Modeling Supply Chains and Markets to Support Humanitarian Response Analysis

by

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Submitted to the Institute for Data, Systems, and Society
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Abstract

In a crisis, information about supply chains and markets for essential commodities can be sparse, yet an understanding of them is critical to delivering effective humanitarian assistance. Humanitarian organizations are looking to improve their processes to assess and analyze supply chains and markets to inform response option analysis. Existing methods remain limited in their consideration of supply chains and markets as inherently dynamic and complex systems; this thesis develops and applies two complementary methods to capture this dynamism and complexity to produce outputs useful for decision-making. The first method, multi-mode information aggregation, involves continuously synthesizing new information from a range of sources to form an understanding of the situation. It was developed and applied to guide United States Agency for International Development (USAID) food security programming to support the maize market system in Uganda in response to the COVID-19 pandemic. A key insight from this application was that female rural traders in border areas may be more significantly affected than other traders. The second method, a system dynamics model, models the behavior of a supply chain for essential commodities in a crisis. It was developed and applied to study the effects of the displacement crisis in Northeast Nigeria on the supply chain for rice in Borno State, and to inform International Committee of the Red Cross (ICRC) processes and response. The model was used to project outcomes for target populations under different scenarios and humanitarian response options, incorporating in-kind assistance, cash assistance, and credit for supply chain actors. A key finding was that when cash assistance is being provided to a broad target population, further humanitarian spending may be significantly more effective as credit to supply chain actors instead of as more cash assistance to the target population. Results from the model also highlighted potential other areas for humanitarian intervention, such as improving access to market information. Broadly, both these methods highlight the need to consider supply chains and markets as complex and dynamic systems that can be disrupted by a crisis and the resulting humanitarian programming, but can also be harnessed to deliver assistance more effectively to people in need.

Thesis Supervisor: Jarrod Goentzel
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I'm in an incredibly fortunate position to write this thesis. Many people have gotten me to this point and across the finish line. It is not possible to list everyone here who has supported me or my work throughout my two years at MIT; here is a highly condensed list.

For the thesis itself, I have first to thank my advisor Jarrod Goentzel. His endless optimism and drive has helped push through every challenge, all the time patient with me. I also have to thank Maria Besiou, for added support and insight throughout the project. Alex Gachoud, Niccolo Giancarli, and Claire Durham at ICRC were not only crucial to the project, but were a pleasure to work with. They contributed not only to the research specifically, but also to my experience in the sector more broadly. From USAID, I want to thank Maggie Linak for her support, as well as Laura Gonzalez and Tor Edwards for earlier work that was key to building the foundation of this thesis.

To Courtney Blair, I am grateful for all I learned in the late night work in Uganda, and (sadly) remote work in the first COVID summer. More than just that, she has been a reliable person to know and talk to. I also enjoyed working with Finley Wetmore during COVID — a good help to keep sane during disrupted times. The support I also received from Tim Russell, Erica Gralla, and Chelsea Graham was always useful, and I wish we had the chance to work together more.

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Acronyms

BAY	Borno, Adamawa, Yobe
DQ	Driving question
EMMA	Emergency Market Mapping and Analysis
FAO	Food and Agriculture Organization
FtF	Feed the Future
HEA	Household Economy Analysis
HP	Host population
ICRC	International Committee of the Red Cross
IDP	Internally displaced person
IFRC	International Federation of Red Cross and Red Crescent Societies
IOM	International Organization for Migration
MAG	Market Analysis Guidance
MSM	Market Systems Monitoring
NBS	National Bureau of Statistics, Nigeria
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
RAM	Rapid Assessment for Markets
RO	Response option
SCA	Supply chain actor
SD	System dynamics
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WFP	World Food Programme

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Chapter 1

Introduction

1.1 Overview

Humanitarian organizations often need to make decisions in rapidly-changing, complex, and information-sparse environments. Almost always, the behavior of markets and supply chains is an important consideration. The project outlined in this thesis developed methods that synthesize information to inform decision-making in such environments. The methods were developed in two contexts: the COVID pandemic and its impact on the agriculture market system in Uganda, and the displacement crisis in northeast Nigeria and its impact on the supply chain for rice. This thesis examines existing methods used by humanitarian organizations to analyze markets, describes the methods developed in this project, and presents and discusses some results from these methods.

Chapter 1 outlines the research questions and context, and provides a literature review. Chapter 2 describes the two methods used in this project. Chapter 3 presents results from these two methods. Chapter 4 discusses the results. Chapter 5 offers some conclusions.

1.2 Research Questions

The research in this project aimed to answer the following questions:

- How can we synthesize information from a varied range of sources to generate an understanding of a complex market system in a crisis?
- How can we improve our understanding of the behavior of an essential commodity supply chain in a crisis with analytical modeling?
- How can we leverage our understanding of a market system or supply chain in a crisis to evaluate response options or interventions, and shape additional ones?

1.3 Contexts

The research in this project was conducted in two separate contexts. The first context is the maize market system in Uganda in the midst of the COVID-19 pandemic. The second is the rice supply chain in Borno State, Nigeria in the midst of the displacement crisis in northeast Nigeria and the Lake Chad Basin. These two contexts were each to develop separate but related methods to assess market systems in a crisis and plan future responses.

1.3.1 COVID-19 in Uganda

1.3.1.1 Market system: Uganda maize

Agriculture employs two-thirds of the labor force in Uganda, provides about half of the country's export earnings [85], and about a quarter of the GDP [29]. The country has fertile soil and favorable year-round climatic conditions. Most of the production is at the smallholder and subsistence level, where the rainfed conditions and low use of agricultural inputs has kept productivity levels low.

This project investigated the market system for maize. Maize is produced in all four regions of Uganda, with a total annual production of approximately 400,000 metric tons (MT). Approximately 14% of this is exported [29].

1.3.1.2 Organization: USAID/Uganda

The United States Agency for International Development (USAID) has been working in Uganda since 1962. One of their programs is Food for Peace (currently under the Office of Food for Peace (FFP)), which since 1964 has aimed to alleviate hunger and poverty globally. FFP funds activities for distribution of cash and in-kind aid in Uganda, as well as other multi-year development activities. In 2020, FFP contributed $40 million, and 45,810 metric tons of food assistance in Uganda [86]

The Feed the Future Initiative (FtF) was launched in 2010 as the *"the U.S. Government's global hunger and food security initiative"* [85]. In Uganda, it aims to reduce hunger and malnutrition by strengthening the market system to improve agricultural productivity.

Together, FFP and FtF represent an important overlap in humanitarian and development work. The need to concurrently consider immediate and long-term needs of affected populations (strengthening the 'humanitarian-development nexus' [63]) is being increasingly recognized by donors, development organizations, and humanitarian organizations. As interventions with humanitarian funding and interventions with development funding increasingly work in similar spaces, the need to develop a common understanding of these spaces becomes more important.

The Market Systems Monitoring Activity (MSM) is an activity funded by USAID to assess the impact of market facilitation activities. It is implemented by the Humanitarian Supply Chain Lab at the Massachusetts Institute of Technology in partnership with The George

Washington University. The work conducted for this thesis was funded by the MSM activity.

1.3.1.3 Crisis: COVID

The COVID-19 pandemic has had widespread global impact. In addition to the public health impact, the various restrictions imposed to limit the spread of the virus have impacted supply chains and market systems. The context for part of this thesis is impact of COVID-19 and the resulting government restrictions on the maize market system in Uganda, during the months May-August 2020. This initial work was carried out by the MSM team, and is referred to in this document as the ‘Uganda project’.

1.3.2 Displacement crisis in Northeast Nigeria

1.3.2.1 Commodity supply chain: Rice in Nigeria

Rice is a significant staple crop in Nigeria, with a per-capita consumption of 35 kg in 2018. Only about 57% of this is produced locally, with Nigeria being the second largest rice importer globally (after China). Importation through land borders is prohibited, but difficult to enforce. In 2015, use of foreign currency for rice importing was banned [24]. These measures have been taken by the government to increase local production, which is expected to grow by 3.2% annually between 2018 and 2023. However, domestic prices remain high due to inflation, the significant excise tariffs for importing, high costs for local production, and high post-harvest handling losses (around 12%, due to poor infrastructure). Preference for imported rice is increasing due to rising incomes and urbanization [54].

The northwest region accounts for 72% of total domestic production. The northeast is a rice deficit area, with rice being supplied from elsewhere in the country. This is reflected in Figure 1-1, which is drawn from the ICRC’s initial 2015 analysis of the rice market system in Maiduguri, the capital of Borno State.

As rice is an important staple food for the region, and it is used in ICRC in-kind assistance, it was selected for the system dynamics model.

1.3.2.2 Organization: ICRC

The International Committee of the Red Cross (ICRC) is an international humanitarian organization established in 1863. Its mission is *“to protect the lives and dignity of victims of armed conflict and violence and to provide them with assistance”*, with its mandate stemming from the Geneva Conventions of 1949.

The Economic Security (EcoSec) unit within the ICRC aims to ensure that people are able to cover their essential needs. In Nigeria in 2020, EcoSec provided food consumption support to up to 357,954 people, and income support to up to 12,035 people [39].

The ICRC recognizes the importance of understanding markets for humanitarian response analysis. To help build market-sensitive interventions, the ICRC needs more in-depth

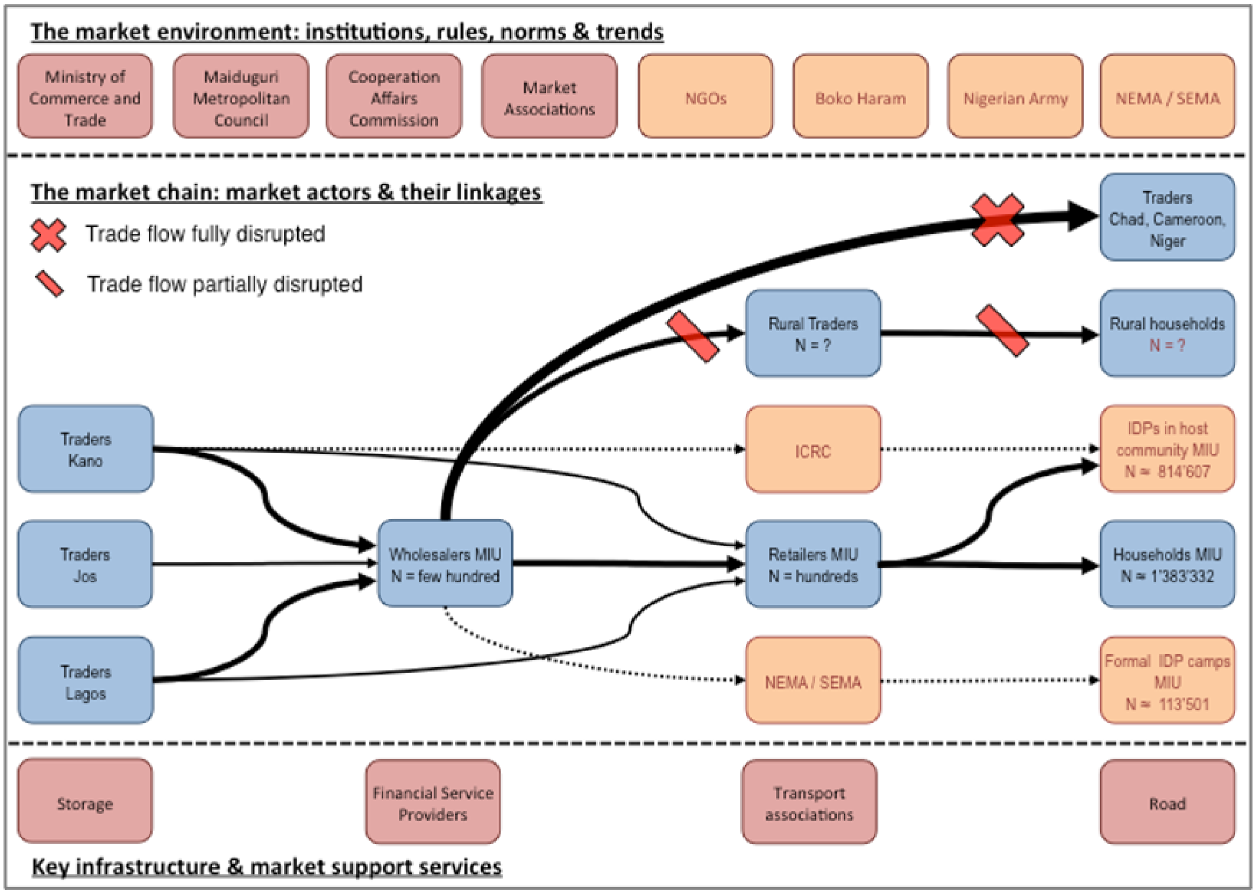

Figure 1-1: Market system for rice in Maiduguri during the insurgency (2015) [22]

market analysis, which it recognizes should be a joint responsibility between programme (EcoSec) and logistics staff. This concept is illustrated in Figure 1-2.

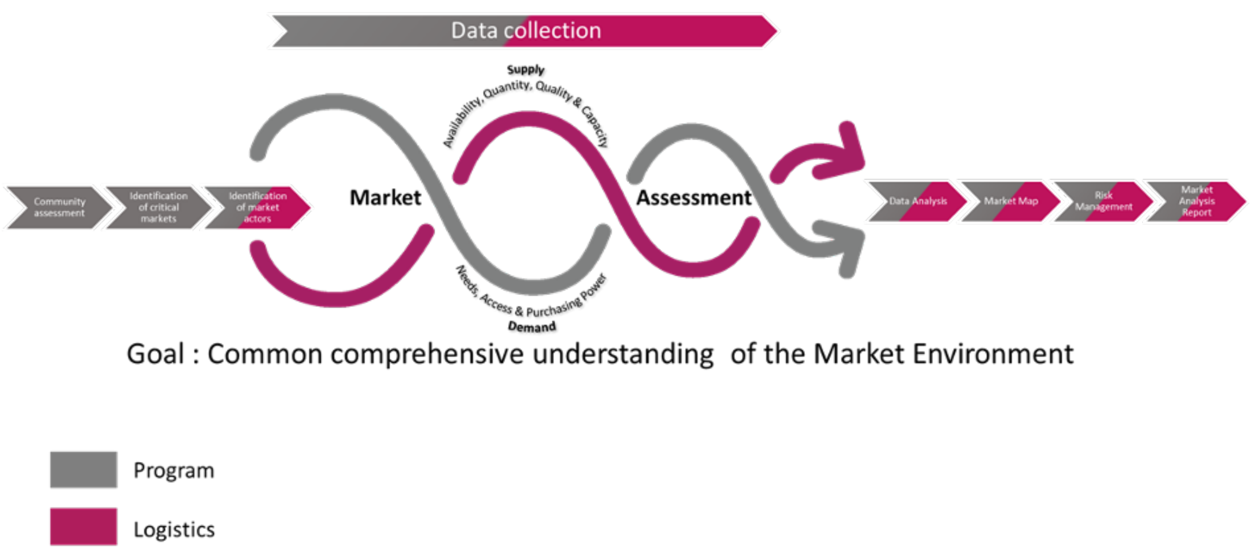

Figure 1-2: Market assessment programme and logistics roles [42]

The ICRC has been collaborating with the MIT Humanitarian Supply Chain Lab since late 2019 to develop a system dynamics model for the rice supply chain in northeast Nigeria. The work presented in this context for this thesis has been supported by staff from ICRC headquarters, with some input from ICRC Abuja. The first phase of the collaboration (late 2019 to May 2020) built a preliminary system dynamics model which is not addressed here. The second phase of the collaboration (November 2020 to September 2021) has built on the previous work, producing the model and results presented in this thesis [42].

1.3.2.3 Crisis: Displacement in Northeast Nigeria

Northeast Nigeria has been disrupted by armed conflict for over a decade. As of January 2021, this has displaced over 3.4 million people in the Lake Chad Basin region, of which 2.7 million are internally displaced people (IDPs) within Nigeria [83]. The main affected states in Nigeria are Borno, Adamawa, and Yobe (the BAY states). Within these states, 5.1 million people are projected to be in need of food assistance during the lean season in 2021 [78].

The conflict began in 2009 with the militant Islamist group Jama'atu Ahlis Sunna Lidda'-awati wal-Jihad (known as Boko Haram) beginning violent attacks in Northeast Nigeria, with a view to establishing an Islamic, Sharia-law governed state [47]. In 2013, the Nigerian government declared a state of emergency in the BAY states, while the United States and United Kingdom designated Boko Haram as a terrorist organization [84] [77]. In 2014, attacks intensified, resulting the thousands of deaths and hundreds of thousands displaced. In February 2014, the National Emergency Management Agency (NEMA) reported that there were approximately 300,000 IDPs in the BAY states. By April 2015, that number had grown to nearly 1.5 million, based on reports from the International Organization for Migration (IOM) [49], with nearly 1 million in Borno state alone. Since this escalation of violent conflict, there has consistently been more than 1.5 million internally displaced people, with more than 2 million internally displaced people since mid-2019. Although emergency has only been declared in the BAY states, evidence suggests that the true scope of the conflict extends to Gombe and Bauchi states as well [25], while OCHA cites 2.6 million people in need in Gombe, Taraba, and Bauchi states [79].

