idiosyncratic. While conflict, droughts, or animal diseases can induce mortality losses across all pastoralist communities, pastoralist farmers with smaller herd sizes tend to be less able to mitigate risk due to greater own-consumption and less income to support animal health. On the other hand, livestock shocks can be covariate across a given species but not at sector level. Kimenyi *et al*. (2014) found that in the case of Mali, the value chain for cattle was severely impacted, as herders were required to move animals to southern areas of the country that became quickly overgrazed and degraded, creating tensions between pastoralists and farmers in those regions, while traders had difficulties both in getting animals to market and in safely accessing and controlling cash for trade. As a consequence, markets seized up, reducing to barter for a time, while additional shocks of animal disease increased as well. While the spike in demand caused by market disruptions increased entry into the butchery node of the value chain, this came at the expense of food safety given the limited experience of new entrants (Kimenyi *et al*., 2014). Small ruminants (particularly sheep and goats), by contrast, were less impacted.

Given the existence of a wide body of literature on animal disease shocks in the developing country livestock sectors, it is instructive to use this as an initial starting point for an assessment of resilience more widely in livestock value chains and in fragile and conflict settings. These both magnify and are magnified by the potential for conflict in conflict-afflicted areas, particularly the Sahel and the Horn of Africa where livestock are critical for both livelihoods and international trade. Generally speaking, animal disease shocks tend to have the greatest impacts among more medium-sized actors (neither the smallest-scale farms nor the largest). Smaller-scale farms are often more diversified in their farm activities such that a shock to livestock holdings only affects a portion of their livelihoods, while bourgeoning commercialized farmers that specialize in livestock are more severely impacted by disease shocks (Nguyen *et al*., 2021). Downstream, the ability of actors to cope depends greatly on their ability to leverage savings and cash flow in alternative activities. The case of HPAI showed that the main impacts on backyard poultry producers was in their inability to leverage chicken sales for petty cash, while commercial farms were much more impacted. Market impacts can be pronounced, but generally short-lived albeit with a lag as both supply and demand bounce back. Nonetheless, important feedback effects based on stakeholder response to disease and mitigation options can significantly influence market dynamics. The prevalence of distress sales whereby farmers sell animals at a discount in reaction to actual or perceived disease can exacerbate both disease and market shocks (Rich *et al*., 2011a). The experience with HPAI in 2008–2009 in Africa and Asia revealed price declines ranging from 20 percent to 60 percent with sales falling from 20 percent to as high as 90 percent (Rich *et al*., 2011a). Downstream losses were high but mitigated through a range of strategies including drawing from savings, family support, and diversification into other activities where possible (Rich *et al.,* 2011a).

In a recent study of African Swine Fever (ASF) in Viet Nam, Nguyen *et al*. (2021) found that the impacts at farm-level of ASF disproportionately affected emerging small- to medium-scale farms whose livelihoods were mainly derived from pig farming. The impacts on sampled smallholder farmers were relatively modest as only 20–30 percent of their incomes came from the sale of pigs, while the largest scale units had high levels of biosecurity that largely buffered the mortality impacts of ASF, but still had a short-term market impact given the reduction in demand. Downstream, an important consequence of ASF was a move towards more selective purchases from large-scale farmers and a move away from cash transactions of live animals and towards the use of remote videos of pigs for sale and bank transfers to minimize personal contact (Nguyen *et al*., 2021).

Rift Valley Fever (RVF) in Kenya in 2007 had a number of nuanced impacts downstream that are often not recognized at policy level and specifically targeted vulnerable, conflict-prone parts of the country in north-eastern Kenya. For instance, movement controls to limit disease spread across the country had a knock-on effect on transporters, whose income pre-RVF was 60–80 percent from livestock trade. Traders typically drew down their savings in response to the outbreak, which made it more difficult to restart operations once the disease subsided. In one region (Mwingi), half of cattle traders and three-quarters of goat traders had not resumed trading activities one month after the conclusion of the outbreak (Rich and Wanyoike, 2010). Similar magnitudes of delayed re-openings were reported by local butchers. Movement controls had pronounced impacts on prices spatially across Kenya, with initial price spikes upon imposition of movement controls and price declines as a result of lower consumer demand. Rich *et al.* (2011a) found similar impacts on employment and distribution in the context of HPAI in Africa and Asia.

More interesting were the various community-level impacts associated with RVF. In NE Kenya (specifically Garissa and Mwingi), slaughterhouses were typically idled for up to three months, with impacts not just on slaughterhouse workers but ancillary activities to the slaughterhouse (e.g. scrap sales, tea vendors, cart transporters). In non-affected regions of Kenya, the lack of throughput had a pronounced shock (with incomes down 70 percent or more) on slaughterhouse workers, who are paid on a piece basis rather than a day wage (Rich and Wanyoike, 2010). The resilience of such actors, particularly ancillary ones to the chain, to these types of shocks is unknown. Presumably, in the absence of alternative activities at community level, there would be a reliance on family, savings, remittances, and other sources to see through such actors during these periods, but almost certainly a return to them once market activities resumed.

Because of the limited coordination inherent in many if not most livestock value chains, the role of collective action in buffering the impacts of shocks has been limited. In the case of HPAI, there was some albeit uneven role of associations and the private sector in helping to craft messages and public awareness about biosecurity and food safety (Rich *et al*., 2011a). In Viet Nam, the success of a local cooperative in managing ASF during the outbreak provides some cautious optimism on the role associations can play as a risk mitigation measure (Nguyen *et al*., 2021). In the context of pastoralist production, de Haan *et al*. (2016) point to the potential role of pastoral associations as a means of enhancing dialogue and participation.

A final aspect associated with livestock value chains and their resilience to shocks concerns the temporal nature of both covariate and idiosyncratic shocks. When shocks such as disease outbreaks take place matter as much, if not more, on the ability of value chain actors to respond, react, and adjust to them. For instance, the first outbreak of ASF in Viet Nam took place in early

February 2019, around the Vietnamese Tet holiday. An earlier outbreak would have had even more pronounced impacts on the sector, given the spike in demand in pig meat that happens between Christmas and Tet. At the same time, the ability of government to respond was significantly affected by the timing of ASF – emergency budgets for compensation were administered at provincial level and many of these were exhausted after the Tet holiday, making it both difficult for government to provide compensation in a timely manner and incentivizing farmers to sell diseased animals, accelerating the spread of disease (Nguyen *et al*., 2021). Likewise, during RVF in Kenya in 2007, the outbreak took place during a time of peak prices and prevented the sale of animals at times when animals were in peak condition (Rich and Wanyoike, 2010).

Based on this review, a number of stylized facts/hypotheses can be generated to help inform a more general perspective of resilience in livestock value chains that will be addressed in the following section:

- The nature of resilience is typically species- and chain-specific.
- Biological delays accentuate and delay the recovery of markets; feedback between value chain nodes accentuate the reactions of markets and biophysical phenomena to shocks.
- Spatial and temporal aspects associated with shocks matter – when and where a shock takes place has a pronounced impact on the total magnitude of a shock and how fast markets recover.
- Overlapping production systems and value chains imply that covariate shocks can also lead to idiosyncratic ones as well. While backyard producers are typically more resilient towards disease, drought, or conflict-related shocks given their diversification into other activities, in some cases (particularly for disease, possibly in certain conflict settings) their presence can act as a spatial externality for others that are more at risk.
- Farm production “generally” recovers from a shock, although as impacts tend to be the most severe among those on the pathway to commercialization, the distributional impact is quite nuanced and under-researched.
- Downstream value chain nodes “generally” recover from a shock albeit at high financial and/or personal cost. There may be consolidation or permanent market exit that past analyses have not sufficiently probed.
- Collective action remains limited as a resilience-building tool, but potential exists to leverage it.
- Public policy (e.g. compensation), at least in the context of animal disease shocks, has overwhelmingly focused on the producer side of the value chain at the expense of downstream actors, despite significant impacts on the latter (Rich *et al*., 2011a; Rich and Wanyoike, 2010; Nguyen *et al*., 2021).

Resilience conceptual framework

In this section, we will advance the concepts elaborated in the previous section to develop a conceptual framework of resilience in livestock value chains. We will then use the framework to further interrogate analytical methodologies that can potentially accommodate this type of analysis and develop a precis for a research agenda for future implementation.

Our starting point is the Resilience Index Measurement and Analysis (RIMA-II) framework developed by FAO (2016). Resilience in this framework is defined as "a capacity that ensures stressors and shocks do not have long-lasting adverse development consequences." (FAO, 2016). This approach considers both short- and long-term impacts and adjustments at household level to shocks. In RIMA-II, four pillars underpin resilience: access to basic services, assets, social safety nets, and adaptive capacity. Access to basic services refers to public services such as health, education, markets, and basic infrastructure (electricity and water) that mitigate risk and vulnerability in the wake of shocks and provide the institutional context that facilitate market transactions necessary for income generation. The use of assets instead of income is motivated by how shocks might influence household financial behaviour in the short- and longer-term and whether their asset base changes in response. Adaptation refers to how well households adapt and reorganize activities in response to shocks. Learning effects and innovation are important components of adaptation (FAO, 2016).

RIMA-II looks at resilience primarily from the vantage point of the household, using econometric techniques to assess the resilience of households to different shocks. However, it is instructive to consider how these concepts could relate in a more systems perspective as found in a value chain. In Figures 1 and 2, the RIMA-II conceptual framework is adapted for analysis of a stylized value chain. In both figures, three different nodes of the value chain (farm, distribution [e.g. traders], and processing) are considered, with each node possessing the different pillars of resilience described above; note that this can be expanded to more complex value chains. In Figure 1, we consider first a covariate shock that affects the entire value chain. Following RIMA-II, nodal actors will engage in different coping strategies including consumption and asset smoothing and partaking in alternative or new livelihoods activities. The nature of these strategies will vary significantly by node, level of formality of a node in the value chain, and the impact of such a shock on relative income. These coping strategies will have both direct short-term effects on one's own node and on others as well as long-term impacts that occur with a lag, which are particularly important in the context of livestock systems. An idiosyncratic shock that influences a single node (say farmers, see Figure 2), will initially impact farmers and downstream actors solely from those strategies taken by farmers, but over time, there will be lagged interaction effects that will transmit both upstream and downstream in the value chain.

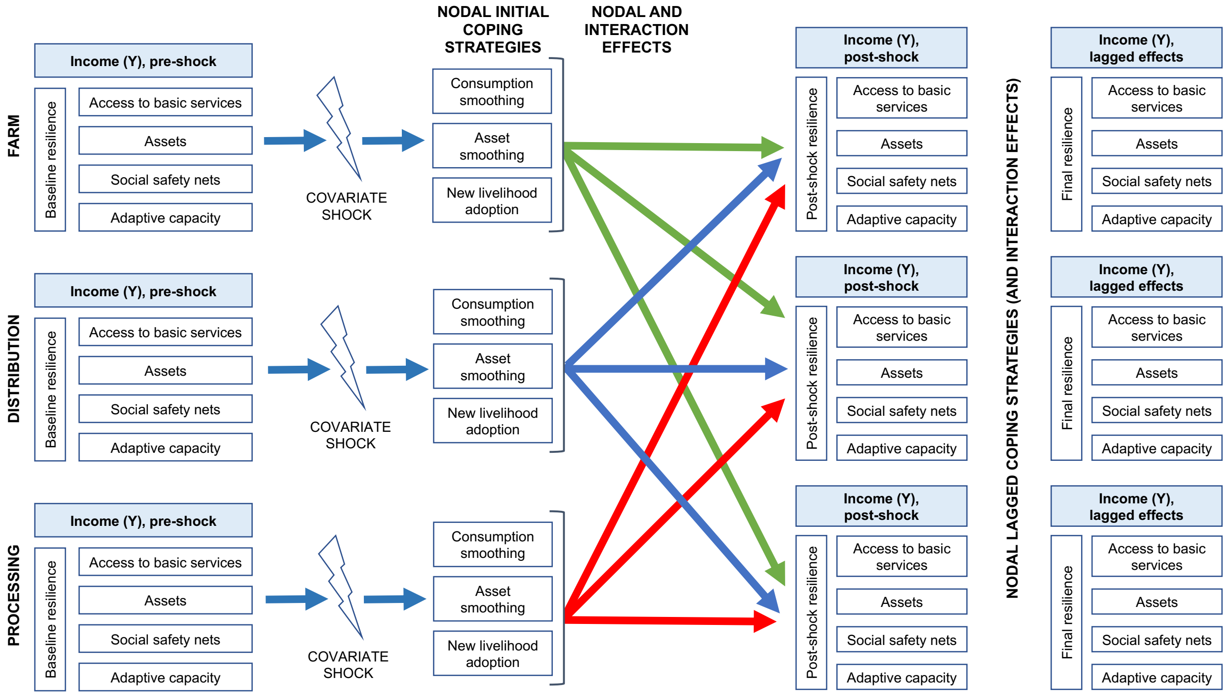
Some important implications provided by the draft framework, and building on the earlier analysis, are as follows:

- The characteristics of pillars of resilience i.e. the relative importance of access to basic services, assets, transfers, and adaptive capacity will differ by (and likely within) a given value chain node. However, this will shape the resilience profile of the value chain in that "weak links" (from a resilience perspective) could undermine otherwise resilient nodes. For example, processors who would otherwise be resilient to an idiosyncratic shock facing its own node (such as a food safety recall) may be much less resilient to a covariate conflict shock or an idiosyncratic shock affecting livestock supply or animal movements.

- The pillars of resilience themselves will be an important component of value chain governance and coordination, with shocks to the resilience capacity of specific actors temporarily or permanently altering the dynamics of the value chain itself. For instance, the exit of traders or other intermediates from the chain due to conflict or a disease-related shock will alter market power in the chain; in extreme cases, markets themselves could seize and not function for a time.
- In livestock systems, much more so than other agricultural systems, the impacts of coping strategies by a value chain actor (and on others) will take place with a lag, given e.g. biological delays in restocking, seasonality, or lumpiness in demand (particularly in informal chains). These will be more pronounced in large ruminant systems (cattle) and much less so in short-cycle species like poultry.
- Coping strategies invariably have feedback effects that may be non-linear and multiplicative. For example, a covariate shock (e.g. conflict) may induce asset smoothing by farmers to retreat from markets and will reduce demand for inputs, while input suppliers may be affected by an inability to source locally produced and imported goods, further reducing animal productivity at farm level and compounding the possibility of other shocks such as disease. From the standpoint of consumption smoothing, farmers may liquidate herd stocks in response to conflict and to have more liquid sources of assets on hand.
- Analytically, the framework suggests a much more holistic perspective than the current RIMA-II framework. In RIMA-II, the unit of the analysis is the household with specification amenable to econometric estimation. In a value chain, where dynamic and evolutionary effects influence resilience pillars, coping strategies, and system structure, an econometric methodology will be less useful. Instead, more multi-sectoral or systems approaches will be required; these will be discussed more in the next section.