Humanitarian response in the region was initially slow to scale up [73]. However, since 2016, humanitarian presence has grown rapidly, with 117 different implementing partners operating in the BAY states in September 2020, of which 63 were national NGOs and 34 were international NGOs [80]. However, between 1.2 and 2.7 million people remain completely cut off from humanitarian assistance — insurgent groups control roughly 40% of Borno state [73].

In June 2021, it was confirmed Boko Haram leader Abubakar Shekau is dead [11]. However, this is not expected to improve the situation as the Islamic State of West Africa Provine (ISWAP), a group that broke away from Boko Haram in 2016, has remained on the offensive [23].

Even more recently, in July 2021, Niger set a goal of returning 130,000 Nigerian refugees to Nigeria by November or December 2021 [2]. This may further increase the number of IDPs in Borno state.

1.3.2.4 Interventions: Cash and voucher programming and in-kind aid

In 2017, a panel of 68 experts in humanitarian innovation, as well as ten individuals affected directly by humanitarian crises, took part in a Delphi study to determine grand challenges in humanitarian aid — defined as *"specific critical barrier[s] that, if removed, would help to solve an important humanitarian problem"*. The Delphi method is a technique that aims to build a consensus by iteratively surveying a panel of experts [57]. The first round of the study produced 83 unique statements representing challenges, with the final round ultimately identifying *"Strengthen Economies"* as the highest priority challenge [20]. Within this challenge, the first specific point listed was *''Scaling up cash-based assistance (rather than in-kind commodities)"*.

A 2015 report by the High Level Panel on Cash Transfers from the Overseas Development Institute similarly states *"Give more unconditional cash transfers. The questions should always be asked:* 'why not cash?' *and* 'if not now, when?'*."* and *"Invest in readiness for cash transfers in contingency planning and preparedness."* as the first two of 12 recommendations for the humanitarian system. The report reasons that unrestricted cash transfers *"align the humanitarian system better with what people need"*, *"increase the transparency [accountability, speed, and flexibility] of humanitarian aid"*, *"reduce the costs of delivering humanitarian aid"*, *"support local markets, jobs, and incomes"*, *"increase financial inclusion"*, and *"most importantly, provide affected populations with choice and more control over their own lives"* [6].

A major output of the 2016 World Humanitarian Summit was the Grand Bargain, an agreement between large donors and humanitarian organizations to improve the effectiveness and efficiency of humanitarian action. One of the ten workstreams is to *"Increase the use and coordination of cash-based programming"*, which acknowledges that although cash transfers are not a panacea, they can work alongside other modalities of assistance to provide effective support [38].

The noted effectiveness of cash transfers has translated to changes in mode of humanitarian assistance. Globally, the share of total international humanitarian assistance disbursed in cash and voucher form has increased from 10% to 18% from 2016 to 2019 (an absolute increase from $2.8B to $5.6B) [14]. Cash transfers have also been a key part of many governments response to the COVID-19 pandemic [52], with social assistance schemes relating to COVID-19 reaching 1.1 billion new people globally [18].

1.4 Literature review

The bulk of the literature review for this project focuses on market assessment and analysis tools used by humanitarian organizations, instead of more typical academic literature. These are existing toolkits, guidances, and methodologies that the methods developed in this project build on and complement. This focus on more operational and practical documents reflects the aim of this thesis to be applicable to existing processes in humanitarian organizations.

1.4.1 Market assessment and analysis tools

As the range of potential response options has widened in humanitarian response, an array of tools to analyze and assess the market have been developed by various humanitarian actors. A comparison of some of these tools has been compiled by CaLP [15]. This section presents a description of many of these tools, as well as a comparison between each other, and to this project. These tools are primarily compared to the methods used for the Nigeria context of this project — the system dynamics (SD) model.

Minimum Standard for Market Analysis (MiSMA)

The Minimum Standard for Market Analysis (MiSMA) [51] is distinguished from most of the other tools in that it forms part of the Humanitarian Standards Partnership (HSP). The HSP comprises several technical and non-technical standards, which together represent a consensus on best practices for humanitarian response. The central document of the HSP is the Sphere Handbook [71], which was created in 1997 by a group of NGOs and the Red Cross and Red Crescent Movement to improve the quality of humanitarian response and to help humanitarian actors be accountable for their actions. The most recent version was published in 2018, which only explicitly dedicates six of its 406 pages to market considerations in humanitarian response.

The MiSMA was initially developed in 2013, and was most recently updated in 2018. It supplements the Sphere Handbook with an additional standard: *"Market analysis is a key component of response analysis that informs the design and implementation of appropriate interventions using and supporting local markets"*. It outlines five key actions to be undertaken to meet this standard:

1. *Scope:* Define the analytical and geographic scope of the assessment
2. *Market analysis team:* Build a competent and knowledgeable team for data collection and analysis
3. *Data collection:* Use data collection methods and information sources of sufficient quality
4. *Analysis:* Use market analysis to adequately inform programme design and achieve programme objectives
5. *Market monitoring:* Use market monitoring to review assessment findings and enable programme adaptations when needed

For each key action, the MiSMA provides steps, key indicators, and guidance notes to help accomplish the key action. This structure mirrors that of standards in the Sphere Handbook. The MiSMA also provides a market analysis checklist to support its practical application and a set of guiding questions for programme decisions.

Minimum Economic Recovery Standards (MERS)

The Minimum Economic Recovery Standards (MERS) is another tool that is part of the Humanitarian Standards Partnership [70]. It was developed in 2007 by The SEEP Network and most recently revised in 2017. The MERS consists of five Core Standards:

1. Humanitarian programs are market aware
2. Efforts are coordinated to improve effectiveness
3. Staff have relevant skills
4. Do no harm
5. Intervention strategies for target populations are well defined

The first and fourth core standards are particularly relevant to this project. The second core standard is a potential application of system mapping, although this is not discussed in detail in this project. The MERS also consists of standards regarding:

- Assessment and Analysis
- Enterprise and Market Systems Development
- Asset Distribution
- Financial Services
- Employment

While the MiSMA is more aimed at humanitarian programming in an emergency, the MERS is more focused on longer term economic recovery. However, it is still applicable throughout a programme cycle.

Certain aspects explored in the MERS are potential ways to expand the current project to incorporate a more holistic view of the economy. Better understanding productive assets is key to understanding and analysing livelihoods, something not done in detail in this project. The same is true for employment. And while financial services are considered in this project, more detail could be useful.

Pre-Crisis Market Analysis (PCMA)

The Pre-Crisis Market Analysis (PCMA) is guidance developed in 2014 and revised in 2016 by the International Rescue Committee and Oxfam that focuses on market analysis *before* the onset of a crisis [53]. In this sense it is complementary to other market analysis tools. The PCMA provides guidance on preparing for pre-crisis analysis, conducting a pre-crisis analysis using existing tools (*e.g.,* the Market Analysis Guidance (MAG)), using the results from this analysis to inform preparedness and disaster risk reduction programming, and keeping the analysis up to date.

This project is complementary to the PCMA in the way that other market analysis tools are. The PCMA can provide guidance on how to implement the methods developed in this project in a pre-crisis setting.

Rapid Assessment for Markets (RAM)

The Rapid Assessment for Markets (RAM) is a set of guidelines developed by the ICRC and International Federation of Red Cross and Red Crescent Societies (IFRC) in 2014 [44]. They are intended, as the name implies, for the short-term assessment of markets immediately after a shock. The results from a RAM are intended to be valid for informing response decisions for only 4 to 6 weeks after a shock. After this, a more detailed market analysis (such as one provided by the MAG) is needed.

The RAM is split into five steps:

1. *Defining the scope of the assessment:* An overview of the area and secondary data is used to define which market systems should be assessed.
2. *Collecting market information:* Market information is collected with interviews and focus group discussions; findings are summarized.
3. *Analysing market information:* Based on the findings, the appropriateness of different response options is determined.
4. *Report the findings:* Findings are compiled into a *RAM Profile Report* for use in response analysis discussions
5. *Monitoring market evolution:* Changes in the market are monitored to inform any changes to interventions

The information aggregation method in this project is particularly relevant for initial information gathering to define the scope of the assessment, analysing the market information, and monitoring the market afterwards. The SD model in this project is an additional way to analyse the market information.

Some aspects of the RAM are also covered in the MAG. The MAG's relation to the SD model in this project is discussed in more detail in Section 2.3.5.

Market Analysis Guidance (MAG)

The Market Analysis Guidance (MAG) is guidance developed by the ICRC and IFRC in 2014 to integrate market analysis into existing phases of the project cycle [43]. It complements the RAM, being intended for two weeks to one year after a shock.

The MAG has informed this project extensively. Because of this, it has been given special attention in this document. See Section 2.3.5 for a detailed comparison of the MAG to the system dynamics model developed for this project.

Emergency Market Mapping and Analysis (EMMA) toolkit

The Emergency Market Mapping and Analysis (EMMA) Toolkit was developed in 2010 [4]. It provides guidelines for market analysis to inform response options and recommendations once an emergency situation has stabilized. Some of the EMMA methodology, regarding market mapping, is referenced in the MAG.

The EMMA toolkit outlines ten steps through which gap analysis (understanding the target population needs and preferences) informs market system analysis (understanding critical market system constraints and capabilities), which in turn informs response analysis (exploring different options and opportunities for humanitarian agencies). Together, these inform the recommendations for action.

The EMMA toolkit is quite extensive (over 200 pages). This project incorporates and synthesizes many aspects covered in the toolkit, most notably market mapping with actors and flows between them, and seasonality. One major difference between the EMMA toolkit and this project is that the EMMA toolkit has a strong focus on household needs, economic profiles, access constraints, and assistance preferences. In the SD model, these aspects get light or no treatment. However, the SD model attempts to turn market snapshots, such as those provided by the EMMA toolkit, into a fuller understanding of dynamic market behavior.

Market Information and Food Insecurity Response Analysis (MIFIRA)

The Market Information and Food Insecurity Response Analysis (MIFIRA) framework, published in 2009, is a set of questions and tools that can be used by humanitarian organizations to anticipate the impact of different response options [7].

The MIFIRA is based around a previously established [8] simple decision tree:

1. Are local food markets functioning well?
   Yes: Provide cash transfers or jobs to target recipients, not food aid.
   No: ↓
    2. Is there sufficient food available nearby to fill the gap?
       Yes: Provide food aid based on local purchases/triangular transactions
       No: Provide food aid based on transoceanic shipments

The MIFIRA expands on these two key questions, breaking the first one down into:

1a. Are food insecure households well connected to local markets?
1b. How will local demand respond to transfers?
1c. How much additional food will traders supply at or near current costs?
1d. Do local food traders behave competitively?
1e. Do food insecure households have a preference over the form/mix of aid they receive?

The SD model mainly addresses 1b. and 1c., takes 1a. and 1d. as inputs, and does not consider 1e.

The MIFIRA breaks the second question down into:

2a. Where are viable prospective source markets?
2b. Will agency purchases drive up food prices accessible in source markets?

2c. Will local or regional purchases affect producer prices differently than transoceanic shipments?

The SD model addresses 2b. and 2c., and does not consider 2a.

Like with other market analysis tools, this project complements the MIFIRA by presenting another way to analyse information to answer these questions. Most significantly, this project investigates the dynamic behavior of markets, whereas the MIFIRA (and other existing tools) are more tailored to assessing markets at a certain, specific point in time.

Market Monitoring, Analysis and Response Kit (MARKit)

The Market Monitoring, Analysis and Response Kit (MARKit) was first developed in 2008 and revised in 2020 by CRS. It is a toolkit to help adapt programming to changes in market conditions [17]. It has a narrower focus than tools like the MAG, focusing mainly on price monitoring, and not including initial assessments or response analysis in detail.

UNHCR Cash Feasibility and Response Analysis Toolkit

The UNHCR Cash Feasibility and Response Analysis Toolkit, developed in 2017, is a suite of tools aimed to help determine the feasibility of cash-based interventions [82]. It is split into seven key areas, most of which having a dedicated separate tool:

1. Market Access and Capacity
2. Protection Risks and Benefits
3. Financial Risks and Benefits
4. Political Context
5. Transfer Mechanisms and Delivery Options
6. Cost-efficiency
7. Skills and Capacity

This project relates most strongly to the tool for market access and capacity, the UNHCR Multi-sector Market Assessment [81]. The SD model also relates to somewhat to cost-efficiency.

WFP tools

The WFP has numerous tools aimed to support market analysis. These include:

- Collecting Prices for Food Security Programming (2017) [13]
- Calculation and Use of the Alert for Price Spikes (ALPS) Indicator (2014) [97]
- Market Analysis Framework (2011) [96]
- Market Analysis Tool: How to Conduct a Food Commodity Value Chain Analysis? (2010) [93]
- The Basics of Market Analysis for Food Security (2009) [92]
- Market Analysis Tool: How to Conduct a Trader Survey? (2009) [94]

- PDPE Market Analysis Tools (2007) [91]:
  - Shock Scenarios
  - Price and Income
  - Terms of Trade
  - Market Integration
  - Import Parity Price

Many aspects covered in these tools have already been discussed, as they are addressed in other tools.

The set of PDPE Market Analysis tools are useful for analyzing specific aspects of the market. However, these aspects are considered in a standalone way. Outputs of the PDPE tools can be used to inform the system dynamics model to form a holistic view of the supply chain and market. For example, the Import Parity Price tool could be used for import price calculation, while the Market Integration tool could help indicate which markets could be modeled together on aggregate.

Emergency Food Security and Livelihoods 48-hour Assessment Tool

The Emergency Food Security and Livelihoods 48-hour Assessment Tool was developed in 2012 by Oxfam [64]. It aims to develop a rapid understanding of food security and livelihoods to inform programming for the first 6 to 8 weeks after a disaster.

The 48-Hour Tool consists of six documents:

1. Objectives and Guidance Notes
2. Assessment Questionnaire
3. Decision Tree
4. Response Menu
5. Reporting Format
6. Annex: Technical Rationale

Unlike some of the other tools, the 48-Hour Tool prescribes fairly specific plan (a menu of 8 different Response Options) for the initial response. Also unlike some of the other tools, the 48-Hour Tool is not focused specifically on markets.

Shock Impact Simulation Model (SISMod)

The Shock Impact Simulation Model (SISMod) was initially developed by the WFP and the FAO in 2009 to assess food security [95]. As opposed to the previously described documents, it is a numerical model. Its aim is to calculate the impact of a shock on household food consumption. It consists of a two-stage demand system: first a Linear Expenditure System to allocate total expenditure to broad commodity groups, second a Linear Almost Ideal Demand System to allocate expenditure to specific food groups.

SISMod can potentially be integrated into the system dynamics model in this project as a replacement for the current simple consumer demand subsystem. SISMod considers prices to be exogenous, a significant advantage of the system dynamics model. However, the system dynamics model does not consider the impact of prices on production, which SISMod does. Overall, SISMod's focus is narrower than the system dynamics model, but provides finer detail in household behavior. Of course, to be able to provide this detail, either more data needs to be collected, or more assumptions need to be made about households preferences.

Response analysis and response choice in food security crises: a roadmap

This Network Paper from ODI, published in 2013, investigates how response analysis is actually conducted by humanitarian organizations, and discusses how to better utilize existing tools to create a more consistent and informed response analysis process [58]. Instead of prescribing what should be done, it aims to clarify the response analysis process for decision makers and field staff. In this sense, it is not strictly a market analysis tool, but does have some important conclusions for market analysis.

Household Economy Analysis (HEA)

Household Economy Analysis (HEA) is an approached developed by the Save the Children Food Economy Group [69]. It is based on primary data collected from households to create baselines of typical food and income sources and spending patterns for different livelihood groups. Shocks and scenarios can then be applied to these baselines to estimate the consumption gap for different groups under those conditions.

Some data from an HEA analysis is used in the SD model in this thesis (see Section 2.3.4.13). HEA is also potentially useful to add more detail to part of the model (see Section 4.4).

1.4.2 Academic literature

There is also a range of peer-reviewed academic literature regarding the aggregation of information for system dynamics models information-poor environments, which is relevant to the methods developed in this thesis.

Luna-Reyes and Andersen 2004 [56] describes some key social science techniques, and how they can be used at different parts of the system dynamics modeling process. While this is not the focus of the system dynamics modeling work in this project, this topic will becoming increasingly relevant if the model becomes more integrated to the ICRC's operations. Developing an efficient and reliable way to harness the knowledge of people who have no system dynamics experience will be important to make the model relevant within the organization. Similarly, Sanò et al. 2014 [67] presents a participatory approach to combine information collected from experts and stakeholders to ultimately build a causal loop diagram and system dynamics simulations. Voinov et al. 2016 [90] notes more methods for participatory modeling, although with a limited focus on system dynamics.

McCabe and Halog 2018 [60] highlights the potential to include stakeholders in system dynamics modeling, ultimately to identify areas where interventions may have the most impact.

Blair et al. 2021 [12] uses a similar system mapping methodology to this project, and is focused on a similar Uganda context. It layers data on a causal loop diagram to test dynamic hypotheses in a complex system. This is a step between qualitative causal loop diagrams, and a quantitative system dynamics model. However, it does not build a system dynamics simulation model.

Closely related to the Uganda context of this project, Queenan et al. 2020 [65] describes the creation of a system map with participants at a workshop. The context was the livestock-derived food system in South Africa. An aim of the workshop was to improve collective understanding of the system, but a system dynamics model was not developed. Lie et al. 2017 [55] focuses on the dairy value chain in Nicaragua, using participatory modeling to build a system dynamics model. The model addressed the production system, but not the market for supply of inputs or demand of outputs. Conversely, the modeling in this thesis does not go into detail for production, but does go into detail for the outputs market and supply chain.

Akkermans and Dellaert 2005 [3] discusses 'fragmented' supply networks, where the supply chain is made up of 'independent and semi-independent' organizations. This is similar to the contexts examined in this project. However, the paper simply discusses such networks without actually building a model.

Muflikh et al. 2021 [61] is a systematic review of the 'contribution of system dynamics to value chain analysis in agricultural development'. Relevant to this project, it notes that *"there were almost no comprehensive models that covered all components in the value chains"*. This highlights the importance of the work covered in this project, where a system dynamics model covers many components of a value chain.

Chapter 2

Methods

2.1 Overview

2.1.1 Positioning of methods

There are two main methods used in this thesis: *multi-mode information aggregation*, and *system dynamics*. The former was developed by the author to intake and process information in various formats to assess the status of a complex system during a crisis. This can serve as the input to a process that develops outcomes based on the input information. The latter is an established numerical modeling method that the author applied to model a supply chain during a crisis. This method still requires some processing of input data. Together, these two methods help make sense of complex systems in a crisis to guide response. These two methods can be linked together, with output from the multi-mode information aggregation forming part of the input to the system dynamics model, although this was not explored in detail in this project.

Although these two methods are complementary, and can be applied together to a single context, the two methods were developed separately for different contexts during the course of this research. The multi-mode information aggregation method was developed in the context of the COVID-19 pandemic in Uganda, specifically to assess the pandemic and corresponding government restrictions on the agriculture market system. The system dynamics model was developed in the context of the complex humanitarian crisis in northeast Nigeria, specifically to investigate the rice supply chain and humanitarian interventions for food security. The positioning of these key methods with their corresponding contexts is shown in Figure 2-1.

Because the methods are complementary, there is some consistency to how they are described in this chapter. Parts of each method are first described in a general way that can be applied to other contexts, then in a more specific way that is specific to the context they were applied in for this thesis. Elements in a system map are conceptually

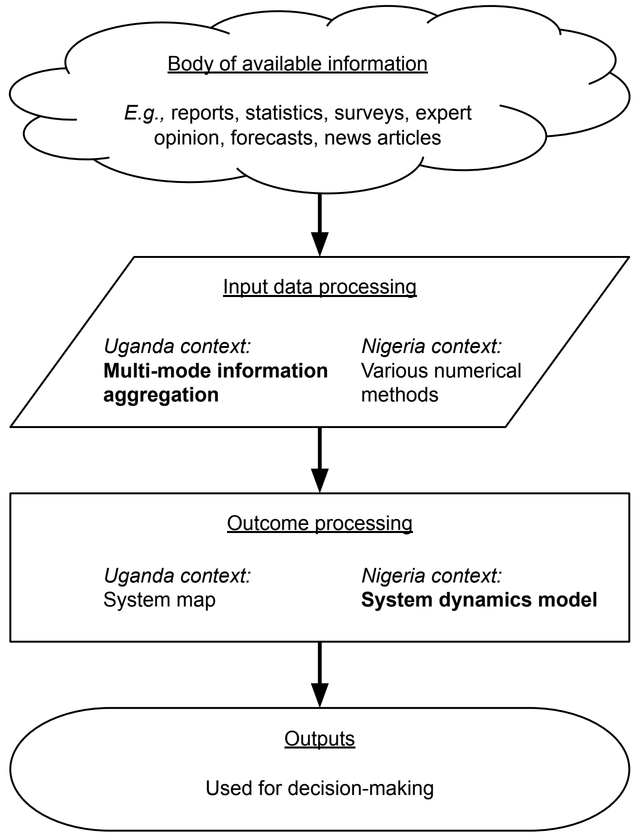

Figure 2-1: Generalized process for processing information and making decisions. **Bold** methods are investigated in detail in this thesis.

similar to variables in a system dynamics model. Thus, they are both formatted as: `Element/Variable name` throughout this document.

2.1.2 Relevance of methods

In both of the contexts in this project, developing an understanding of the market systems that supply people with essential items (in this case, staple foods) is key to improving outcomes. Understanding the market and supply chain allows for better prediction of what will happen in different scenarios, and as a result a better understanding of potential interventions. Provided the methods to do this are viewed as legitimate and credible by decision makers, this prediction can lead to quicker funding for a quicker response. This can be more effective and efficient than later funding. On this logic, research on measuring and modeling systemic issues *that can later on lead to* catastrophic outcomes can be much more valuable. Unfortunately, it can be hard to measure the impact of early action, since it tends to focus on embedded systemic issues, instead of the more obvious outcomes of these issues down the line.

Of course, in the case of understanding any complex system, it is naturally hard to know whether one's understanding is accurate. Making sense of complex systems requires analysis whose complexity reflects that of the system itself. However, added complexity to a model has diminishing returns, as it can begin to distract from more credible parts of the model. Added complexity that is no longer accurate can weaken the credibility of the entire model. Thus, any method that attempts to make sense of a complex system needs a balance of complexity and fidelity, which was attempted to maintain throughout the development of these methods.

2.2 Multi-mode information aggregation

2.2.1 Motivation

In a crisis, information is imperfect, but decisions still need to be made. Often the situation evolves too rapidly for the design and implementation of rigorous surveys, so information at hand needs to be used to form as full a picture as possible of the situation. The multi-mode information aggregation method developed for this project aims to add structure to what can otherwise be an unstructured process.

It is inevitable that people making sense of a rapidly evolving situation will make use of formal and informal information sources. The multi-mode information aggregation method accounts for this both as a reality (we are bound to incorporate diverse sources into our understanding, whether we are conscious of it or not) and a necessity (in a crisis, information is limited so whatever information does exist needs to be used effectively).

However, there are three main issues with this inherent way we process information. The multi-mode information aggregation method attempts to correct for each of these issues. Firstly, the main actors in a crisis are large organizations made up of many people. Each person will have taken in their own unique set of information, leading to their own internal understanding of the actual situation. These internal understandings are patched together via various methods (personal discussions, publications, meetings, etc) to form an organization's collective understanding. However, this patching together of information is imperfect. Individuals may be unaware of, or may not recall, specific sources of information that led them to form their individual understanding of the situation. Sharing information is also time-consuming, and it is easy for pieces of information to be lost or misinterpreted. Power dynamics within an organization may also affect the extent to which some individuals' understandings are able to shape the organization's collective understanding.

Secondly, certain pieces of information can be unintentionally misused. From a previous example, we might have read in an article that total imports have decreased by 50%, leading us to think that agriculture inputs availability may be disrupted. However, this may be an imprecise — and incorrect — attribution of this piece of information. Although it may be true that *total* imports have decreased by 50%, *agriculture-related* imports may have remained constant, with the decline in total imports being driven by other sectors. This mis-attribution is easy to do, particularly in a crisis, where information is scarce and there may be pressure to make decisions quickly.

Thirdly, inputting diverse pieces of information into a numerical model is not trivial. In the case of system dynamics, the ideal input would be time series data for multiple variables in the model. However, the pieces of information that make up our understanding of a situation may not clearly correspond to certain variables, let alone be in a complete time series. More work needs to be done to translate an internal understanding of a situation into a form useful for modeling.

2.2.2 System mapping

The method of information aggregation developed in this project is closely tied to *system mapping*. The output of the information aggregation method serves as an input to a system map, which can be further used to support a range of activities.

General description

A system map is a representation of a complex system. It is made up of elements and connections. Each element represents a component of the system, and connections show how various elements influence each other. System maps are similar to causal loop diagrams, which can form the basis for a system dynamics model. System maps can also directly form a basis for system dynamics models, as a way of communicating the concepts and logic of a numerical model in a non-mathematical way . Standalone, system maps can also be used for many purposes, outlined below.

- *Collaboration:* Multiple stakeholders can use a system map to visualize the concepts or elements of the system the other stakeholders are working on. From this, collaboration opportunities can be identified, where multiple stakeholders doing similar work in similar geographic areas can work together.
- *Communication:* A system map can be used to communicate the various elements of a complex system, and how they relate to each other.
- *Sense-making:* The various elements in a complex system can be laid out clearly in a system map to aid the user to develop an understanding of a system. Furthermore, multiple stakeholders can build and use a system map together to build a collective understanding of a system.

A system map is made up of elements, each representing a requirement of the system to function effectively. Elements are connected together to indicate which elements enable each other. If there is a connection going from `Element A` to `Element B`, this implies that `Element A` enables `Element B`. This means that whoever built the map believes that if `Element A` is true, there is a higher likelihood that `Element B` will be true than if `Element A` were not true. This does not imply that `Element A` *causes* `Element B`. There could be many other elements that enable `Element B`, and without them being true as well, `Element B` will not be true. Conversely, it may only take one of `Element B`'s elements to be true for `Element B` to be true.

A system map can include subsystems. A subsystem is a group of elements that are closely related to each other. A subsystems can be made up of elements that capture the actions of a certain actor, or elements that are related to a similar concept. Elements within one subsystem will typically have many connections between each other, as well as some connections to elements in other subsystems.

Uganda context system mapping

In the Uganda project the core decision tool was the USAID/Uganda FtF MSM Activity Agricultural Market System Map (shortened to the Agriculture Map), developed by the Market Systems Monitoring Activity. The Agriculture Map captures the market system for maize in Uganda, including the subsystems:

- Inputs Importing and Manufacturing
- Inputs Distribution
- Farmer Practices
- Commodity Distribution
- Financial and Business Services
- Agricultural Services
- Human Resources
- Regulatory
- Extension Services
- Household Resilience

The full system map is shown in Figure 2-2. This map is not intended to be legible, it is just to show the rough number of elements and and subsystems that are included.

An example element in this system map is `Farmer has access to buyer or market`. This is shown in Figure 2-3, with some nearby elements also shown to illustrate this example. For clarity, other elements have been omitted from this figure. There is a connection going from `Farmer has access to market information` to `Farmer has access to buyer or market`. This implies that `Farmer has access to buyer or market` is enabled by `Farmer has access to market information`. In other words, if a farmer has access to market information, then it is more likely that the farmer will access a market. Of course, `Farmer has access to market information` is not the only thing required for market access, but it helps enable it. Other elements, such as `Cooperatives/Producer Organizations organize collective marketing`, also enable `Farmer has access to buyer or market`.

From `Farmer has access to buyer or market`, we can continue to follow the chain of logic through the Agriculture Map. There is also a connection going from `Farmer has access to buyer or market` to `Farmer has adequate income`, implying that market access enables income generation by the farmer.

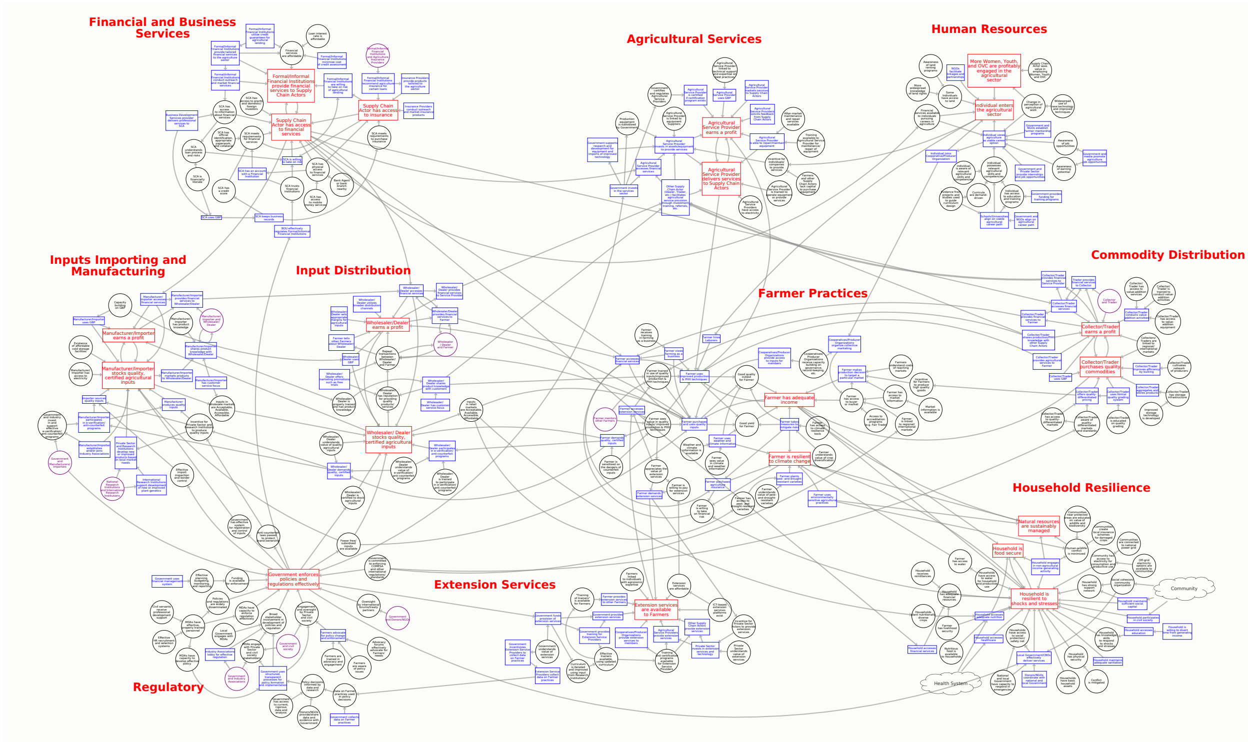

Figure 2-2: The USAID/Uganda FtF MSM Activity Agricultural Market System Map

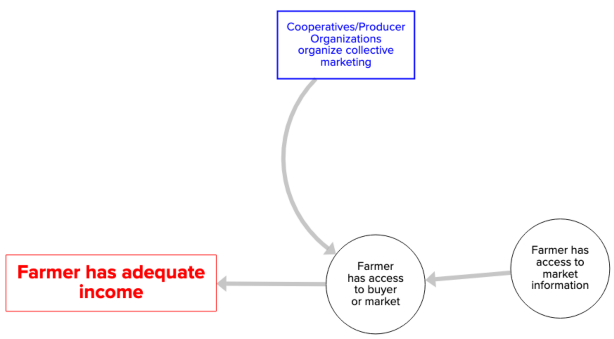

Figure 2-3: Example elements from the Agriculture Map

2.2.3 Structure

The multi-mode information aggregation method aims to transparently compartmentalize information, showing a clear logical chain between the source of the information, and its influence on the model.

The set of information discussed here is based on work conducted for USAID/Uganda as the Feed the Future Market Systems Monitoring Activity. This work was aiming to assess the impact of the COVID-19 pandemic on the agriculture market system in Uganda (specifically for maize), and was conducted from April to August 2020.

The key components of the method are sources, facts, and elements. These components are shown embedded in the information aggregation process in Figure 2-4.

The following sections describe each component of the method as following:

1. *General description:* A high-level description of how the method can be applied in any context
2. *Implementation in Uganda context:* A more specific description of how the method was applied in the Uganda context

2.2.3.1 Sources

General description

A source is the original document that a piece of information came from. This could be in any format, such as a news article, a report, data from a survey, government statistics, notes from a meeting, or an email. The source could have been produced by any organization or person, at any time. The scope of the sources also varied — for example, a survey might only cover a certain demographic or geographic area.

To maintain transparency and traceability, each source is documented with key attributes of the source, outlined in Table 2.1. Some of these attributes will not be applicable to all sources. Each source is also given a unique identification number.

Source Attribute	**Description**
Name	The name or title of the document
Type	The type of the document
Author	The author of the document
Publication date	The date the document was published
Information date	The date the information in the document is from
Scope	The geographic, temporal, or conceptual scope of the information in the document
URL	A link to the document
Reliability	The perceived reliability of the source

Table 2.1: Potential source attributes

Some attributes, such as reliability and scope, may be difficult to record in a clear way. The specific way that they are recorded can be adjusted depending on the context, and can be done in a way that fits with the rest of the methodology.

One example of how reliability can be evaluated is outlined in the most recent IPC Technical Manual, Protocol 2.4 [50]. This method considers both the 'Soundness of Method' and 'Time Relevance' of evidence.

Implementation in Uganda context

In the Uganda context, the sources were documented in a live Google Sheet, which allowed multiple people to add sources simultaneously. Over the course of the project, 259 unique sources were documented. An example is outlined in Table 2.2.

Source Attribute	Value
ID	S8
Name	EPRC Special Issue No. 1: How has the COVID-19 pandemic impacted Ugandan businesses? Results from a business climate survey
Type	Study
Author	Economic Policy Research Centre (EPRC)
Publication date	May 1, 2020
Scope	Rapid survey using EPRC Business Climate Index to 147 business establishments
URL	https://eprcug.org/research/education?task=document.viewdoc&id=652

Table 2.2: Example source

2.2.3.2 Facts

General description

Each source is subsequently broken down into facts. A fact is typically in the form of a sentence, capturing a specific piece of information from the source. While every source will likely contain a multitude of facts, not all will necessarily be relevant to the model. A source may turn out to have no relevant facts, or it may have many relevant facts. The relevance of the fact is at the discretion of the team conducting the assessment.