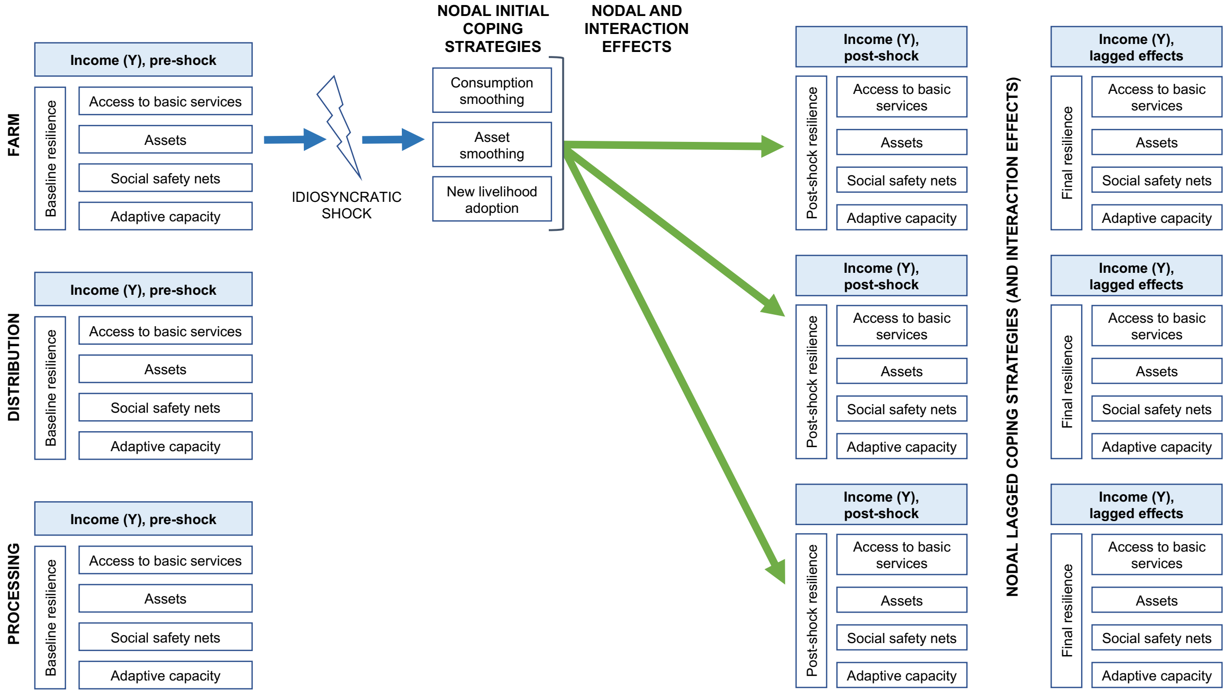
The adapted conceptual framework in Figures 1 and 2 provides guidance in the context of resilience in two crucial ways. First, it gives a means of understanding how and where different analytical frameworks used in livestock value chain assessments more generally can be used and transformed to understand issues of resilience. Second, it provides a roadmap for unpacking nodal-level resilience strategies and dimensions that are affected and transformed by interactions and feedback with other value chain actors. This helps us in understanding the types of fit-for-purpose nodal-level interventions that might be required to address different types of shocks, particularly in conflict areas where nodal capacity to mitigate risk and support adaptation may be quite heterogenous and where the impacts of resilience-building strategies may not manifest in the short- or medium-run.

Figure 1. Resilience conceptual framework: covariate shocks



Source: Adapted from FAO. 2016. *Resilience Index Measurement and Analysis – RIMA-II*. Rome. https://www.fao.org/3/i5665e/I5665E.pdf

Figure 2. Resilience conceptual framework: idiosyncratic shocks



Source: Adapted from FAO. 2016. *Resilience Index Measurement and Analysis – RIMA-II*. Rome. https://www.fao.org/3/i5665e/I5665E.pdf

Methods for analysis of livestock value chains

In this section, we highlight the types of analytical methods that can used to analyse resilience in livestock value chains based on the conceptual framework presented in the previous section. Not all methodological frameworks used for livestock sector analysis are appropriate in this context. For example, the Livestock Sector Investment and Policy Tool (LSIPT, see Dutilly *et al*., 2011), while highlighting the multi-functional aspects of livestock from multiple vantage points (micro, meso and macro) and their role in livelihoods lacks the ability to model behavioural responses to shocks in its forecasting, whether at household, value chain, or national level. Similarly, the use of computable general equilibrium (or CGE) models is precluded by the lack of granularity of value chain dynamics found in the social accounting matrices (SAM) used to underpin a CGE model.[1] Valuable research using econometric techniques has been conducted by the Livestock Policy Lab at FAO to address issues of resilience in the livestock sector due to climate shocks, for example (Acosta *et al.,* 2021b), though the focus here has primarily been at the household (production) node of the value chain. Time-series techniques, such as vector auto-regressive (VAR) or vector error-correction models (VECM) models as applied by Barratt *et al*. (2019) to calculate the indirect costs of animal diseases, are valuable in the use of a reduced-form approach, but in a value chain context where the evolution of system structure as a result of a shock is of interest in analysis, such an approach is limited in utility.

Instead, we focus our attention below on three approaches that have been used in value chain contexts explicitly: qualitative value chain analysis, system dynamics approaches, and partial equilibrium models. The latter two approaches are particularly relevant in the context of resilience where an important analytical construct is in comparing equilibrium (or a steady-state) before and after a shock. Partial equilibrium models (as well as CGE and some econometric approaches) provide guidance on impacts and equilibrium arising immediately after and some time after a shock. By contrast, system dynamics models highlight more granularity on the adjustment process (in terms of herd structure and specific value chain actor behaviour) in moving from one state to another as a result of a shock. Unlike partial equilibrium and CGE models, system dynamics models may not have an explicit equilibrium but instead show different evolutionary patterns of change over time; such models would thus illustrate differences between a baseline trajectory (without a shock) versus a trajectory in which a shock takes place.

1.1 Qualitative value chain approaches

A range of qualitative and mixed methods approaches have been used to examine shocks to livestock value chains. In the absence of standardized quantitative approaches, value chain approaches, following the tools outlined in Kaplinsky and Morris (2001), have become ubiquitous in the analysis of livestock systems, particularly related to disease impact assessment studies (see for example Taylor and Rushton [2011], Rich and Wanyoike [2010], Alarcon *et al*. [2017] or McLeod *et al*. [2009]). Generically, value chain studies help to map and

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[1] The Rural Investment and Policy Analysis (RIAPA) initiative of the International Food Policy Research Institute (IFPRI) has made improvements in both the use of more disaggregated SAMs (species and value chain activities) and links to upstream livestock herd dynamics through the use of the LEAS (Livestock Economics and Animal Systems) model (Aragie *et al*., 2021). However, even with the most disaggregated SAM, typically only production and processing nodes of the value chain are specified, with other intermediate markets specific to livestock not directly modeled.

identify chain actors and product flows, identify governance mechanisms that drive coordination and power in the chain, explore opportunities for upgrading, and assess the benefits of value chain participation (Kaplinsky and Morris, 2001). In livestock settings, these studies have been used to qualitatively identify actors in the value chain that may act as risk hotspots for the persistence and spread of disease. In a similar vein, such techniques could also plausibly identify and describe the characteristics of those actors are more prone to external shocks and their resilience towards those, though the intersection of resilience metrics and formal qualitative value chain methods has yet to be formalized. In conflict areas, less work using this approach has been conducted on the livestock sector, though Hiller *et al*. (2014) cite a study on value chain development in South Sudan, while Kimenyi *et al*. (2014) assess the role of conflict on various agricultural sector dynamics, including livestock, in Mali and Nigeria. By systematically mapping the flows and levers of transactions within the value chain, value chain studies collect a range of qualitative and quantitative information in often granular detail. Recent work by Indrawan *et al*. (2018) looked carefully at the role of value chain governance (specifically issues of market power and organization) and asset specificity as important drivers of stakeholder behaviour associated with investments in biosecurity and actions on mitigation. This is particularly relevant for pastoral systems in conflict-affected zones, as the breakdown of traditional governance mechanisms to mediate conflict has been driven by various types of market and environmental shocks to pastoral livelihoods (de Haan *et al*., 2014). This area would be amenable to a more thorough interrogation of the role that governance drivers have on conflict and resilience and vice-versa.

Data from value chain work often relies on focus group discussions, checklists, key informant interviews, and other rapid data collection techniques, and as such may not be fully representative as would a formal household survey in terms of specification of absolute numbers or the ability to do rigorous statistical/econometric analysis. The companion concept note on the resilience in AFVC of small and medium enterprises (McIntosh, 2022) provides an example of the value chain mapping tools highlighted above that overlay a standard mapping of AFVC (or livestock value chain) actors alongside dimensions of resilience, such as redundancy in service provision, climatic shocks, movement controls and trade restrictions, price shocks, and so on.

A relatively recent innovation in this area is the use of qualitative system thinking tools to engage in the development of mental models and causal loop diagrams with stakeholders. This process, known as group model building, helps stakeholders work through the causal relationships that influence or are a consequence of a particular problem through a facilitated process (Vennix, 1996). This also allows for the identification of what are termed leverage points that could influence the behaviour of such systems (Berends *et al*., 2021b). Even in their qualitative guise, significant information on the nature, dynamics, and relationships embedded within a value chain can be collected. A spinoff of group model building, termed spatial group model building, uses maps and participatory GIS techniques to uncover spatial and temporal patterns of value chain flows and processes that enhance stakeholder understanding and joint learning (Rich *et al*., 2022). Spatial group model building was used in Zambia to address spatial and socioeconomic drivers of East Coast Fever control (Mumba *et al*., 2017) and in Timor-Leste to understand the sociocultural and institutional context of African Swine Fever (Berends *et al*., 2021a). In the latter, the authors identified the primacy (and current lack) of trust relationships between veterinary services and producers in service provision and the role of linking credit provision to biosecurity investments.

Similar to value chain analyses, group model building sessions rely on the development of checklists of information through which a tightly facilitated process of stakeholder focus groups is administered. An advantage of this approach over value chain mapping is in its ability to generate testable hypotheses of specific leverage points and their prospective impacts on system behaviour that could be further quantified in a system dynamics model (to be discussed in the next subsection).

If we relate value chain and group model building (GMB) methods to the conceptual framework developed in the previous section, value chain analysis potentially provides clarity on the pillars of resilience at nodal level, particularly in describing specific coping strategies of chain actors and how they may transmit along the value chain. Group model building techniques add another dimension of motivating the contextual drivers of resilience and their causal influences.

1.2 System dynamics approaches

System dynamics approaches are an increasingly common method to unpack the rich dynamics inherent within livestock value chains. System dynamics models represent a simulation approach to the study of complex systems, complementing the qualitative work found in conventional value chain analysis. They have their origins in industrial engineering to study dynamic improvement processes and grounded in the theory of nonlinear differential equations. system dynamics models are particularly useful where dynamic processes and feedback mechanics underpin behaviour, which make them highly relevant for livestock markets. At value chain level, system dynamics models can quantify the dynamic and evolutionary impacts of various shocks and interventions (policy, environmental, technical) on different actors in the value chain; while usually focused on financial impacts (e.g. impacts on profits or net income), a range of impact dimensions could be considered. Moreover, they can easily accommodate overlaying livestock production alongside downstream marketing, environmental, epidemiological, and institutional dimensions and their interactions (Rich *et al*., 2011b). This provides a rich laboratory for conducting scenario analysis and impact assessment to predict alternative trajectories of system evolution and change, based on various shocks.

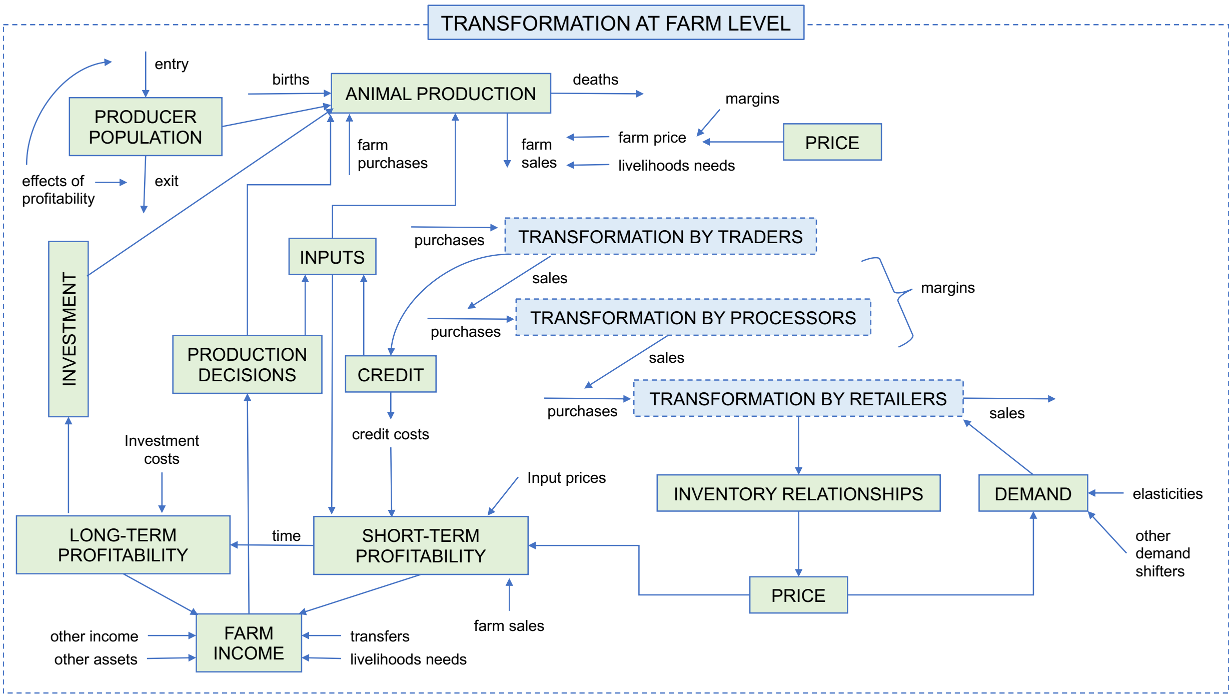
A system dynamics model of a value chain is a set of stocks, flows, and technical parameters for each node in the value chain. Each node represents a system-wide average of a given actor class (farmers, traders, processors, etc.) in the value chain. A stock represents the amount of livestock (or meat) a value chain actor holds at time *t*. For farmers, the biology of animal production from young animals to old ones is often modelled as a cohort model that highlights the transition of animals within different age classes, as well as inflows of purchased animals and outflows of animals sold or those that die. Further downstream in the value chain, the amount of animals of meat held in inventory at time *t* depends on previous period stocks, purchases (inflows), and sales (outflows). These inflows and outflows, from farm to fork, are influenced by technical parameters (breeding rates, death rates, etc.), market parameters (prices as mediated by demand, expected profitability, costs), and environmental factors (carrying capacity, rainfall), which themselves can be subject to other external shocks (drought, demand shocks, disease, conflict) that affect the evolution of the value chain over time. The profitability of market participation by each node can be readily computed over a simulation period based on prevailing prices, sales, and costs, as well as assets held by different actors (physical assets, financial, etc). While the numbers of actors associated with each node are usually kept fixed, it would be possible to consider scenarios of value chain entry and exit as mediated by external shocks.

Figure 3 provides an abstraction of a system dynamics model of the value chain. The figure as shown highlights production, marketing, investment, and profitability from the standpoint of the production (farm) node, with downstream sales to traders, processors, and retailers shown in aggregate (as a dotted box). For each value chain node, the relationships associated with production, transformation, and profitability as shown for farmers here would themselves be directly modelled. Using the nodal relationships in Figure 3 as a guideline, farm production of animals would be modelled as an age-cohort model to highlight not only the biology of production but also the different use values of animals and their vulnerabilities to shocks (e.g. death from drought or disease). Downstream, animals are sold to different intermediaries and transformed into meat, with eventual sale at retail driven by consumer demand. Farm profitability depends on the amount of revenue earned from farm sales valued at the farm-gate price less input costs including the provision of credit, which can be modelled endogenously (Berends *et al*., 2021b). We distinguish between short-term profitability, which through total farm income influences production decisions taken in the next period, and long-term profitability, the latter determined by successive profitability over time, and which influences decisions to invest in greater capacity (e.g. animal holdings, land, other value chain functions). Perceptions of profitability also influence decisions associated with entry into the system or exit. Income from livestock farming is one aspect of household income, which can also include other farm activities, non-farm activities, transfers, asset withdrawals, and costs associated with livelihoods obligations.