Each fact is documented with the fact's key attributes, outlined in Table 2.3. Some of these attributes may not be applicable to all facts.

Implementation in Uganda context

In the Uganda context, all facts were documented in the same Google Sheet as the sources to allow for easy referencing to the sources, and simultaneous collaboration. Over the course of the project, 444 facts were documented. An example fact is outlined in Table 2.4, which is a fact that was drawn from the example source in Table 2.2.

Fact Attribute	Description
Content	A sentence or phrase that captures the content of the fact
Source ID	The source that the fact is from
Date	The date the fact is from, which may be different than the source's date(s)
Reliability	The perceived reliability of the fact, which could be different than the source reliability

Table 2.3: Potential fact attributes

Fact Attribute	Value
Content	55% of agricultural businesses see reduction in access to credit
Source ID	S8
Date	May 1, 2020

Table 2.4: Example fact

2.2.3.3 Elements

General description

In a system map, elements are connected together to indicate how the different parts of the complex system interact. Each element can have a status, which is a qualitative measure of the element. The element's status on a system map is intended to reflect the status of what the element represents in the real world. Elements and their status are described in more detail in the Market System Measurement Toolkit, developed by the Market System Monitoring Activity [88].

In a crisis, the element's status can indicate how much the element has been affected by the crisis. In the Market System Measurement Toolkit, this is referred to as the 'shock status'. In this document it will simply be referred to as the 'status'. The element's status can take on a range of values, such as:

- *Impacted to point of being non-functional*, meaning that what the element represented had essentially ceased due to the crisis.
- *Significantly impacted*, meaning that what the element represented had been affected significantly in a negative way the crisis.
- *Somewhat impacted*, meaning that what the element represented had been somewhat affected in a negative way by the crisis.
- *Not impacted*, meaning that what the element represented had not been affected in a significant way by the crisis.

- *Improved*, meaning that what the element represented had been affected in a positive way by the crisis.

The status the element can be determined from the incoming processed information. Each fact is assigned to one or more element, with an implication for the element's status.

The incoming processed information can be used to determine the status of elements on the system map. Each element in the system map was documented with the attributes shown in Table 2.5, among other things that are not relevant to the information aggregation process and thus not shown here.

Element Attribute	**Description**
Name	The element's name from the system map
Corresponding facts	A list of facts assigned to the element, each with the date, source, and implication for the element's status
Status	The element's shock status

Table 2.5: Element attributes

Implementation in Uganda context

For the Uganda COVID project, the element status represented the extent to which the element was impacted by the COVID shock (the COVID pandemic and corresponding government restrictions). An example is shown in Table 2.6, which is the element that the fact in Table 2.4 was assigned to.

Element Attribute	**Value**
Name	`Supply Chain Actor has access to financial services`
Corresponding facts	55% of agricultural businesses see reduction in access to credit (May 1, 2020, Implied status: Significantly impacted) *Other facts assigned to the element ...*
Status	Significantly impacted

Table 2.6: Example element

2.2.4 Process

Compartmentalizing information allows for robust processes to manage it. The end-to-end process in the multi-mode information aggregation method involves four broad steps:

1. *Source capture*, in which relevant sources are documented.
2. *Fact extraction*, in which documented sources are read (or processed in some other way, such as watching a video or listening to an audio recording), and relevant facts are documented.
3. *Fact assignment*, in which documented facts are assigned to elements on the system map, with an implication for the element's status.
4. *Element assessment*, in which an element's status is determined or updated based on its corresponding facts and their implications for its status.

These steps are shown diagrammatically in Figure 2-4. The numbers on the boxes in Figure 2-4 indicate the number of that that component in the Uganda COVID project, *e.g.*, there were 259 sources used in the project, and the system map consists of 318 elements.

These steps can be taken asynchronously by multiple people trained in the multi-mode information aggregation method. Information technology that updates changes in real time, such as Google Sheets, can facilitate this. For example, multiple people can be capturing sources at the time time by noting the details in a shared document. As a backlog of documented sources builds up, other people can extract facts from the sources, noting the facts elsewhere in a shared document.

Because of this flexibility, the cadence in which these steps are taken can be easily adjusted to suit the project. On one extreme, the steps can be taken continuously, resulting in a near-continuous assessment of element status. On the other extreme, the steps can be taken a single time in sequence, resulting in a one-time assessment of element status. In the Uganda COVID project, source capture was conducted daily, fact extraction and fact assignment was conducted weekly, and element assessment was conducted approximately fortnightly. This allowed for several assessments of the system as a whole over the course of the project. The process of system assessment (the grey-out component of Figure 2-4) is not addressed in this document, but is described in other documentation by the MSM team [35].

2.2.4.1 Source capture

General description

Source capture is the process of recording a new source in the information aggregation workstream from the body of potential sources. The body of potential sources used in a project is critical to the project's credibility. The body of potential sources should be agreed upon and made clear at the beginning of the project.

Once the body of potential sources has been agreed upon, processes (ideally automatic ones) should be put in place to ensure that sources are regularly being added from this body to the information aggregation workstream. Processes could include automated email alerts, newsletter subscriptions, automated processes to pull new data from an online source, or regularly scheduled contacts with specific people.

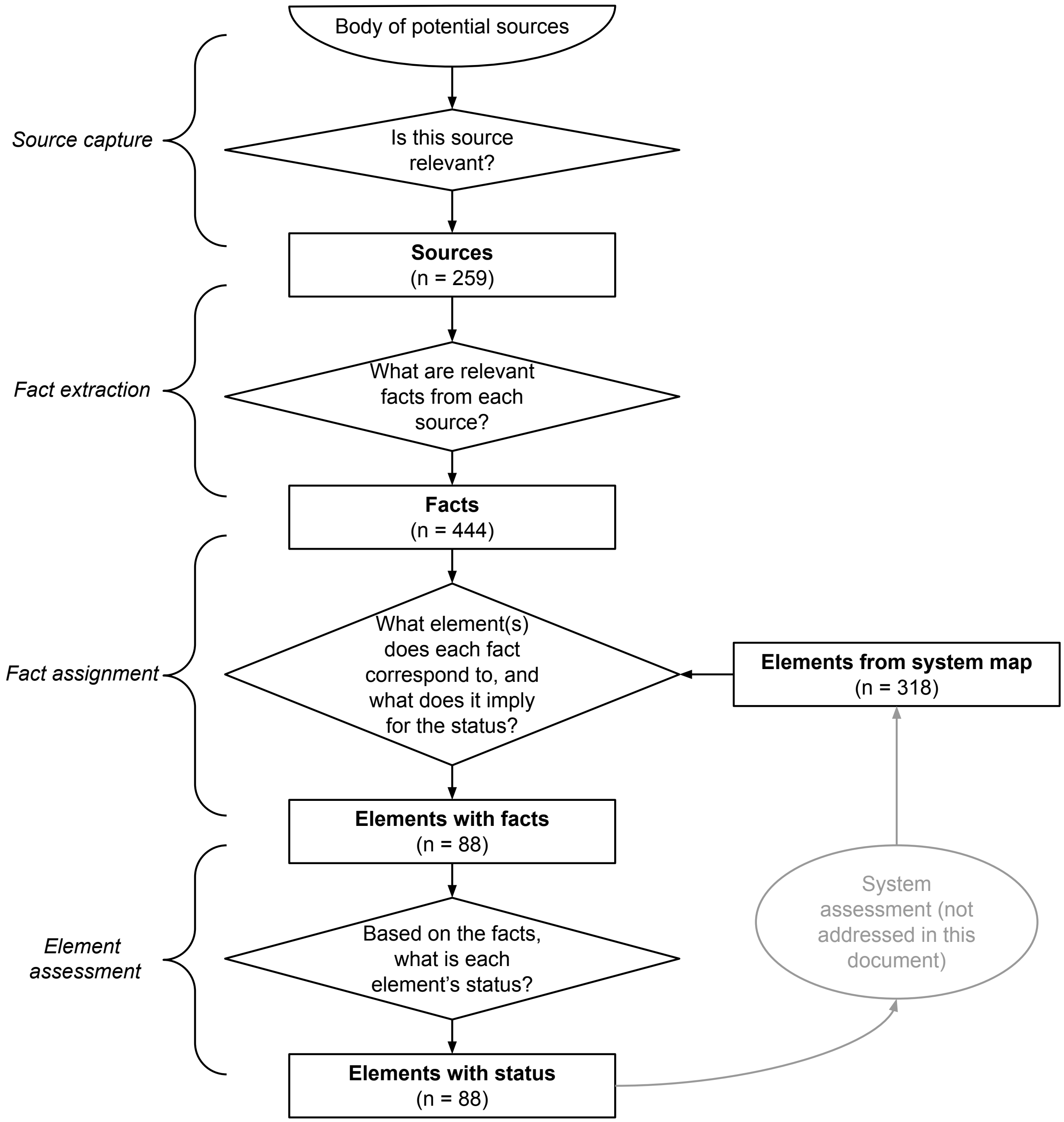

Figure 2-4: Information aggregation process

Implementation in Uganda context

For the Uganda project, various Google news email alerts were set up for relevant phrases (*e.g.*, 'uganda agriculture', 'uganda maize'), certain Ugandan online newspapers were checked daily (*e.g.*, *The Daily Monitor*, *The Independent*), regional newspapers were checked less frequently (*e.g.*, *The East African*), the Bank of Uganda site was checked weekly for updated trade data, and new food prices from FAO FPMA and other sources were checked weekly. Key informant interviews were conducted at different times throughout the assessment. Key informants comprised input dealers, producer groups, trader groups, USAID staff, and other professionals working in the agriculture sector.

2.2.4.2 Fact extraction

General description

Fact extraction is the process of recording relevant facts from each source, if there are any. This can take different forms for different types of sources. For an article, this involves reading the article. For data, this involves processing it and noting important aspects of the processing data (*e.g.,* 'The retail price of maize has increased by X% from March to June').

Like source capture, fact extraction should be conducted at regular intervals. Fact extraction can occur alongside source capture (*i.e.,* facts are extracted right after the source is recorded), or can be done in batches (*i.e.,* facts are extracted from all unprocessed sources at some regular interval).

Implementation in Uganda context

For the Uganda project, facts were typically extracted on the last day of the week from sources captured earlier that week.

2.2.4.3 Fact assignment

General description

Fact assignment is the process of determining which element each fact is most relevant for, and what the fact implies for that element's status. In some cases, a fact may be assigned to multiple elements. To be done efficiently, this requires a good knowledge of the system map being used for the project. However, the system map should have sufficiently descriptive element names and an intuitive enough structure so that someone with limited knowledge can still assign facts accurately.

Implementation in Uganda context

For the Uganda project, facts were assigned to elements at the time they were extracted from the source (at the end of each weekly).

2.2.4.4 Element assessment

General description

Element assessment is the process of determining an element's status based on its previous status, and any facts that have been assigned to it. For example, if an element's status was previously unknown (*i.e.,* there was no information about it), but has recently had a fact imply that the element's status is *Significantly impacted*, its status should be updated to *Significantly impacted*. Conversely, it an element's status was previously *Not impacted* based on previous facts, and it recently had a fact imply that the element's status is *Significantly impacted*, its status shouldn't be updated to *Significantly impacted per se*. The element's new status should be determined based on how relevant and credible all the facts that have been assigned to it are. If the facts that indicated the element's status is *Not impacted* are outdated or not particularly credible, and the fact indicating a status of *Significantly impacted* is recent and credible, the element's status should be updated to *Significantly impacted*.

Element assessment can be aided by organized and visual spreadsheets to show the facts that have been assigned to an element, and their implication for the element's status.

Implementation in Uganda context

For the Uganda project, element assessment was conducted every two weeks. This was aided with a coloured spreadsheet, a screenshot of which is shown in Figure 2-5.

Element name	Previous status	Updated status	Fact status 1	Fact status 2	Fact status 3	Fact s
Collector/Trader earns a profit	Significantly imp	Somewhat impa	Jul 19 - GoU tenders fo	Jul 17 - Over the next	Jul 9 - Produce has sp	Jul 8 -
Farmer has adequate income	Significantly imp	Somewhat impa	Aug 28 - Buyers for co	Aug 18 - 93% of survey	Aug 18 - 60% of farm h	Aug 18
Farmer has access to buyer or market	Significantly imp	Significantly im	Aug 28 - Local buyers	Aug 28 - Farmers have	Aug 18 - 44% of house	Aug 18
Individual enters the agricultural secto	Improved	Improved	Aug 28 - More people	Jul 17 - Some people a	Jul 9 - People have ret	
Supply Chain Actor has access to fina	Significantly imp	Somewhat impa	Aug 28 - Input dealers	Jul 10 - Banks have tol	Jun 5 - UDB provides	May 20
Collectors/ Traders are linked to reg	Somewhat impa	Somewhat impa	Jul 9 - Certification at t	Jul 8 - Obtaining UNBS		
Extension services are available to far	Significantly imp	Significantly im	Jul 17 - Agro-veterinar	Jul 9 - The relationship	Jun 9 - Access to field	May 20
Household receives remittances	Somewhat impa	Significantly im	Aug 18 - In-country rer	Jul 8 - Remittances ha	Jun 15 - Work has drie	May 28
Household has adequate financial res	Significantly imp	Significantly im	Aug 18 - Reasons for i	Aug 18 - 70% of respo	Aug 18 - 87% of house	Aug 18
Household engages in non-agricultura	Significantly imp	Somewhat impa	Aug 18 - Only 8% of ho	Aug 18 - 14% of rural h	Jun 11 - Vendors had u	
Inputs in retail markets are Acceptable	Significantly imp	Significantly im	Aug 28 - Some input d	Aug 18 - 7% of rural ho	Aug 18 - Main reasons	Jun 10

Figure 2-5: Element assessment sheet from Uganda project

In Figure 2-5, the first column is the name of the element, automatically populated from the system map. The second column is the element's previous status, also automatically populated from the system map. The third column is the new status, based on its previous status, and the facts that are assigned to the element. The fourth column and onwards contains the facts that are assigned to the element, coloured by the status that it implies for the element, and sorted by date (most recent in the leftmost column). We can see that the element in row one (`Collector/Trader earns a profit`) previously had a status of *Significantly impacted*. Its most recent facts have had the implications for its status: *Not impacted*, *Somewhat impacted*, *Somewhat impacted*, and *Somewhat impacted*. This has been sufficient for its status to be revised to *Somewhat impacted*. Further down, in the eighth row, we can see the element `Household receives remittances`. Its most recent facts have had the implications for its status: *Impacted to point of being non-functional*, *Significantly impacted*, *Somewhat impacted*, and *Somewhat impacted*. This has led to its status being changed from *Somewhat impacted* to *Significantly impacted*.

2.2.5 Feedback to information collection and data gaps

In addition to being a tool to assess systems, the information aggregation process can assess how information is being gathered, and uncertainty about the system. Combined with system mapping, this can be used to show where information is lacking about a system. This can aid the legitimacy of an assessment by being transparent about where information is lacking. Further, this can guide where new information should be gathered.

The metadata from the information aggregation process (*e.g.,* how many facts each element has, how recent those facts are, where those facts are typically coming from) can be just as important as the data itself, and can be used to guide further information collection.

2.3 System dynamics

2.3.1 System dynamics overview

System dynamics is a numerical modeling method that relies on stocks, flows, feedback loops, and time delays to help understand the nonlinear behavior of complex systems [72].

System dynamics was chosen as a modeling method because many of its strengths align well with the requirements of a complex supply chain model to inform a humanitarian actor. Firstly, a supply chain in a crisis involves many effects that interact in a complex way, which can be represented in a system dynamics model with relative ease. Secondly, a supply chain in a setting with displacement involves the physical movement of people and good with corresponding time delays. The flow of material and corresponding time delays is considered implicitly in system dynamics. Thirdly, a humanitarian setting involves many actors, with potentially multiple groups within each actor. System dynamics' visual nature can facilitate collaboration, even among those with limited experience with the method. Finally, data can be limited in a humanitarian context, but trends and logic can be inferred. Trends and logic can be embedded into a system dynamics model, so that even in the absence of data some outcomes can be inferred.

2.3.2 Model scope

The model developed is generalizable for situations with conflict causing displacement between two regions, with separate but linked supply chains for a commodity between those regions. Baseline production estimates of the commodity are exogenous (*i.e.,* factors influencing the production level, other than conflict, are not considered). Household behavior is considered only for purchasing, *i.e.,* the household demand only depends on the current system state, not anything in the household's history. Macroeconomic factors are not considered; the baseline inflation rate is exogenous.

In the specific application in the Nigeria context, the model scope includes the supply chain for rice being sold in Borno State, Nigeria. The model includes production estimates at a national level, but the rest of the supply chain only at a state-wide level.

2.3.3 General uses of data in the model

Data can broadly be in used in the model two ways. These two ways, outlined below, relate to the distinctions of model variables in Section 2.3.4.