In a system dynamics model, each of these components is explicitly modelled, parameterized through both primary and secondary data collection which can be facilitated by the GMB methods noted in the previous section. From the standpoint of resilience, shocks and coping strategies in the system can be directly simulated in such a framework. For example, a drought would induce higher mortality in animals (particularly younger animals) which would have both direct (immediate) impacts on animal availability downstream and lagged impacts on future supplies, given less breeding stock available in future. Reduced supply would raise prices, lowering consumer demand and (depending on supply elasticities) reducing farm revenue. These shocks could be buffered in part by the provision of credit and transfers that would offset the income shock to households. Training at farm level in herd management practices could further mitigate shocks by influencing production decisions. Entry or exit decisions throughout the chain could further mediate and influence the dynamics within the value chain.

Issues of conflict could also be directly modelled following the model of Saeed *et al.* (2013). In this model, agents are classified as farmers, soldiers, or bandits, with the transition between states (stocks) depending on both economic and psychological dimensions. In particular, as farm income drops, the movement from farming to banditry becomes more attractive, creating more bandits and the stealing of resources from farmers (Saeed *et al*., 2013). Social norms and cohesion also play a role in maintaining group identity and determining whether groups remain in their current state or not. While stylized, potential exists to relate more fully the linkages between economic interactions as found in the value chain and political economy ones.

Figure 3. An abstraction of a system dynamics model of a livestock value chain



Source: Author's own elaboration.

To date, these approaches have been used in a range of applied analyses of developing country livestock chains, including *inter alia* beef sector trade and disease dynamics in Botswana (Dizyee *et al*., 2017), Burkina Faso (Rich and Wane, 2021), Cambodia (Rich and Roland-Holst, 2014), and Namibia (Naziri *et al*., 2015); pig sector development strategies in Myanmar (Berends *et al*., 2021b); dairy sector interventions and investments in Nicaragua (Lie *et al*., 2018); and small ruminant trade dynamics from the Horn of Africa (Mtimet *et al*., 2021; Wanyoike *et al*., forthcoming). The model by Berends *et al*. (2021b) is particularly salient in the context of resilience as it was used to address the interactions between pig production, marketing, and consumption with the provision of resilience-building mitigations such as credit and institution building (i.e. the development of producer groups and organizations) that were endogenously modelled. Over different temporal scales (short-term, medium-term, long-term), this model highlighted the financial benefits accruing to different actors in the value chain based on alternative investment options and identified value chain level trade-offs. Likewise, Mtimet *et al.* (2021) considered the impacts of both animal (RVF) and human (COVID-19) disease shocks on the value chain for sheep and goats in Somaliland, contrasting impacts amongst different value chain actors insofar as identifying those actors that are more prone to financial stress from external shocks in conflict zones. This provides a potential template for looking at resilience-enhancing interventions in future.

Unlike many types of economic analyses, intermediaries within the value chain can be addressed in a system dynamics model, in terms of their marketing behaviour (trade in goods and services), ability to influence prices, and role in the provision of financial services. Monopoly or monopsony power of specific value chain nodes can be directly modelled; see Dizyee *et al*. (2017) for an example of modelling the monopsony power of the Botswana Meat Commission in a system dynamics format. In other cases, where perfect competition exists, intermediary prices can be defined by way of a fixed margin. The absence or reduction of intermediaries or other system actors due to conflict or other market shocks (e.g. COVID-19) has not been addressed in previous sustainable development models but could be if such data were available.

At the same time, production and marketing behaviour are not the only dimensions that can be modelled. For instance, production interactions between livestock production and feed (pasture or crops) can be directly modelled (see Wanyoike *et al.* [forthcoming] and Dizyee *et al*. [2017] for examples on pastures). Rich and Roland-Holst (2014) further modelled a simple crop-livestock system of rice and the use of livestock for animal draught power to highlight linkages in more intensive systems. Rasmussen *et al*. (2012) used system dynamics modelling to model the drivers of land use changes and their impacts on crop-livestock systems. Moreover, learning and adoption effects that influence production and marketing patterns can be modelled that could serve as leverage points for intervention through extension activities or capacity building (see Lie *et al*. [2018] or Berends *et al*. [2021b] for examples).

Despite the many virtues of system dynamics approaches, system dynamics models can be both computationally and data intensive to develop, though some breakthroughs have been made recently to at least partially obviate these challenges. Participatory processes such as group modelling building (Lie *et al*., 2017; Berends *et al*., 2021 and noted in the previous sub-section) provide a relatively rapid way to characterize system behaviour and obtain data from stakeholder-mediated discussions. In addition, Dizyee *et al*. (2021) has recently generated a suite of species-specific generic value chain models that cover many of the important value chain processes used to model the value chain. A combination of these approaches alongside value chain mapping holds promise in generating necessary context-specific models that can be used with more generic templates. This will be discussed more in the next section.

1.3 Partial equilibrium approaches

Multi-market, partial equilibrium approaches are another approach utilized in the context of livestock value chain assessments. Multi-market approaches can be further disaggregated into horizontal or vertical analyses. Horizontal models couch livestock in the context of the broader agricultural system, e.g. various livestock species integrated with different crop and feed markets. This approach has been used in large partial-equilibrium models of the global agricultural and livestock economy such as IMPACT (Msangi *et al*., 2013) and GLOBIOM (Havlik *et al.*, 2014), with the latter having somewhat more resolution on the livestock sector. Other approaches include national models looking at agricultural diversification strategies (Goletti and Rich, 1998) and those that have examined the impacts of animal diseases (Rich and Winter-Nelson 2007; Nguyen *et al*., 2021; Jean-Pierre *et al*., 2022). In such horizontal models, there is limited resolution of value chain processes between farm to fork. The model of Rich and Winter-Nelson (2007), from which the models of Nguyen *et al*. (2021) and Jean-Pierre *et al*. (2022) were in part derived, considers supply and demand relationships for live animal and meat markets but intermediaries in the value chain (as in a system dynamics model) are not modelled explicitly nor are alternative market structures (e.g. deviations from assumptions of perfect competition). At the same time, inferences about intermediate markets, at least from the standpoint of transactions costs in trade, can be made. For instance, the above-referenced models utilize a variety of margins and transaction costs between production and consumption to calibrate price relationships in local and international markets that can be shocked to look at issues such as market closures (Rich and Winter-Nelson, 2007; Nguyen *et al*., 2021) or improvements in transport infrastructure (Goletti and Rich, 1998) as scenarios.

Vertical approaches, by contrast, explicitly look at the market structure from farm to fork in vertically linked markets. The standard model is what is termed an equilibrium displacement model (EDM). An EDM is a reduced form, linear approximation of supply and demand relationships in vertical markets in which relationships are specified in elasticity form (percentage changes) by totally differentiating a set of structural supply and demand relationships (Wohlgenant, 1989; Pendell *et al*., 2010). In this way, shocks to either supply or demand in the system can be measured based on their impacts on changes in quantity or price; computations of producer or consumer surplus can also be made. An advantage of such an approach is that where elasticity estimates are available, parameterizing such a model is straightforward.

The origin of this approach is seminal work by Muth (1964) and Gardner (1975) that derived equilibrium conditions and elasticity relationships in a vertical system of production, consumption, and marketing systems that can be used to explore the impacts of shocks in any of these three markets. Holloway (1991) expanded this to consider imperfect competition in such markets, providing a lens into value chains where such relationships are important. Later work by Freebairn *et al*. (1982) and Wohlgenant (1993) adapted this approach to examine the impacts of research expenditures in a vertically integrated system; Holloway (1989) expanded this to disaggregated markets for both processing and distribution. Other applications include impact assessment of the distributional effects of animal identification and traceability (Pendell *et al*., 2010; Shear and Pendell, 2020); country of origin labelling (Brester *et al*., 2004); and shocks to marketing margins and price spreads in livestock and meat markets associated with COVID-19 (Lusk *et al*., 2021).

On their own, partial equilibrium approaches do not well address the pillars of resilience or coping strategies, but can serve as an initial way of abstracting impacts of various conflict, environmental, or production related shocks, assuming some mechanism that supply and/or demand is impacted or in intermediary markets how market power may change. However, combined with aforementioned qualitative approaches, they may have some utility in at least a rapid assessment of prospective resilience effects, though without the granularity that systems thinking tools provide.

Quo vadis: indicators and a modelling agenda

Deepening our engagement with the resilience of livestock value chains requires a more integrated approach that takes into account (a) the biology, dynamics, and feedback effects of livestock production and markets; (b) the roles played by and governance features of market intermediaries that can both accentuate and mitigate risk and who themselves are impacted by upstream and downstream shocks; (c) the multifunctional roles that livestock play (and in turn the respective resilience of each of those functions); (d) identification of the specific dimensions of the pillars of resilience and coping strategies per value chain node; and (e) given these pillars and strategies, the transmission, dynamics, and measurement of impacts throughout the value chain. This necessitates a mixed methods approach to contextualize quantitative modelling results with a more nuanced interpretation of impacts from observed shocks.

In the next two sections, we highlight two research strategies. First, we articulate the types of indicators that underpin a systems approach to resilience in livestock systems. We then discuss a strategy for collecting data and conducting analytical studies in this area.

1.4 Indicators for resilience at value chain level

As discussed earlier, the RIMA-II framework provides a set of resilience pillars to assess the capacity to manage shocks at household level. To look at a value chain, we will need to consider the possible suite of indicators and strategies that could be adopted by node. In Table 1, we look at nodal data that could be collected at nodal level to assess the drivers of resilience. While following the spirit of RIMA-II, a number of specific nuances exist in Table 1 amongst the different nodes. First, while RIMA-II focuses on indicators at household level, the indicators in Table 1 will refer (outside the producer level) to specific actors, businesses, or operations and the assets, services, transfers, and capacity that influence their activities within the value chain (and not specific to those in their households *per se)*. In addition, market and input services from government, particularly extension and veterinary services play a more pronounced role as do services downstream to facilitate export or food safety. The suite of assets held by different value chain actors will also differ, with downstream operations (particularly processors and retailers) potentially holding more physical infrastructure and durable assets. While social safety nets are not like to appreciably differ from RIMA-II, the focus of such transfers might. In particular, upstream actors tend to be covered more by such transfers (e.g. the use of compensation by government in animal disease outbreaks as an example). Adaptive capacity in Table 1 highlights the use and sources of credit (whether formal or informal), the depth of income diversification, access/use of training in nodal-specific upgraded practices (management, technology, handling), and participation in horizontal coordination mechanisms such as producer groups, associations, or cooperatives. The latter highlights the ability of nodal actors to obtain financial, physical, or managerial resources necessary to recover from shocks. While RIMA-II addresses both networks and credit on a cursory level, what's listed in Table 1 tries to deepen our knowledge of sources and volumes of credit access and teases out more specifics on the networks engaged in themselves.

The types of questions provided here serve important roles as exogenous leverage points that influence the dynamics of a systems-based approach to a livestock value chain. An important question concerns the types of indicators used to measure the resilience of the value chain itself. Within the system dynamics literature, recent work by Herrera and colleagues (Herrera, 2017; Herrera and Kopainsky, 2019) has looked at the explicit measurement of agricultural systems resilience, building on earlier work from the ecology literature (see e.g. Walker *et al.* [2004]). These models were used to develop indices of different dimensions of resilience at the level of the system, namely concepts of hardness (the ability of a system to bounce back from a shock without affecting metrics of performance); elasticity (the ability of a system to maintain at its original steady state after a shock); and an index of resilience, defined as the probability of keeping a system at its original steady state after a shock (Herrera and Kopainsky, 2019).

Past value chain research using systems thinking tools (Dizyee *et al.*, 2017; Berends *et al.*, 2021) has typically used profitability at nodal and whole-of-chain level as the main metric of performance, with intervention options typically highlighting temporal (short- vs. long-run) impacts and trade-offs between different nodes. While the concepts of hardness, elasticity, and an index of resilience could be applied to nodal profitability, other metrics of performance may also be relevant. An incomplete list of potential performance indicators could include the following:

- Net numbers of market actors at nodal level (capturing entry/exit and changes in market organization or governance as a result of a shock)
- Numbers of actors engaged in different, more successful or resilient coordination mechanisms e.g. producer groups or cooperatives – Berends *et al.* (2021b) endogenized the movement of farmers into producer organizations and group based the relatively profitability and benefits that membership brought to such farmers
- Herd dynamics changes e.g. changes in cohort structure (such as more older animals in a herd/flock), changes in herd sizes, use of different breeds with different productivity/resilience profiles and consequent changes in marketing and volumes of meat traded.
- Time to “normal” recovery, in terms of profitability, herd sizes, etc.
- Nodal cashflow, to highlight to ability and strategies taken by value chain actors to mitigate risk and manage shocks (Berends *et al.*, 2021b).

In the last section, we provide some guidance on a strategy for developing systems models and collecting model data necessary to operationalize this approach.

Table 1. Prospective dimensions of resilience in livestock value chains

Pillars of resilience	Prospective dimensions				
	Input supply	Farmers	Traders	Processors	Retailers
Access to basic services	• Access to mobile network (Y/N) • Access to electricity (Y/N) • Access to water (Y/N) • Access to tarmac roads (distance) • Access to extension services (distance) • Frequency of extension service visits (times per month) • Distance to markets (km)	• Access to mobile network (Y/N) • Access to electricity (Y/N) • Access to water (Y/N) • Access to tarmac roads (distance) • Access to extension services (distance) • Access to veterinarian (distance) • Access to input shops (distance) • Frequency of extension service visits (times per month) • Frequency of veterinary service visits (times per month) • Distance to markets (km)	• Access to mobile network (Y/N) • Access to electricity (Y/N) • Access to water (Y/N) • Access to tarmac roads (distance) • Access to extension services (distance) • Distance to markets (km)	• Access to mobile network (Y/N) • Access to electricity (Y/N) • Access to water (Y/N) • Access to tarmac roads (distance) • Access to extension services (distance) • Distance to markets (km) • Frequency of government inspection (food safety, public health)	• Access to mobile network (Y/N) • Access to electricity (Y/N) • Access to water (Y/N) • Access to tarmac roads (distance) • Access to extension services (distance) • Frequency of government inspection (food safety, public health)
Assets	• Number of vehicles owned (car, motorbike, truck) • House (own/rent) • Kiosk (own/rent) • Mobile phone • Farm inputs (plough, animal traction, tractor) • Number of animals (by age class – cattle; by age class – pigs; sheep/goats; camels; chickens) • Hectares of land (owned/rented)	• Number of vehicles owned (car, motorbike, truck) • House (own/rent) • Mobile phone • Farm inputs (plough, animal traction, tractor) • Feed inputs by type (kg) • Number of animals (by age class – cattle; by age class – pigs; sheep/goats; camels; chickens) • Hectares of land (owned/rented)	• Number of vehicles owned (car, motorbike, truck) • House (own/rent) • Kiosk (own/rent) • Mobile phone • Number of animals (by age class – cattle; by age class – pigs; sheep/goats; camels; chickens) • Hectares of land (owned/rented) • Cooling facility (refrigerator, freezer) • Animal pens (capacity; dimensions, m^2)	• Number of vehicles owned (car, motorbike, truck) • House (own/rent) • Kiosk (own/rent) • Mobile phone • Processing facility (owned/rented) • Slaughter slab (owned/rented) • Slaughter implements • Cart (owned/rented) • Cooling facility (refrigerator, freezer) • Animal pens (capacity; dimensions, m^2) • Processing infrastructure (hooks, knives, tables, etc.)	• Number of vehicles owned (car, motorbike, truck) • House (own/rent) • Kiosk (own/rent) • Mobile phone • Butchery shop (own/rent) • Cutting tools (knives, etc.) • Market space (own/ren) • Market furniture (table, cutting boards, chairs, etc.) • Cooling facility (refrigerator, freezer)