- *Input data:* The data is used directly as an *input variable*, or is used to calculate an *input variable* or *input processing variable*. Varying degrees of processing may be needed to use the data in the model.
- *Comparison data:* The data is not directly used for any calculation in the model. It is merely used as a comparison for the model's behavior. Comparison data can be compared against model *internal variables* or *output variables*. Comparison data may also be need to be processed before use.

Data can also take a variety of formats for either of these uses in the model. Data can be quantitative or qualitative, although qualitative data will need to be processed into a quantitative format for use in the model. Possible original data formats include:

- Regularly measured and published data, such as food prices for some commodities in some markets.
- One-time measurements of certain values, which could be from one-time reports.
- Regularly calculated and published data, such as consumer price indices.
- Estimates of certain values, such as food insecurity levels in hard-to-reach areas.
- Expert opinions about the behavior of a parameter that can be converted into a quantitative format.
- Response plans that outline a humanitarian organization's historical or planned response.

Data can also come from a variety of sources. Potential sources are outlined in Table 2.7. These sources are typically regular publications made by an organization.

Source name	*Data available*
FEWS NET	Food security conditions and food prices
IOM DTM	Numbers of displaced people
WFP VAM	Food and some other commodity prices
ACLED	Conflict events
USDA PSD	National production and trade estimates for some commodities
FAO GIEWS	Food prices
UN OCHA 3W	Humanitarian actor presence
UN Comtrade	Traded volumes for categories of products
WFP Market Monitors	Local food prices and some analysis

Table 2.7: General data sources for humanitarian supply chain modeling

Data is also aggregated and made available various places, outlined in Table 2.8. There is some overlap in the data included by these aggregated sources. These sources can also include much more than what is outlined in the table.

Source name	*Data available*
ReliefWeb	Many reports from humanitarian organizations
Humanitarian Response	Details regarding humanitarian operations
Humanitarian Data Exchange	Many datasets relevant to humanitarian response from a variety of sources
Cash and Learning Partnership	Reports and methodologies related to cash programming
Logistics Cluster	Information regarding logistics capacities
Food Security Cluster	Information and reports regarding food security
Food Security and Nutrition Network	Reports regarding food security
MarketLinks	Reports regarding market-based programming
AgriLinks	Reports regarding agriculture

Table 2.8: Aggregated data sources for humanitarian supply chain modeling

2.3.4 Model structure and formulation description

This section describes the system dynamics model. For a more detailed description of the formulation, with screenshots of each subsystem, see Appendix A: Detailed SD Model Formulation.

Each part of this section describes part of the model in three parts:

1. *General case:* the general version of the model
2. *Implementation for Nigeria context:* how the general version has been implemented to best fit the reality of the Nigeria context
3. *Input data for Nigeria context:* where applicable, the input data that is used to run the model in the Nigeria context

2.3.4.1 Model Nomenclature

Whenever a specific model variable is mentioned, it is typeset as: `Model variable`. Each variable falls into one of the below categories:

- *Input variable:* This is a variable whose value is not affected by any other variables in the model. This could also be known as an 'input parameter'. in the field of system dynamics this can be referred to as a 'constant' (as it is in the Powersim software), which can be misleading, as it is not necessarily constant. An input variable can be set by external data that is read into the model, or set directly by the user in the model itself. It can be set as a single unchanging value for the whole simulation, or can be a timeseries (meaning it takes different values at different times in the simulation).

- *Input processing variable:* This is a variable whose value is *only* affected by input variables. These variables are used to process inputs, *e.g.,* by smoothing them, changing units, or combining multiple inputs in some way. Like input variables, input processing variables are not affected by system behavior.
- *Internal variable:* This is a variable whose value is determined by other variables in the model (at least one of which is another internal variable), *and* affects at least one other internal variable. Internal variables affect, and are affected by, system behavior. In this sense, internal variables serve as the core of the model. Internal variables can also indicate outcomes of the model, such as an actor's revenue, although this outcome must also affect other internal variables in the system to be considered an internal variable.
- *Output variable:* This is a variable whose value is determined by other variables, but doesn't affect any other variables (except other output variables). Output variables do not affect system behavior, and are only used to measure certain outcomes of the system.

A variety of acronyms are used to shorten the names of variables in the SD model. Types of supply chain actor (SCA) are in Table 2.9, other actors are in Table 2.10, types of consumer are in Table 2.11, and geographic areas are in Table 2.12.

Acronyms are combined to further specify an actor. For example, `HA W stock` indicates the stock for the Wholesaler in the Host Area. Acronyms can be further combined to indicate flows between actors. For example, `HA W-R volume` indicates the material flow from the Host Area Wholesaler to the Host Area Retailer.

Since the three SCAs in the model behave in similar ways, their variables are often described together: in this document, `T/W/R Price` indicates something that applies to the Trader Price, Wholesale Price, and Retail Price.

Acronym	*Full wording*	*Meaning*
T	Trader	Actor buying rice from a Farmer for sale to a Wholesaler
W	Wholesaler	Actor buying rice from a Trader for sale to a Retailer
R	Retailer	Actor buying rice from a Wholesaler to sale to Consumers

Table 2.9: SD model SCA acronyms

Acronym	*Full wording*	*Meaning*
F	Farmer	Actor producing rice for sale to a Trader
C	Consumers	People that can access the retail market to purchase rice from a Retailer
I	Importer	Actor importing rice for sale to a Wholesaler
Hum	Humanitarian Actor	Actor that can purchase rice from Importer, Trader, or Wholesaler for distribution to Consumers

Table 2.10: SD model other actor acronyms

Acronym	*Full wording*	*Meaning*
IDPs	Internally Displaced Persons	People that have moved from the Affected Area to the Host Area to become Consumers there
HP	Host Population	People that are permanently Consumers in the Host Area
AAP	Affected Area Population	People that have remained as Consumers in the Affected Area, but could become IDPs if they move to the Host Area

Table 2.11: SD model consumer acronyms

2.3.4.2 Overall model structure

General description

The system dynamics model was developed to be generalizable to any situation that includes people being displaced into a different region, with different but linked supply chains for a certain commodity in the two regions. The regions the model is split into are outlined below, and in Table 2.12.

Acronym	*Full wording*	*Meaning*
SA	Source Area	The area where rice is being produced for the Host Area or the Affected Area
HA	Host Area	The area where the Host Population and IDPs are the Consumers
AA	Affected Area	The area where the Affected Area Population can access the retail market, and where production might be affected by conflict

Table 2.12: SD model geographic acronyms

- *Affected area (AA):* The geographic area(s) that are most directly affected by the disruption. People are potentially leaving this area because of the disruption, and the supply chain in this area is potentially being disrupted. The number of people remaining in the affected area is the `AA population`.
- *Host area (HA):* The geographic area(s) that are not directly affected by the disruption, but are where the displaced people are moving to. The number of people that have moved from the affected area into the host area is the `IDP population`. The number of people that lived in the host previous to the disruption is the `Host population`.
- *Source area (SA):* The geographic area(s) where the modeled commodity is being produced for sale within the country. This may include the host area, but may not include the affected area, since the production in the affected area is modeled separately.

Each region may not necessarily be contiguous, and may consist of an aggregation of many separate regions that are not defined by administrative boundaries. For example, the affected area might be the rural area surrounding the urban host area, all within the same administrative region.

While the whole model is linked together, and it is important to consider each individual subsystem as part of a broader system, for the purposes of documentation the model can be broken down into several conceptual subsystems. They are:

- *AA Population Dynamics:* modeling how people move between the AA and the HA
- *AA Production and Consumption:* modeling the production and the onsite consumption of food (food that does not enter the supply chain) in the AA
- *Supply Chain Actor (SCA):* this subsystem is repeated three times in the model for each area (the trader, wholesaler, and retailer in the AA and the HA) and can be broken down into smaller parts to facilitate description:
  - *Supply and Price:* how the supply level and price are calculated
  - *Cash:* how the SCA manages cash
  - *Retained Earnings:* how the SCA chooses to retain earnings
  - *Demand:* how the SCA's demand is calculated
  - *Supply Chain Credit:* how credit between supply chain actors affects cash
  - *External Credit:* how external credit affects SCA behavior
- *SA Production:* calculating production levels in the SA
- *Humanitarian Actor:* inputting humanitarian actor behavior to the model
- *Consumer Demand:* calculating demand from consumers (IDP and HP)
- *Imports:* calculating import price and volume

These conceptual subsystems are described in more detail in the following Sections 2.3.4.3 through 2.3.4.14. An even more detailed description is in Appendix A: Detailed SD Model Formulation.

Implementation in the Nigeria context

In the Nigeria context, some parts of the model are not being used. This is to reflect the trade patterns of rice, and the current focus of humanitarian programming. In the AA, only the Production and Consumption subsystem is active. The rest of the supply chain in the AA is not modeled. It is assumed that there is no trade between the AA and the HA, and that material only flows from the SA to the HA. This is because Borno state is a production deficit area for rice.

Figures 2-6, 2-7, and 2-8 show how at a high level how the material, cash, and information flow through the model, respectively. Strictly speaking, the information 'flow' is not actually a flow in the system dynamics sense, but is included here to because it is one of the key flows typically referenced when studying supply chains.

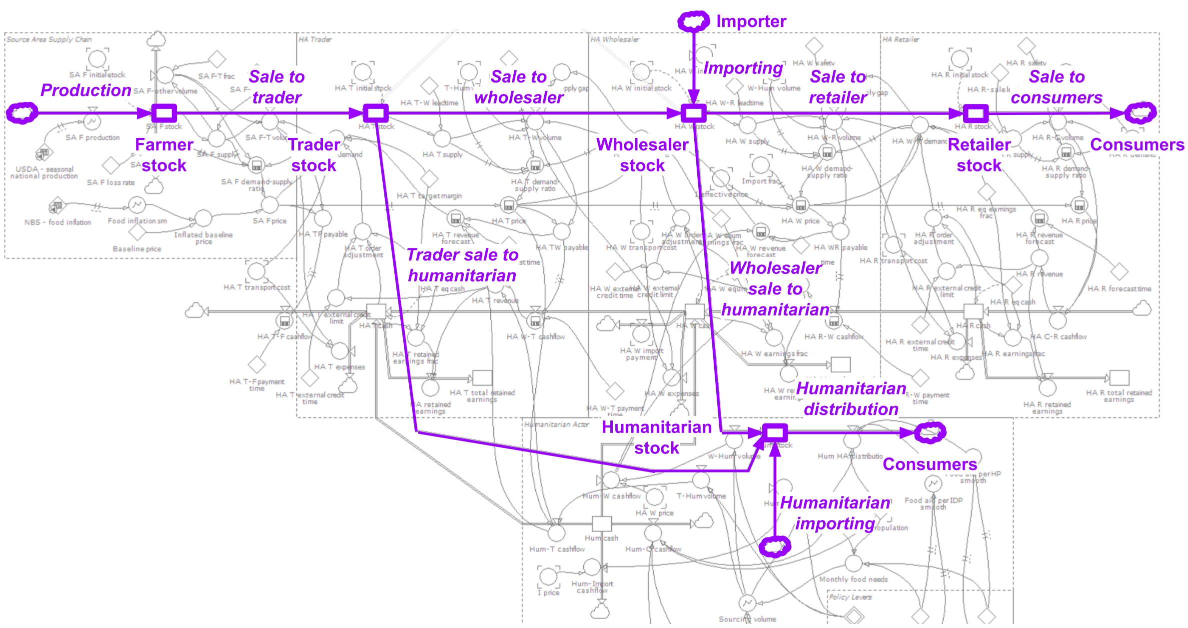

Figure 2-6: SD model high-level material flow

The material flows downstream, from the SA Farmer to the HA Trader, HA Wholesaler, HA Retailer, and ultimately HA Consumers (IDP and HP). The HA Wholesaler can also import. The Humanitarian Actor can source from the HA Trader, HA Wholesaler, or import, to distribute to the HA Consumers.

Cash flows upstream, from the HA Consumers through to the SA Farmer. Cash can also flow from the Humanitarian Actor to who they are sourcing from.

The price information 'flows' downstream, meaning that downstream prices are influenced by upstream prices. Demand information 'flows' upstream, meaning that upstream demand is influenced by downstream demand. However, this flow is imperfect, as an

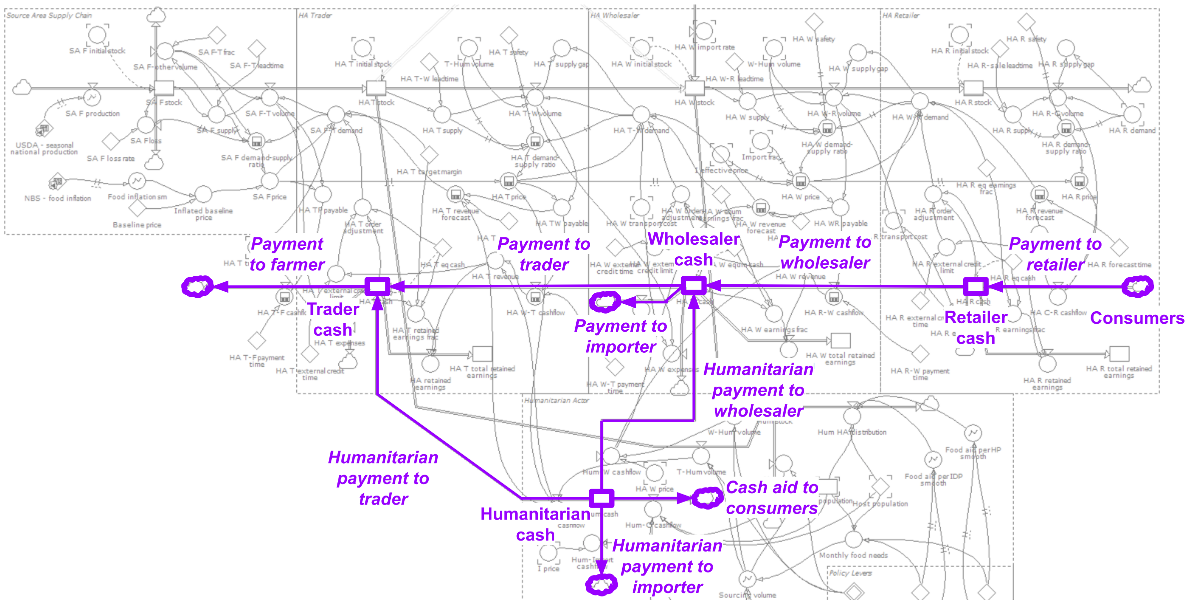

Figure 2-7: SD model high-level financial flow

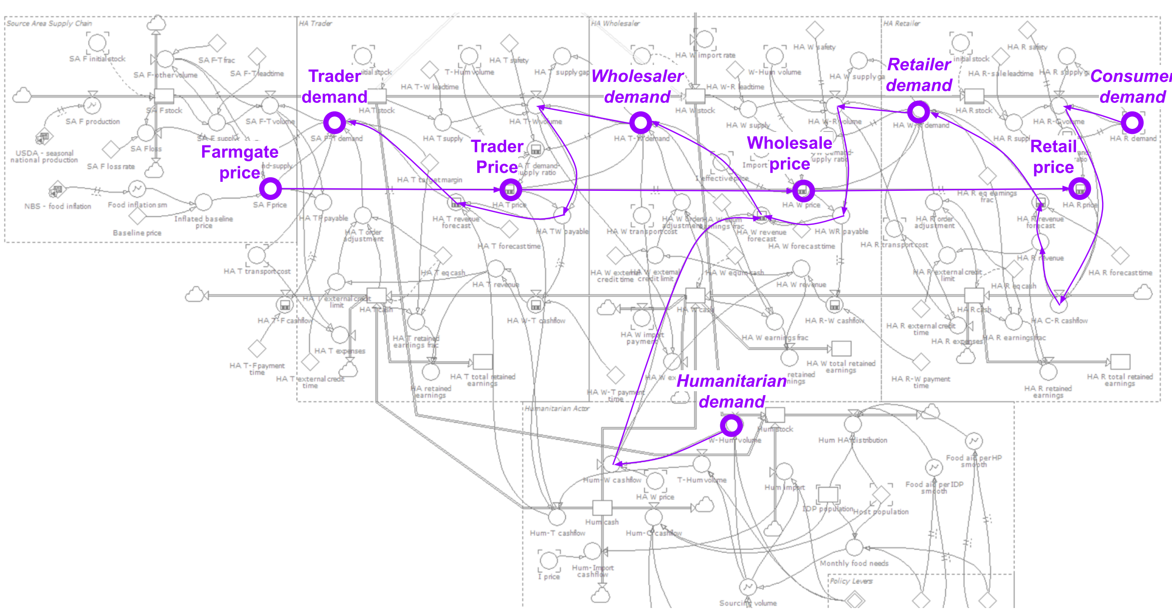

Figure 2-8: SD model high-level information flow

actor may choose to modify their demand based on certain conditions. This is explored more in Section 2.3.4.8.