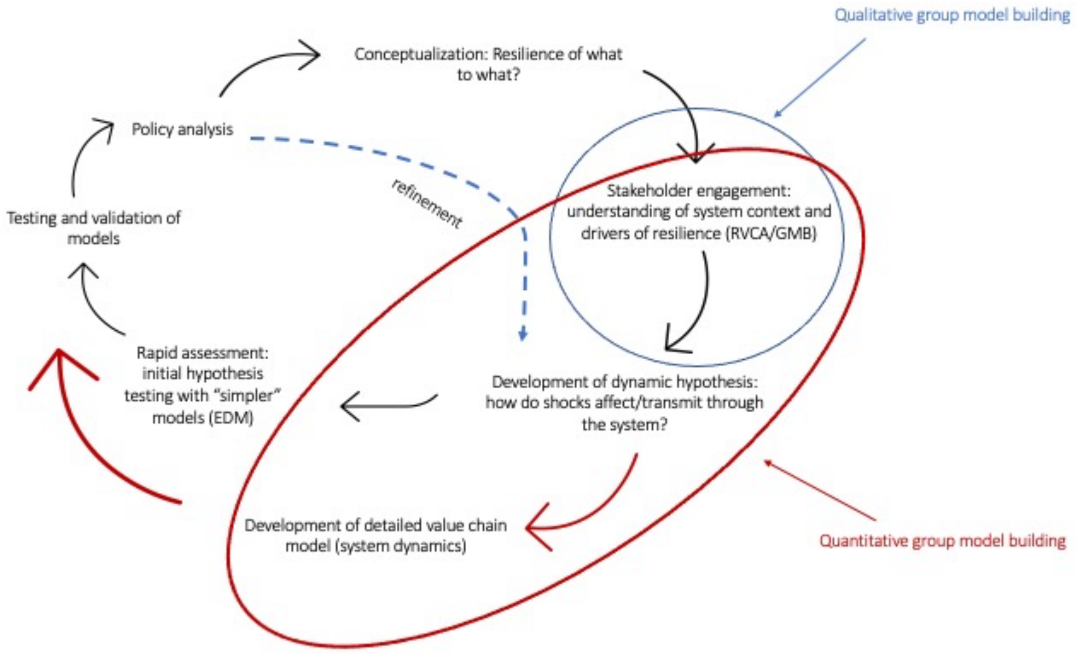
Pillars of resilience	Prospective dimensions				
	Input supply	Farmers	Traders	Processors	Retailers
Social safety nets (transfers)	As per RIMA-II, though emphasis/importance may differ by node • Volume and sources of credit (amount, percent) • Participation in producer groups or cooperatives				
Adaptive capacity	• Sources of income (%) • Training in input practices (# years)	• Sources of income (%) • Training in animal management and herd health practices (# years) • % of livestock vaccinated for specific diseases (FMD, PPR, Newcastle)	• Sources of income (%)	• Sources of income (%) • Training in improved processing practices (# years)	• Sources of sales (%) • Training in good handling practices

Source: Author's own elaboration.

1.5 Analytical methods

In the context of systems thinking, Herrera (2017) proposed an iterative framework for engaging with resilience in complex systems, through which a simulation approach using system dynamics would be used to test developed dynamic hypotheses on resilience and leverage points for policy. In Figure 4, we adapt this approach slightly to incorporate an initial qualitative lens on livestock systems in conflict-affected areas, using participatory processes such as rapid value chain analysis (RVCA) and GMB. We will subsequently sharpen our earlier analysis of how a GMB approach would be appropriate and the various steps required to implement it. From such a qualitative analysis, dynamic hypotheses on leverage points for intervention could be developed which, depending on resource availability, could be applied in a rapid assessment framework using adapted EDM tools or through the development of a comprehensive system dynamics model of the value chain, following Berends *et al*. (2021b) that used GMB tools both qualitatively and quantitatively.

Figure 4. Conceptual framework for participatory impact assessment of resilience in livestock value chains



Source: Adapted from Herrera, H. 2017. From metaphor to practice: Operationalizing the analysis of resilience using system dynamics modelling. *Systems Research and Behavioral Science*, 34(4): 444–462. https://doi.org/10.1002/sres.2468

The process of group model building is an important stakeholder-led means of obtaining contextual information about a complex system such as a livestock value chain. Rich (2021) and Rich *et al*. (2022) walk through the process of group model building and the use of what are termed "scripts" for facilitation. A script is a set of facilitated, time-bound activities aimed at collecting a set of specific information from a stakeholder group. In spatial group model building, after some initial introductory activities, one of the first data-gathering scripts is the use of a participatory GIS platform to develop common spatially explicit understanding about a particular system. Rich *et al*. (2022) describe the use of a tool called Layerstack, which is akin to an offline GIS – a paper base map of a region (whether village, community, region, or nation, depending on the scope of analysis) is overlayed by plastic acetates that represent different data layers, such as land use patterns, climatic zones, socioeconomic areas, conflict zones, and so on. During this script, a facilitation team goes through a set of guided questions on characteristics of the value chain and asks participants to label where these attributes take place, using markers or stickers. Reference modes, or the behaviour of such attributes over time, are graphed using a simple x–y graph with the x-axis denoting time and the y-axis denoting qualitatively whether a given attribute (for example, market sales) has increased, decreased, remained constant, or oscillated over time. This exercise is an essential one in learning how the value chain works and gaining a common understanding amongst stakeholders on the spatial context in which they operate, which in turn assists in subsequent scripts and data gathering (Rich *et al*., 2022).

After the participatory GIS exercise, stakeholders are asked to identify and prioritize key problems within the value chain, which are tallied and voted upon through an agreed process. Each of these priority problems is then interrogated more deeply through a "causes-and-consequences" script that uses system thinking tools (causal loop diagrams) to identify causal factors of a problem, their consequences and feedback. This exercise helps with providing initial insights on possible risk factors and leverage points for intervention. From this exercise, participants next identify core parts of the value chain (termed modules) that serve as the building blocks of a qualitative mental model that could be subsequently parameterized quantitatively. Modules could include the different nodes of the value chain (from farm to fork) as well as other contextual drivers, including institutions, finance, feed, gender, etc. Dimensions of resilience as explored by McIntosh (2022) for SMEs and AFVC could be easily adopted. These modules are iteratively built with stakeholders and integrated together. Throughout the process, consensus and agreement on what is developed is solicited to ensure buy-in and joint-ownership (Rich *et al*., 2022).

Group model building exercises can remain exclusively qualitative or descriptive or can be a formal part of a quantitative model building process. In the former, denoted in the blue circle in Figure 4, the objective is to gain qualitative insights on the value chain used to generate hypotheses on prospective leverage points for policy; this can be complemented with standard rapid value chain analysis techniques or surveys. This was the approach taken by Berends *et al*. (2021a) in the context of understanding the animal health system underpinning ASF control in Timor-Leste. By contrast, in the latter, denoted by the red oval in Figure 4 and used by Berends *et al*. (2021b) in Southern Myanmar, each of the modules developed from the participatory process was subsequently modelled and parameterized using system dynamics software. Stakeholder discussions provided details on not only the structure of the system but also generated specific data points used in the model, which were triangulated from other available primary and secondary data and an external reference group of experts. Where data were uncertain, graphical parameters and/or the use of probability distributions were used, with Monte Carlo simulations run to generate probabilistic results. Once the model was complete, interventions were discussed with the stakeholder group and agreed upon, after which simulations and results shared with stakeholders and model structure fine-tuned as needed. While the model was developed to inform the implementation of different development interventions (new technologies, adoption of hybrid pigs, institutional development, etc.), these also captured the role that value chain shocks such as from disease outbreaks played in their uptake. In particular, an important finding from the simulations was that while the provision of microfinance helped to fuel uptake of hybrid pig varieties in lieu of less productive traditional ones, the price fluctuations caused by regular disease outbreaks cause more farmers to eventually drop out of hybrid production given their inability to generate cashflow to service loans. The model further pointed out the benefits of packages of interventions that combined had much larger positive impacts than any one individual intervention alone (Berends *et al*., 2021b).

The resource requirements for group model building can be modest, at least for qualitative approaches. Identifying a team of facilitators in-country is an essential part of the process. They will need to be trained in systems thinking tools and GMB scripts; tools and manuals for training exist (see Rich, 2021) and experience with teams in Myanmar and Timor-Leste revealed that local teams will gain enough facility in GMB facilitation after a week or so of intensive training. The focus groups themselves typically rely on the use of a stakeholder group of 10–15 value chain actors, selected carefully to reflect participation amongst the different value chain nodes, ensure gender diversity, and to minimize any issues with power or conflict within the group (Lie *et al*., 2017; Berends *et al*., 2021b). Typically, both qualitative or quantitative GMB utilizes between three and five focus group sessions requiring half a day. An online GMB recently administered in Ghana had more sessions (six) that were of shorter duration, roughly 90 minutes to two hours (Enahoro *et al*., 2021). While the first two sessions are typically conducted back-to-back on consecutive days, subsequent ones are usually a week or two apart to allow the team to process and synthesize the information gathered. Quantitative GMB sessions are more resource and time-intensive in that after the final focus sessions, significant time may be required to build, test, troubleshoot, and finalize the quantitative model to be used. As noted earlier, generic concept models as developed by Dizyee *et al*. (2021) may be one way to short-circuit this process to some extent, though depending on the setting, there can be value in a more customized model for a given context. The development of system dynamics models also requires core expertise in systems modelling, which is more difficult to find and takes longer to train.

Data requirements for a system dynamics model typically include the following, though this is by no means exhaustive:

- Data on herd dynamics (age composition, years in age state, total herd size, net offtake rates, natural mortality, fertility rates, parturition rates), triangulated with secondary data on herd dynamic trends. Typologies of production systems can be used where relevant/desired (Seré and Steinfeld, 1996).
- Data on quantities purchased and sold by value chain actor and prices received, including marketing margins and seasonal trends and final consumption at consumer level.
- Inventory relationships (i.e. time spent in inventory) at different value chain nodes and responsiveness of quantities and inventories to price (elasticities).
- Where feed markets are directly modelled, information on feed area, yield, rainfall, quality of feed resources, processes of feed dynamics (either/both environmentally through rainfall or human use and the process of adoption of different types of feed or pasture resources (Lie *et al*., 2017; Wanyoike *et al*., 2023). Links with pasture/feed to herd growth can also be modelled.
- Data on conversion rates from animals to carcass to final cuts for consumption,
- Imports and exports and trends over time (by month/season), where relevant.
- Disease dynamics (contact rates, infection rates, recovery rates, mortality rates) where epidemiological dynamics are relevant (Rich and Roland-Holst, 2014).
- Partial budgets, particularly highlighting Input use and production costs, to compute profitability for different value chain nodes.
- Information on farm decision-making for investment based on changes in profitability (Lie *et al*., 2018).
- Learning and adoption effects in the use of alternative technologies or practices (Berends *et al*., 2021b).

Where resources preclude a full quantitative model, the stakeholder engagement process could nonetheless inform the development and use of more parsimonious approaches that could be used to generate insights on the impacts of shocks on value chain resilience. As noted earlier in the review, outside of system dynamics models, EDM approaches provide significant detail on the interactions in vertically linked markets without the need for specifying complex structure. EDMs require data on elasticities (own- and cross-price) in modelled markets at a minimum; more complex EDMs incorporate elasticities of substitution and cost shares. The majority of EDMs have been developed for the United States of America. markets where copious data exists for the estimation of robust elasticities. In conflict-affected zones, this data is unlikely to be available, meaning that elasticity estimates will need to be gathered from the literature and assumed based on expert knowledge and consultation. Confidence bounds could be placed on elasticity assumptions, with a Gaussian quadrature used to generate distributions of results where uncertainty exists (Rich and Winter-Nelson, 2007).

An EDM approach, on its own however, does not capture the nuances of livestock production and so to properly specify an EDM for livestock requires linking such a model to a more robust model of herd dynamics. One approach under development by the author is linking a herd model DynMod (Lesnoff, 2008), used in system dynamics model and LSIPT to model herd evolution, to downstream markets specified in an EDM. Recent developments at the International Livestock Research Institute (ILRI) and the International Food Policy Research Institute (IFPRI) have created a version of DynMod in GAMS (see Punt *et al*., 2021), making such joint approaches possible.

Data requirements for an integrated EDM would include:

- Data on herd dynamics (age composition, years in age state, total herd size, net offtake rates, natural mortality, fertility rates, parturition rates), triangulated with secondary data on herd dynamic trends.
- Data on elasticities (supply, demand, cross-price) in upstream and downstream markets, including response of herd inventories to expected prices (based on naïve expectations of previous period prices, see Rich and Winter-Nelson [2007].
- As available, for each value chain node (and any horizontally linked markets such as feed as desired), data on the cost share of meat, the share of inputs used by meat producers, and the elasticity of substitution between meat (or inputs) and marketing inputs in production (Bhattacharya *et al*., 2009).

1.6 Operationalization of methods to inform policy and the choice of intervention options

To conclude this paper, it is useful to provide some guidance on the various types of resilience building interventions that could emerge from the analysis provided above. These interventions represent an additional overlay in terms of data collection, which will also be described below.

The use of a systems thinking paradigm to assess the impacts of different interventions in livestock value chains has been described earlier in Section 4.2; what follows is an expansion of that analysis to highlight intervention options. GMB techniques with stakeholders, in addition to being a useful approach to interrogate the structure of a livestock value chain, can also play a pivotal role in identifying fit-for-purpose intervention options that can subsequently be tested through the development of formal system dynamics models of the value chain itself. In Nicaragua, Lie *et al*. (2017, 2018) used stakeholder consultation to first prioritize the set of problems facing the dairy sector, with later focus groups identifying the suite of interventions (increased concentrate use; improved pasture; subsidies; extension/training) that was later tested with their model. Similarly, Berends *et al*. (2021) used participatory processes to jointly identify a suite of interventions associated with upgrading in the pig value chain in southern Myanmar, including different microfinance loan modalities, extension with animal health workers, training, artificial insemination, and institutional innovations through producer groups and organizations; the role that disease shocks from African Swine Fever was also modelled in conjunction with these. In both cases, the structure of these interventions was built with stakeholders and added as an overlay in their models. The model of Berends *et al*. (2021) is particularly instructive as it endogenized the decision of a producer to join and remain in a producer group based on the relative benefits received and the ability of that group to provide services of value over time. Similarly, different loan options and modalities (alternative amortization schedules, balloon payments, varying length of loans) were further modelled as different scenarios to identify how different financing mechanisms can improve profitability and resilience.

From a resilience perspective, a number of interventions that enhance resilience could be considered, including the use of vaccines, provision of commercial feed and/or fodder, better access to water, social protection, access to credit, upgrading to new species, improved access to input and output markets, and so on. Participatory processes using systems thinking empower stakeholders to collectively prioritize these options and use the models developed to visualize trajectories of change, further helping with buy-in for the implementation and ownership of identified options. Precedent already exists in the use of these models to inform investments – the model of Berends *et al*. (2021) was used by development partners World Vision and Vision Fund to target their pilot investments and develop fit-for-purpose loan structures in southern Myanmar that allow for larger amounts of loan capital and tailored repayment schedules that are more suitable to the vagaries of pig production.

An additional benefit of such approaches is the ability of systems models to address varying temporal impacts (short-, medium- and long-term). In the livestock sector, as noted earlier in the paper, there may be a significant delay in the impact of certain interventions such as feeding, vaccines, or improved genetics on production, given the long delays especially present in ruminant species (cattle, pigs). Having this knowledge *ex ante* is critical in the development of resilience-building interventions to ensure their sustainability over time and which do not trade-off short-run expediency for long-term impact.

The additional data requirements to bolt on these interventions into a resilience-oriented systems thinking platform are fairly modest, particularly where participatory processes are used. Additional triangulation with other stakeholders will be required. This information will include technical information on the costs of different interventions, production and marketing structures (where relevant, e.g. for feed or issues of market access), and input-output parameters that translate investment into impact. The latter may be informed by both secondary data from similar contexts and/or stakeholder engagement to provide a range of plausible effects which can be simulated through a range of sensitivity analyses. In addition, modelling learning and innovation effects that translate knowledge to action is critical. Within a system dynamics model, overlays that model such processes directly (Rogers, 2010) can be easily employed.

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