2.3.4.3 AA Population Dynamics

General description

The primary factor driving population movement in the model is conflict. As conflict increases, the perception of danger in the AA increases. This increases the displacement rate and reduces the return rate, leading to a increasing IDP population and a decreasing AA population. Other factors can also contribute to displacement rates, such as pull from humanitarian aid in the HA, which could increase displacement. Conversely, insurgent groups may offer aid for people to stay in the AA; this has allegedly been the case in Borno state, with ISWAP offering cash to people to stay in areas they control [1].

There are many existing models for population movement, some of which are catalogued by the Centre for Humanitarian Data [75] (including some that use system dynamics [30]). These models are more sophisticated than this subsystem in the model. However, this level of sophistication is currently not necessary for the level of fidelity required by the SD model in this project, and require more input data than may be available in this context.

Implementation in Nigeria context

For the SD model in the Nigeria context, the level of conflict is calculated from the number of recent deaths in Borno state, normalized to be between 0 and 1. The intervention pull factor is determined from humanitarian interventions, relative to existing outcomes in the AA. A basic depiction of the subsystem is shown in Figure 2-9.

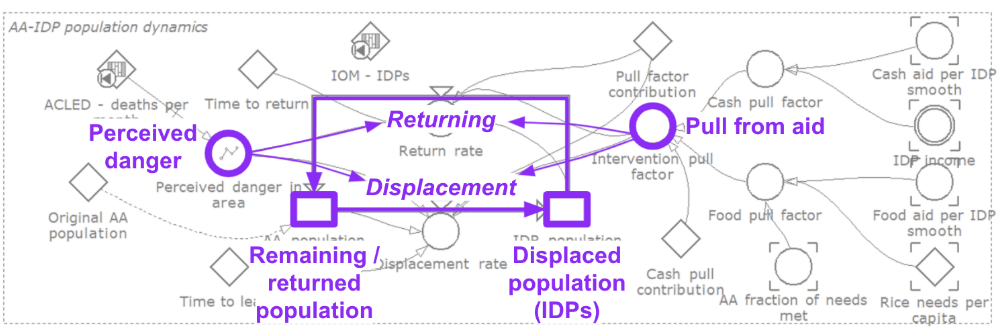

Figure 2-9: AA Population Dynamics

Use of data in the Nigeria context

Conflict data is incorporated into the AA Population Dynamics subsystem as in Table 2.13. Processing conflict data for use in the model is straightforward; deaths are aggregated on a monthly and state-wide level, and divided by the maximum monthly deaths in Borno state. This produces a number between 0 and 1 for each month, representing the amount of danger in Borno state during that month.

IDP population data is incorporated into the model as in Table 2.14. Unlike conflict data (which is used as a model input), population data is used merely as a comparison for the

Data attribute	Conflict data implementation
Use type	Input (population dynamics and SA production)
Data type	Regularly published data
Data source	ACLED (in use) [66]; UCDP (alternate) [74]
Source frequency	Weekly
Source format	Incidents with date, location, type, number of fatalities
Model format	Deaths per month in Borno state due to conflict, normalized by the maximum monthly deaths in the timeframe in question

Table 2.13: Conflict data summary

Data attribute	IDP population implementation
Use type	Comparison to model output (AA population dynamics)
Data type	Regularly published data
Data source	IOM DTM baseline assessments [48]
Source frequency	Every two months
Source format	Numbers of IDPs in various locations around the country
Model format	Number of IDPs in Borno state

Table 2.14: IDP population data summary

model output, except for IDP population at the start time of the simulation which is used as the initial IDP population in the model. Data in the IOM DTM dataset is documented at a fairly granular level, even presenting coordinates for locations of IDP groups. However, for use in the model, the data is aggregated at a state level.

2.3.4.4 AA Production and Consumption

General description

Production levels in the affected area are based on how many people are in the affected area, and what the level of conflict is. In this subsystem, the consumption in the AA is only directly from the farm, not from food that has passed through the supply chain.

Implementation in Nigeria context

In the Nigeria context, the production level assumed to be seasonal. A description of how seasonal data is incorporated into the model is in Section 2.3.4.11. Because the rest of the AA supply chain is not considered in the Nigeria context, all AA production is either lost or consumed.

2.3.4.5 SCA: Supply and Price

General description

The supply that a SCA has available (*i.e.,* the maximum volume that can be moved from them to the downstream SCA) is based on their stock level and the leadtime between them and the downstream SCA. The supply level could be doubled from their stock doubling, or the leadtime halving.

The SCA's price (*i.e.,* the price that they sell at) is based on the upstream price (*i.e.,* the price that they buy at), their expenses, their earnings (described in Section2.3.4.7), and their demand to supply ratio (*i.e.,* how much is demanded from them divided by how much they can supply). The furthest upstream price (`Baseline price`) is exogenous.

Implementation in the Nigeria context

In the Nigeria context, prices were only calculated for the HA, since this was the only area for which the full supply chain was modeled. It was assumed that the price varies proportionally to the demand to supply ratio, meaning that the price would double if the downstream demand doubles while the supply remains constant. This is a fairly crude assumption for this context, but creates model behavior that is plausible. The relationship between demand to supply ratio is difficult to determine, but can be adjusted in the model. For example, if less price variation is appropriate, the price could be proportional to the square root of the demand to supply ratio, where a quadrupling of the demand would result in a doubling of the price.

The only SCA expenses considered were transportation costs, which were assumed to be per kg of material moved. Transportation costs were assumed to be borne only by the wholesaler and trader, which each paying for half of the total transportation cost. Ultimately, the total transportation costs will become part of the retail price regardless of which actor pays. However, their distribution across actors does affect actor behavior, and prices along the supply chain.

Use of data in the Nigeria context

Transportation cost data is incorporated into the model as in Table 2.15. In the model, the transportation cost is the average cost per weight of commodity that the supply chain actor has to pay for transportation. With regards to how transportation costs are inputted to the model, it is assumed that they only vary in time due to fuel costs varying. Other causes of variation can be incorporated in the model itself. The benchmark cost is an estimate of the total transportation cost for the commodity from farmer to consumer, at a certain time.

Data attribute	Transportation cost implementation
Use type	Input (transportation costs)
Data type	Infrequent benchmark data, with monthly variation based on regular inflation data or regular fuel prices
Data source	*Benchmark:* Borno State Millet Transaction Cost paper from 2013 (in use) [10]; WFP Lake Chad Analysis from 2016 (alternate, although has accuracy issues) [9] *Inflation:* NBS transportation inflation (in use) [62]; FAO headline inflation (alternate) [27] *Fuel prices:* WFP VAM (alternate) [98]; ICRC logistics purchasing data (alternate) [41]
Source frequency	*Benchmark:* One-off *Inflation:* Monthly *Fuel prices:* Weekly
Source format	*Benchmark:* Overall marketing costs by actor, overall fraction of marketing costs for transportation (Millet paper); Average transportation distances and average costs per distance (WFP Analysis) *Inflation:* Index for transportation inflation (NBS) or national headline inflation (FAO) *Fuel prices:* Petrol and diesel prices in Borno state (WFP VAM); Fuel purchase costs at selected times (ICRC)
Model format	Transportation cost pegged to inflation (currently directly from the inflation index, but an index can also be developed from fuel prices) and equal the benchmark value at the benchmark time

Table 2.15: Transportation cost data summary

This total cost is then pegged to inflation, as in the equation below.

$$\text{Total Cost}_{(\text{Month no. } i)} = \text{Benchmark Cost} \times \frac{\text{Inflation index}_{(\text{Month no. } i)}}{\text{Inflation index}_{(\text{Month no. } B)}}$$
$$\text{Where: } B = \text{Month no. when benchmark cost was measured}$$

The inflation index can either be drawn straight from the NBS or FAO inflation data, or can be calculated from the fuel prices in the WFP VAM. Once the total transportation cost has been calculated, it can be broken down into costs for each individual actor. This is done in the model itself, and is described in Section 2.3.4.

A baseline price for the commodity is incorporated into the model as in Table 2.16. Unlike other input data that is pegged to inflation, the baseline price does not have a set benchmark value. Instead, the benchmark value can be adjusted to fit the modeled wholesale and retail prices to comparison data. In this sense, the benchmark value does not have much

Data attribute	Baseline price implementation
Use type	Input (SA production, used as a baseline for all prices in the model)
Data type	Floating benchmark, regular inflation data
Data source	NBS food inflation (in use) [62]; FAO headline inflation (alternate) [27]
Source frequency	Monthly
Source format	Index for food inflation (NBS) or national headline inflation (FAO)
Model format	Benchmark value is adjusted to fit retail and wholesale prices to comparison data, variation in time pegged to inflation

Table 2.16: Baseline price data summary

meaning in itself, but represents an underlying price for producing the commodity.

$$\text{Baseline Price}_{(\text{Month no. } i)} = \text{Benchmark Price} \times \text{Inflation index}_{(\text{Month no. } i)}$$

2.3.4.6 SCA: Cash

General description

An SCA's cash stock depends on inflows and outflows, essentially as balance sheet. Revenue from the downstream SCA (or humanitarian actor) is the inflow. Payment to the upstream actor, expenses, and retained earnings are outflows. The cash stock level can be negative, indicating the SCA is in debt to an external party.

Implementation in the Nigeria context

No modifications were needed for the Nigeria context.

2.3.4.7 SCA: Retained Earnings

General description

An SCA retains earnings if its cash stock goes above a certain amount. This cash exits the system permanently. This is equivalent to earnings above any expenses that the SCA incurs.

In the model, the equilibrium earnings fraction (`T/W/R equm earnings frac`) is the fraction of revenue that a SCA retains when the market is in equilibrium. The market is defined to be in equilibrium when all supplies, demands, and prices in the model are constant.

Implementation in the Nigeria context

No modifications were needed for the Nigeria context.

2.3.4.8 SCA: Demand

General description

The SCA demand is the maximum amount the SCA will purchase from the upstream SCA. This is based on the SCA's buying price, expenses, revenue forecast, cash level, and credit access. SCA demand will increase if any of the following situations occur:

- The buying price decreases
- The expenses decrease
- The revenue forecast increases
- The cash increases (unless it is already above the level at which the SCA retains earnings)
- The SCA's external credit time increases (unless the cash level is above the level at which the SCA is retaining earnings)

An SCA's revenue forecast is based on the level and trend of their current revenue. This means that the revenue forecast will increase if either their selling price or volume increases.

Implementation in the Nigeria context

No modifications were needed for the Nigeria context.

2.3.4.9 SCA: Supply Chain Credit

General description

Along the supply chain, an SCA is able to allow deferred payments from the downstream SCA. This is set as the `F-T/T-W/W-R payment time`. In this implementation, the downstream actor must ultimately pay the full amount. Because of this, the amount payable to a upstream SCA from a downstream SCA (`F-T/T-W/W-R payable`) is used for the upstream SCA's revenue forecast. This is because this revenue is guaranteed in the future.

Implementation in the Nigeria context

No modifications were needed for the Nigeria context. For the simulations in this document, there is no supply chain credit unless otherwise stated.

2.3.4.10 SCA: External Credit

General description

An SCA reduces its demand if its cash decreases. As its cash decreases towards its credit limit, it reduces its demand towards zero. Without external credit, an SCA's credit limit is zero.

Implementation in the Nigeria context

No modifications were needed for the Nigeria context.

2.3.4.11 SA Production

General description

SA Production is based on the aggregate production volumes for whatever the source area is defined as. The production levels can be seasonally adjusted. All of the commodity that is produced is either moved to the HA Trader, to somewhere else in the country (other than HA or AA), or is lost (based on `SA F loss rate`). The commodity that is moved to the AA is assumed to be done so via the HA trader.

Implementation in the Nigeria context

Production levels and seasonality were calculated based on input data, as described in the section below. For simplicity, it was assumed that only up to a certain fraction of `SA F stock` would be traded into the HA. The maximum value for this fraction is equal to the variable `SA F-T frac`. The remaining amount is traded into other unspecified parts of the country.

Use of data in the Nigeria context

Production data is incorporated into the model as in Table 2.17. Production data is calculated based on a yearly production estimate made for Nigeria by USDA PSD. This is distributed over the months of the year according to when production is completed on farms (*i.e.*, the harvest months), as in the equation below. This value is later smoothed for input to the model, as described in Appendix A: Detailed SD Model Formulation.

$$\text{Production}_{(\text{Month } i, \text{ Year } j)} = \frac{1}{12} \times \text{Yearly Production}_j \times \text{Seasonal Factor}_i$$

$$\text{Where: } \sum_{i=1}^{12} \text{Seasonal Factor}_i = 1$$

Data attribute	SA production implementation
Use type	Input (HA production)
Data type	Regularly published volume data, with seasonal variation added
Data source	*Volume:* USDA PSD [89] *Seasonality:* FEWS NET [28]
Source frequency	*Volume:* Yearly *Seasonality:* n/a
Source format	*Volume:* Estimated yearly volumes of national rice production *Seasonality:* List of months for rice harvest in north and south of country
Model format	Monthly national production based on yearly production distributed over harvest months

Table 2.17: Production data summary

2.3.4.12 Humanitarian Actor

General description

The behavior of the Humanitarian Actor in the model is exogenous, meaning that its actions are predefined as input variables. This can certainly be modified in the future, where certain humanitarian action is performed only if certain thresholds are met. But currently, response options by the Humanitarian Actor are fully defined externally, and inputted to the model.

Including the humanitarian actor as an actor in the model is an important conceptual step. It implicitly captures a major theme of market assessment and analysis — that actions by humanitarian actors can have unintended effects. By clearly embedding the humanitarian actor in the model, it makes this consideration unavoidable, and shifts the conceptualization of humanitarian response from being *on* a system from the *outside*, to being *part* of a system from *within*. More operationally, this helps the model user consider how the humanitarian actor's actions integrates with those of other market actors, and any harm the humanitarian actor might be unintentionally doing to the system. These concepts have a basis in several high-level guiding documents for humanitarian response:

- *The Code of Conduct for the International Red Cross and Red Crescent Movement and Non-Governmental Organisations (NGOs) in Disaster Relief* [45]:
  - Principle 6: *"We shall attempt to build disaster response on local capacities"*
  - Principle 9: *"We hold ourselves accountable to both those we seek to assist and those from whom we accept resources"*
- *SPHERE Humanitarian Charter* [71]:
  - From Principle 9: *"we aim to to minimize any negative effects of humanitarian action on the local community"*
- *SPHERE Core Humanitarian Standard* [71]:

- From Commitment 3: *"Fully consider market conditions when analysing which form of assistance (cash, voucher, or in-kind) will have the greatest positive outcome"*, *"Buy goods and services locally when possible"*, *"Mitigate negative repercussions on the market to the extent possible"*, and *"Aid can undermine livelihoods and market systems . . . Anticipate these potential negative effects, monitor and take actions to prevent them if possible"*

Implementation in Nigeria context

In the Nigeria implementation, the options the Humanitarian Actor has are:

- Cash assistance amount at different times, to IDPs and HP independently
- Food assistance amount at different times, to IDPs and HP independently
- Sourcing for food assistance (HA Trader, HA Wholesaler, or importing)
- Credit to trader amount (set as `T/W/R external credit time`)

2.3.4.13 Consumer Demand

General description

Consumer demand is calculated based on the income, cash and food assistance, and preferences of the population groups. The specific implementation of the subsystem is flexible; all that it needs to output is the total consumer demand (in volume) for a given retail price.

The total consumer demand on the retailer is the sum of the demand from all population groups. No group receives preferential treatment in actually accessing the retailer, *i.e.,* if the retailer is only able to meet 50% of the total consumer demand, every consumer will receive only 50% of what they demand.

Implementation in the Nigeria context

In the Nigeria context, only one commodity (rice) is considered. For a household, the demand on the retail market is based on the retail price, the household income, any cash or food assistance the household is receiving, and their preferences (captured by the maximum fraction of income the household would spend on rice, and the maximum possible amount of rice they would demand). A household demand would go up (unless the household is already purchasing their maximum possible amount) if:

- Income increases
- Retail price decreases
- Cash aid increases
- Food aid decreases
- Maximum fraction of income spent on rice increases

Data attribute	SA production implementation
Use type	Input estimate (consumer/HA demand)
Data type	Infrequent benchmark data, regular inflation data
Data source	*Benchmark:* Save the Children Borno State Household Economy Analysis 2017 (in use) [68]; ICRC 2015 BAY States MAG (alternate) [21] *Inflation:* NBS rural inflation (in use) [62]; FAO headline inflation (alternate) [27]
Source frequency	*Benchmark:* One-off *Inflation:* Monthly
Source format	*Benchmark:* Estimates of household income *Inflation:* Index for inflation in rural areas (NBS) or national headline inflation (FAO)
Model format	Income pegged to rural inflation, with some distribution between households assumed

Table 2.18: Income data summary

Use of data in the Nigeria context

Income data is incorporated into the model as in Table 2.18. Mean household income is assumed to track rural inflation, and equal a certain benchmark value at the time the benchmark value was measured, as in the equation below.

$$\text{Mean Income}_{(\text{Month no. } i)} = \text{Benchmark Income} \times \frac{\text{Inflation index}_{(\text{Month no. } i)}}{\text{Inflation index}_{(\text{Month no. } B)}}$$
$$\text{Where: } B = \text{Month no. when benchmark income was measured}$$

It is also assumed that there is a distribution of household income. In the model, household income is distributed to three groups: low, middle, and high. It is assumed that the three income groups have the same population (each one third of the total population).

$$\begin{aligned}\text{Low Income} &= (1-k) \times \text{Mean Income}\\ \text{Middle Income} &= \text{Mean Income}\\ \text{High Income} &= (1+k) \times \text{Mean Income}\\ \text{Where: } k &= \text{Measure of income variation}\end{aligned}$$

In the equations, the measure of income variation k is set based on an estimate of how much income might vary across the groups. For reference, the standard deviation of this distribution is $\sqrt{\frac{2}{3}}k$. The value of k can be inferred from the source of the benchmark. In this case, the benchmark actually provides values for 'poor' and 'very poor' IDP and host population households. The value of k selected was based on the difference between these two values to create a three-group distribution with the same standard deviation.

Note that income is also split between IDP and HP groups. In the model, both the IDP and HP groups are broken into three income groups, resulting in six total income groups, all of which are pegged to rural inflation.

Note also that this approach is flexible to producing a variety of different income distributions if desired. For example, an income distribution that is skewed to have more low income may be more representative, but this is not investigated in this project.

2.3.4.14 Imports

General description

Imports can be allowed at any point in the supply chain. The import price is exogenous, and can be marked up to reflect government policy. The import volume can also be restricted to reflect government policy.

Implementation in Nigeria context

In the Nigeria context, only the HA Wholesaler can import. The amount they import is based on their sourcing gap (*i.e.,* the difference between how much they demand from the HA Trader, and how much they actually receive).

The Humanitarian Actor can also import.

Use of data in the Nigeria context

Data attribute	SA production implementation
Use type	Input (importer)
Data type	Regularly published price and exchange rate data
Data source	*Price:* FAO GIEWS FPMA [26] *Exchange rate:* Google Finance Ticker [36]
Source frequency	*Price:* Weekly *Exchange rate:* Daily
Source format	*Price:* International prices of commodities in USD *Exchange rate:* USD to NGN exchange rate
Model format	Price for Thai 100% B rice, in NGN

Table 2.19: Import price data summary

Import price data is incorporated into the model as in Table 2.19. It is used as an input to the model for the baseline import price. There is currently only one specific commodity used to calculate the model import price, but this can easily be expanded to incorporate other varieties of rice. 'Thai 100% B' rice was chosen for the model because Thailand is a major rice exporter to Nigeria. The import price (in USD) is converted to NGN with the monthly-averaged historical exchange rate. In the model, additional costs due to tariffs and the importer's margin are incorporated; this is outlined in Section 2.3.4.

2.3.5 Relating the MAG to the SD model

The MAG was used to inform the model structure and formulation. This section relates the SD model to the MAG.

The MAG is structured into five chapters which roughly cover the phases of a project cycle:

1. *Assessment:* how to integrate market information into assessments, considering the following aspects:
   - Critical market systems
   - Market structure
   - Impact of the shock on demand and supply
   - Competitiveness
   - Macro-level factors that can influence that market's capacity to respond
2. *Response Analysis:* how to conduct response analysis considering the the market assessment findings, referring to common steps in response analysis:
   - Identifying a broad range of response options
   - Defining the response options' appropriateness
   - Analysing the response options' risks and feasibility
3. *Price Monitoring:* how to use market information for price monitoring, referring phases in price monitoring:
   - Data collection
   - Analysis
   - Decision-making
4. *Evaluation:* how to use market information in determining the impact of the project on market systems and market actors, referring to steps in the evaluation process:
   - Identifying market systems that have been most affected by the project
   - Identifying market actors that have been affected by the project
   - Assessing the impact of the project on the primary beneficiaries of the project
   - Assessing the general impact of the project on the market
5. *Contingency Planning:* how to integrate market information in contingency planning.

An important concept for assessment in humanitarian situations is *optimal ignorance* [19]. It can be too costly or infeasible to develop a thorough understanding of a situation; developing an understanding that is 'good enough' is more useful for planning response. The MAG is based on this principle, as is the system dynamics model developed for this project.

The MAG emphasizes close cooperation between the logistics and programme departments when conducting a market assessment or analysis. Both departments should have a good understanding of markets, but connecting their information about procedures and constraints is needed to develop a full picture of possible responses. This close cooperation is considered implicitly in the model. The supply chain of the humanitarian actor is built in to the market supply chain, which considers both the movement of material and the movement of cash for procurement.

The MAG is broken into many 'driving questions' (DQ) that are supported by 'tools'. The following sections go through many of the driving questions and tools in the MAG, and discuss how they relate to the SD model.

2.3.5.1 MAG Chapter 1: Assessment

This chapter focuses on how to gather information to develop a minimum understanding of the market. At this point, it is important to make a clear distinction between the RAM (Rapid Assessment of Markets, also developed by ICRC and IFRC) and the MAG. This is clarified in Table 2.20.

	RAM	**MAG**
Time conducted	Within 48 hours after a shock	A few weeks after a shock or later
Guides responses	4 to 6 weeks after a shock	Much later after a shock

Table 2.20: RAM and MAG timescale comparison [43]

DQ 1.1: Which market systems should the assessment focus on?

This question aims to determine which market systems are the most critical to the lives and livelihoods of the target population. This question is outside the scope of the SD model. In its current version, the model only captures one market system, which is chosen before the model is setup and run. However, the model could potentially be used to examine the criticality of various market systems, by either modeling several commodities in parallel, or by making separate model for each commodity and comparing results.

DQ 1.1 is supported by tools *1.1*, *1.2*, and *1.3*. *Tool 1.1* is a list of secondary data sources which could be used to determine the critical market systems. Many of these data sources are being used elsewhere in the model for other purposes. *Tool 1.2* is a list of questions to ask the target population to determine their access to and dependency on the market. Some questions relate to parts of the model, in particular the `IDP market access` and `HP market access` variables. It also relates to household income (`IDP income` and `HP income`) and its seasonality. Although these variables are not considered in detail in the model, this could be a useful avenue for model extensions. *Tool 1.3* is a series of steps to select the market system(s) to focus. These steps are outside the scope of the model, but could serve as useful framing, should the model be extended to consider different commodities.

DQ 1.2: How are the selected market systems structured?

This question can be addressed with two mapping exercises — market system mapping and marketplace mapping. A market system map can serve as the basis for the model core structure. Marketplace mapping addresses more geographic issues, and can help define the geographic scope of the model.

DQ 1.2 is supported by *Tool 1.4: Market Mapping*, which is based on mapping methodologies from the EMMA [4] and Practical Action [5] toolkits. This tool firstly walks through the creation of a baseline market system map. Note that this is distinct from the MSM system mapping methodology discussed in Section 2.2.2. The questions addressed by the tool are outlined below, with their relation to the SD model explained.

1. *Who are the actors involved with the commodity and what do they do?*
   - This suggests which actors could be included in the SD model.
2. *How does the commodity move in the market chain?*
   - This suggests how the basic material supply chain of the SD model can be structured. For example, `HA T stock` has flows going to both `HA W stock` and `AA W stock`.
3. *How many actors of each type are there?*
   - The number of actors isn't explicitly considered in the model, but could have implications for competitiveness.
4. *What is the volume of commodities in the market chain?*
   - This suggests typical material stock levels and flows in the SD model. For example, `HA T stock` might have an initial value of 50,000 MT, and `HA T-W volume` might have an initial value of 20,000 MT/mo.
5. *How does the monetary value change through the chain?*
   - This suggests the price of the commodity at various points in the supply chain. For example, this could inform equilibrium values for `SA F price`, `HA T price`, `HA W price`, and `HA R price`, and the margins between these prices.
6. *What types of relationships and linkages exist?*
   - This adds complexity to the flows in the model. The strength of the relationship between actors could affect the terms of credit between them, the price volatility, and the volume.

In constructing the market system map, *Tool 1.4* also addresses supporting infrastructure and services, although in a fairly limited way. This could indicate where additions to the model could be be. For example, transportation costs might be considered for one actor but not another. The tool also addresses the external environment, *i.e.,* the rules, regulations, issues, and trends that influence the market system. The SD model considers key parts of the market environment, such as conflict and displacement, but does not currently consider other parts. If needed, other key features of the market environment can be included in the specific way that they influence an actor.

The tool goes on to detail 'emergency' maps, which build on the baseline market system map by representing the effects of a disaster. This is captured as changes in volumes, number of actors, provision of infrastructure and services, or external environment. This is analogous to what the SD model does, and can serve as a useful reference. Under the same conditions, the SD model should produce results that are similar to those captured on an emergency map.

The tool also details 'forecast' maps, which represent changes that are expected to happen in the immediate future, accounting for government and non-government support. This is also analogous to what the SD model does. A prediction from the SD model could help inform a forecast map. Alternatively, a forecast map based on expert opinion could help check the validity of the SD model's predictions. A forecast map is shown in Figure 2-10.

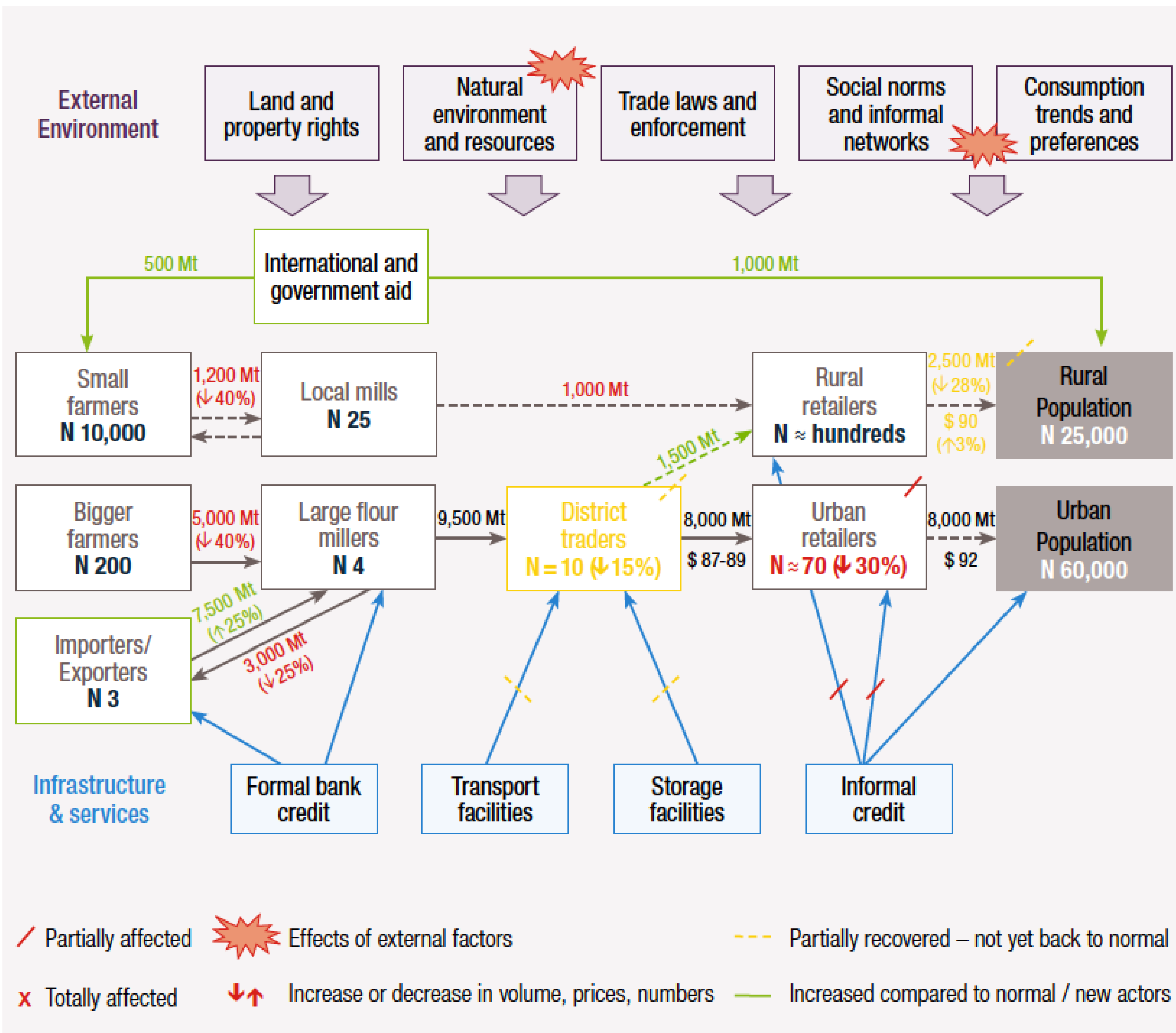

Figure 2-10: MAG example forecast map

In addition to guidance on creating a market system map, *Tool 1.4* recommends creating a marketplace map, which considers geography. The SD model does not explicitly consider geography, but a marketplace map could inform how to structure and content of input data to the model. For example, the marketplace map might identify a certain area of a country as the main production area of a commodity, with a certain transport route to the affected area. This could inform where to look for input data for `SA production` and transport costs.

DQ 1.3: What is the impact of the shock on the target population's access to markets?

This driving question addresses the target population's market access, using *Tool 1.5: Focus Group Discussions with the Target Population*. The tool consists of a series of questions, many of which pertain directly to SD model variables.

The questions relating to critical markets for essential food and non-food items are outlined below, with their relation to the SD model explained.

1. *Has the shock had an impact on households' access to the market?*
    - This pertains broadly to `IDP market access` and `HP market access`. Sub-questions about quantity and price could suggest how `HA R-C volume` and `HA R price` changed during the shock.
2. *Has the shock had an impact on households' market dependency or use?*
    - This indicates the fraction of food that is obtained from the market, which is not currently explicitly incorporated into the model.
3. *Has the shock affected households' capacity to access what they need from the market?*
    - This is measured by the output variable `HA fraction of demand met`, and internal variable `HA R demand-supply ratio`, both of which indicate the extent to which the retail market meets retail demands.
4. *Has the shock affected households' access to credit and social support?*
    - The SD model does not explicitly consider household *credit*, but can incorporate changes in other forms of support such as remittances as changes in `HP income` and `IDP income`.
5. *Has the shock affected the physical access of households to the market?*
    - This informs changes in `IDP market access` and `HP market access`.
6. *Has the shock limited the access of any particular social group (gender, age, ethnicity, wealth, etc.) to the market? How? Why?*
    - If the population groups are disaggregated in the SD model, this can inform the `IDP market access` and `HP market access` for each group.
7. *Has the shock affected households' preferences and choices in terms of type and/or quality of commodities?*
    - The SD model does not consider quality. It also does not explicitly consider other commodities. However, preference for the modeled commodity is somewhat captured with the input variable `Max fraction of income spent on rice`.

The tool contains two further sets of questions, pertaining to critical markets involving commodities sold for income and critical markets involving labour sold for income. These sets of questions pertain to `IDP income` and `HP income`. These incomes are not modeled, as both these variables are input variables. However, these questions can inform the level to set these inputs variables at.

DQ 1.4: What is the capacity of local traders to response to changes in demand?

This question is highly relevant to the SD model. Many aspects are captured in *Tool 1.6: Focus group discussions & individual interviews with traders*. The question also references the WFP's Market Integration tool, part of WFP's broader guidelines on market analysis. As noted in the *Tool 1.6*, gathering details of traders' business can be difficult as they may not be willing to divulge this information, particularly in a FGD.

The questions in *Tool 1.6* are outlined below, with their relevance to the SD model explained.

1. *Characteristics of the trader(s):*
   - *Describe the typology of the trader(s).*
     - This may indicate whether the trader in question would be classified in the model as a retailer (`R`), a wholesaler (`W`), or a trader (`T`).
   - *What are the commodities they trade?*
     - The model only considers one commodity; this question can help inform which commodity to model. However, the main driver for which commodity to model should be based on what households depend on the market for, as in *Tool 1.2*.
   - *Who are their customers? Where do they come from? Do customers change depending on the season?*
     - This could supplement information from household surveys about how the market access of different populations changes over time (*i.e.*, `IDP market access` and `HP market access`). This could also inform whether the trader serves the host area (`HA`) or the affected area (`AA`), although this could be better inferred from the trader's location.
2. *Procurement:*
   - *When, where, and from whom do traders procure the commodities? What is the origin of the commodities?*
     - This can supplement information from *Tool 1.4* regarding how the market system is structured.
   - *How has the shock affected the quantity of commodities traders buy? (How much did traders buy during 'normal' times, after the shock, now?)*
     - In the SD model, the amount a trader demands is affected by several variables, such as `T, W, R safety`, `T/W/R forecast time`, and `T/W/R equilibrium earnings fraction`. This question can indirectly indicate how some of these variables might have changed due to the shock. It may also indicate changes in the leadtimes (`F-T/T-W/W-R/R-sale leadtime`) due to supply constrictions. The answers to this question are useful to inform the model, but understanding the trader's underlying reasoning for making these decisions would be even more useful.
   - *Do traders expect to buy different quantities in the next months?*

    - This question can indirecty inform the structure of the forecasting function, *i.e.*, how traders use existing information to predict future volumes.

3. *Borrowing money:*
    - *Do traders borrow money to purchase the commodities they sell? If so, on what conditions (how much, who from, when, interest rate, payoff time)?*
        - If money is borrowed from an external source, the maximum amount borrowed is indirectly set by the `T/W/R external credit time`, but payoff time is not considered. If money is borrowed from the trader's supplier (*i.e.*, the goods are purchased on credit), the payoff time is set by `T-F/W-T/R-W payment time`, but the amount borrowed is not considered. In both cases the interest rate is set to zero in the model.
    - *How has the shock affected traders' access to credit?*
        - Changes in access to credit can be implemented in the model by changing the previously described variables.
4. *Purchasing prices:*
    - *In which months are the purchasing prices higher? And lower?*
        - All prices in the model are internal variables. Answers to this question can supplement any existing price data, which can be used to fit price changes in the model (`F/T/W/R price`) to price changes in reality.
    - *How has the shock affected the purchasing prices of key commodities?*
        - This question can also be used to help fit prices in the model to prices in reality.
5. *Competition:*
    - *How many traders sell the same commodities in the area?*
        - With knowledge of average volumes, knowing the total number of traders could inform total volumes.
    - *Are all the traders the same size?*
        - This question can further inform typical total volumes.
    - *Can consumers negotiate prices?*
        - The model considers that prices are negotiable to a degree (*i.e.*, that the retail price will decrease as supply increases), but does not consider any mechanics of price negotiation. However, the rate of price change relative to changes in supply and demand (`F/T/W/R demand-supply ratio`) can be adjusted by changing the delay time in the calculation for `F/T/W/R price`.
    - *How do traders set the prices for the commodities they sell?*
        - The model assumes that individual traders do not have market power, *i.e.*, that the price in the market is set by the relative supply and demand, the typical margin, and the upstream price. If the market becomes less competitive and individual traders have more influence over prices, this could be reflected as an increase in the equilibrium margin.
6. *Transport:*
    - *How do traders normally transport the commodities to the warehouse and/or marketplace (means of transport ownership, costs, distance, time, reliability)?*

    - Knowledge of how commodities are transported can inform how transportation costs are calculated in the model (`T/W/R transport cost`), and how they can be estimated based on typically more available data such as fuel prices. Transportation time can form part of the leadtimes (`F-T/T-W/W-R leadtime`).
  - *How has the shock affected transport movements and costs?*
    - Changes in transportation can be captured as described above.
7. *Storage capacity:*
  - *What storage capacity do traders have?*
    - The model does not consider limits on storage. However, stock values (`F/T/W/R stock`) should be checked against typical storage capacities to ensure they are sensible.
  - *When and for how long do traders store commodities?*
    - The duration of storage is not considered in the model.
  - `Where do they store them and at what cost?`
    - Storage costs are not considered in the model, but could be incorporated as an additional expense in `T/W/R/ expenses`.
  - `How has the shock affected storage capacity and costs?`
    - Although the model does not consider limits on storage, changes in storage capacity due to a shock can be compared against changes in the modeled stock.
8. *Volume of sale:*
  - *What is the volume of sales during the different months of the year (in 'normal' times, after the shock and now)?*
    - This can inform what the typical traded volumes are along the supply chain (`F-T/T-W/W-R/R-C volume`). However, since these are internal variables, they can only be adjusted by changing the leadtimes (`F-T/T-W/W-R/R-C leadtime`), which are input variables.
  - *What do you expect to happen in terms of sales in the coming months?*
    - Similarly to procurement, this can indirectly inform the structure of the forecasting function.
9. *Selling prices:*
  - *How has the shock affected the selling prices of the key commodities? (What were the selling prices during 'normal' times, after the shock, and now?)*
    - Similar to purchasing prices, answers to this question can supplement any existing price data, which can be used to fit price changes in the model (`F/T/W/R price`) to price changes in reality.
  - *How are selling prices expected to change in the next month or two?*
    - Similar to questions about predicted volumes, this indicate how to model forecasting.
10. *Credit to customers:*
  - *Do traders extend credit to their customers? If not, why not? If yes, when, to whom, under what conditions?*

    - Similar to the question about borrowing money, this can indicate how credit is offered along the supply chain, with the payment time corresponding to the `F-T/T-W/W-R payment time` variables.
  - *How has the shock affected trader practice regarding the provision of credit to customers?*
    - Changes in credit along the supply chain can be modeled as changes in the payment time, outlined above.
11. *Trader judgement of the general situation and the future:*
  - *How have traders adapted? How are they coping with the current situation?*
    - This question can be important to understand trader business models, which can inform variables `T/W/R eq cash`, `T/W/R equm earnings frac`, `T-F/W-T/R-W payment time` and the formulation for the variables `T/W/R order adjustment`.
  - *How long do traders estimate it will take for the situation to return to 'normal'?*
    - Timescales from this question can be compared against rough timescales in the model results. Understanding change over time can also inform how the above variables might change over time as the crisis evolves.
  - *What is preventing the situation from returning to 'normal'?*
    - Instead of informing specific variables, this question can inform the validity of the model results. For example, if traders claim that credit constraints are preventing the situation from returning to normal, one would expect this behavior in the model as well.

DQ 1.5: Do market actors behave competitively?

This question is also highly relevant to the SD model, mainly pertaining to how collusion can inflate prices along the supply chain. Collusion can also depress wages, but this is not considered in the model.

Tool 1.4: Market Mapping (from *DQ 1.2*) provides information for the number, size, and specialization of traders, while *Tool 1.6: Focus group discussions & individual interviews with traders* (from *DQ 1.4*) addresses barriers to entry. Together these can inform the degree of trader competitiveness, which is captured in the model by the variables `T/W/F equm earnings frac`, which is the fraction of revenue that is retained by each actor when the market is in equilibrium (*i.e.,* when supply and demand are constant). Note that this variable represents purely retained earnings, and does not comprise operating expenses. A higher level of competitiveness would lead to a lower value of `T/W/F equm earnings frac`. In extreme cases, lack of competitiveness could also affect how the variables `T/W/R price` are formulated. In a normal case, they are based on relative supply and demand, but collusion could lead to the price being fixed or artificially inflated beyond what the equilibrium earnings fraction causes.

DQ 1.6: How can macro-level factors influence the market's capacity to respond to the emergency?

This question encompasses a broad range of factors, some of which are incorporated in the model. Questions addressing these factors are captured in *Tool 1.7: Interviews with Key Informants*. Many of these questions simply provide another viewpoint for issues that are addressed in other tools (*e.g.,* traded volumes, prices, seasonality, humanitarian response, infrastructure, financial services). Key informant responses can be synthesized with other responses to inform how these aspects are captured in the model.

However, depending on the specific key informant, more information can be gathered to show how certain macro-level factors actually influence the supply chain. Instead of informing the specific value of different variables in the model, this could inform how parts of the model are actually formulated.

One major consideration is imports, and how the exchange rate and import policies influence the supply chain. These are currently captured as the input variables `NGN to USD exchange rate`, `I USD price`, `Importer margin`, `Tariff rate`, and `Import fraction cap`; input processing variable `I effective price`, internal variables `W import rate`, `W import payment`, `Import frac`, and `W price`. Key informant knowledge can shape how this is actually formulated, *e.g.,* specifically how import price influence wholesale price.

Another consideration is social and cultural issues. Key informants might be able to indicate how different groups have different market access, preference, and income (variables `IDP/HP market access`, `Max fraction of income spent on rice`, and `IDP/HP income`). Their knowledge may also be useful to better inform the actual formulation for consumer demand.

2.3.5.2 MAG Chapter 2: Response Analysis

This chapter outlines how to use and integrate market information into a response analysis process. This is highly relevant to the SD model, as the SD model also incorporates market information to inform response options.

DQ 2.1: How can market information help identify a range of potential response options?

This questions aims to ensure that market-based interventions are included in a longlist of response options. It is supported by *Tool 2.1: Long-listing Response Options*, which provides a list of potential interventions, categorized by the support target and level of market functionality they are appropriate for. It also provides a flowchart for deciding which categories of interventions could be appropriate.

The SD model can help answer questions in the initial flowchart: *"Is the market able to meet the demand for commodities or income after the shock?"* and *"Will the market system be able to meet the demand for commodities and income with some help?"*. These questions can be assessed in the model by considering what fraction of the retail demand (`HA R demand`) is actually being met by the market (`HA R-C volume`) with different market-based interventions in place.

The some of the potential interventions listed in the MAG (page 45) can be incorporated into the SD model. All of the interventions for *"Support to the target population"* and *"Market system working well"* are a form of cash or voucher assistance. These can be incorporated into the model by changing the amount of `IDP cash amount` or `HP cash amount`. However, any restricted assistance (*i.e.,* vouchers that can only be used for a certain thing) needs to be treated carefully. The model assumes that all cash aid is unrestricted, meaning the household may spend some on the modeled commodity, and some on other things. Thus, only a fraction of it actually flows into the modeled supply chain. In the model, this fraction is capped at *Max fraction of income spend on rice*. However, restricted assistance may change the amount spent on the modeled commodity by different amounts depending on what the restriction is. For example, if the assistance is restricted to water access, it may increase the amount the household spends on food, but not as much as if the assistance were restricted to food itself. Conversely, if the assistance is restricted to a commodity that could substitute for the modeled commodity, it would likely decrease the amount spent on the modeled commodity. Essentially, if restricted transfers need to be modeled, the consumer demand subsystem of the model needs to be further built to incorporate a fuller set of household preferences.

The interventions for *"Support to the target population"* and *"Market system not working well"* consist of in-kind assistance. Only the food in-kind assistance options can be incorporated into the model, as `IDP in-kind amount` and `HP in-kind amount`. The only way that in-kind assistance of other items would be incorporated into the model would be if they lead to a change in how much income is spent on the modeled commodity. As with restricted cash assistance discussed above, this would require a more complex consumer demand subsystem.

Table 2.21 outlines how interventions for *"Support to the market system"* and *"One-off, short-term support"* can be incorporated into the model.

Table 2.22 outlines how interventions for *"Support to the market system"* and *"Structural, long-term support"* can be incorporated into the model.

DQ 2.2: How can market information help screen response options against their appropriateness?

This driving question takes a qualitative approach to analyzing the appropriateness of different response options, based on the criteria:

- Cost-efficiency
- Cost-effectiveness
- Market readiness
- Risk of inflation and other market distortions

MAG response option	Incorporation to the model
Cash grants / credit to traders to restore liquidity	Credit can be modeled as the `R/W/T external credit time` variables, and grants can be modeled as inflows to `R/W/T cash`
Cash grants / credit / vouchers to warehouse owners to re-establish stock capacity	The model does not differentiate between warehouse owners and other types of supply chain actors, so this could be modeled the same as grants to traders above
Grants / vouchers to transporters	Decrease to `Total transportation cost`
Public works to repair / rebuild market structures	Market structures not currently considered in the model, but employment could increase `IDP/HP income`
Organization of vouchers and commodity fairs	Possibly increase `IDP/HP market access`
Cash grants to support small processing industries and cooperatives to re-activate the supply chain; call for government action to ensure security and access to market	Increase `IDP/HP market access`, possibly reduce `F-T/T-W/W-R/R-C leadtime`, possibly input cash to `R/W/T cash`, possible increase `R/W/T external credit time`, possible increase `F-T/T-W/W-R credit time` due to increased security and trust

Table 2.21: Response options for one-off, short-term support to the market system

- Secondary impact on markets

Tool 2.2: Analysing Market-related Appropriateness criteria provides a suggestion of market information that can be used to inform these criteria. This tool has a quantitative basis that can be supplemented in various ways by the model. Table 2.23 shows how the various criteria outlined in MAG (table on page 47) can also be informed by the model.

The next part of *Tool 2.2* is a scoring matrix to rank the response options based on the criteria previously outlined. Here, the output of the model for the various criteria can be used to supplement the more qualitative information.

DQ 2.2: How can market information help analyse the feasibility of response options?

The final driving question in the Response Analysis chapter considers how feasible responses are, based on criteria:

- Agency mandate and strategy
- Agency capacity to implement the response
- Budget available
- Risk analysis

MAG response option	Incorporation to the model
Rebuild national stocks	Increasing national stocks could be modeled as an input to `SA F stock`, which is essentially the amount of rice available at a national level
Repair national, regional warehouses	Warehouse capacity is explicitly not considered in the model, but increases in capacity can be approximated as increases in leadtime, which can improve food availability (see Section 3.2.7.1 for more)
Support government in infrastructure rehabilitation	Improved infrastructure may results in reduced `Total transportation cost`
Support financial access to credit facilities	Improving credit access may be equivalent to increasing `T/W/R external credit time`
Facilitate small producers' forward-contracting	The dynamics of forward-contracting are not considered in the model, but may be a useful extension
Provide vocational training and diversify production	This may increase `SA F production` and reduce `SA F loss rate` long-term
Promote producers' organizations / develop marketing strategies	More details would be needed to determine the potential impact, but could include supply chain credit, forecast times, and business models (*e.g.*, margins).
Improve access to market information	This would increase `T/W/R forecast time`
Call on government to ease import/export restrictions	This would increase `Imports fraction cap`, but exports are not currently incorporated
Issue trading licenses	If this makes the market more competitive, it may reduce `T/W/R equilibrium earnings fraction`

Table 2.22: Response options for structural, long-term support to the market system

Tool 2.3: Analysing Market-related Risks presents a process to assess the various risks. Some risks are difficult to incorporate into the model (*e.g.*, security risks, fraud, product quality). However, the model can be useful for analysing risks that it can incorporate (*e.g.*, price increases, some damaging market behaviors). Being a model, it can be run in any combination of scenarios and response options to compare the outcomes, and estimate the relative effectiveness of various risk mitigating measures.

2.3.5.3 MAG Chapter 3: Price Monitoring

This chapter (and the following ones) is less relevant to the SD model than the first two MAG chapters. However, price monitoring is important for the calibration of the SD model.

MAG market-related criteria	**Relevant model output**
Cost-efficiency	The cost of cash and in-kind assistance is incorporated into the model, and can be used to estimate cost-efficiency (see Section 3.2.6)
Cost-effectiveness	The purchasing gaps of the beneficiaries are modeled (*i.e.,* how much of the commodity they are able to access), and can inform what the beneficiary outcomes are
Risk of inflation	Prices are calculated in the model (`T/W/R price`) and can be used to estimate inflation in a certain market relative to the rest of the country
Potential for market disruptions	The model may be able to show when there is a risk of non-competitive behavior due to high demand to supply ratios
Secondary impacts (or multiplier effects) on markets	SCA revenues and retained earnings can be used to inform this

Table 2.23: Market-related appropriateness criteria

This is explored in Section 3.2.3. If the model is being used to project prices in the future, newly collected price data should be compared against the model's projections. If there are hypotheses behind why prices are exhibiting a certain behavior (*e.g.,* seasonality, inflation, transportation, leadtimes), these can be tested with the model.

The model can also be used to analyze different potential responses to price changes, similarly to how it is used for response option analysis.

Unrelated to the specifics of the model, the guidance for price monitoring in the MAG fits well with the model's ethos. Data should be collected and analysed meticulously, and care should be taken in attributing behaviors to causes.

2.3.5.4 MAG Chapter 4: Evaluation

The evaluation of a project can relate to the SD model in two ways.

Firstly, the information gathered in the evaluation of a project can be valuable to refining the model. This information can strengthen the model's logic. It can also provide updated values for model input data (*e.g.,* updates on household incomes and spending patterns).

Secondly, the model can be used to test hypotheses about why the project did or didn't produce certain outcomes. New information from evaluation (*e.g.,* that supply chain credit increased) can be put into the model, and the model can be re-run for the past year.

The new output can be compared to reality to test the hypothesis of what caused certain outcomes.

2.3.5.5 MAG Chapter 5: Contingency Planning

Contingency planning needs to be incorporated throughout the project cycle. In a general sense, the model can support this by simulating different scenarios to the extent that they can be meaningfully inputted to the model.

2.3.6 Model validation process

This section outlines a general method for system dynamics model validation. The details of the validation process for the SD model in this project are in Section 3.2.1.

2.3.6.1 Process

The validation of a system dynamics can consist of a range of tests, such as: boundary adequacy, structure assessment, dimensional consistency, parameter assessment, extreme conditions, integration error, behavior reproduction, behavior anomaly, family member, surprise behavior, sensitivity analysis, and system improvement [72].

In this project, some of these tests were conducted with stakeholders, and some were conducted without stakeholders. The validation conducted with stakeholders was split into two distinct and sequential parts:

1. Structure and formulation validation (equivalent to structure assessment and parameter assessment)
2. Behavior validation (equivalent to behavior reproduction and behavior anomaly)

Once structure and formulation validation is complete, behavior validation can be conducted. Each step may require some iteration within the step. Figure 2-11 provides a summary of the validation process.

Other typical tests (dimensional consistency, extreme conditions, and integration error) were conducted without stakeholder input, as this was not necessary to assess performance.

Structure and formulation validation

Structure and formulation validation is intended to check that the individual parts of the model are formulated and connected together in a way that reflects the modeling team's best estimation of reality, at a level of fidelity and complexity appropriate to the project.

Key questions to consider for the structure of the model are:

- Are the actors represented in the model appropriate? Have they been appropriately aggregated?
- Are the flows between actors appropriate?

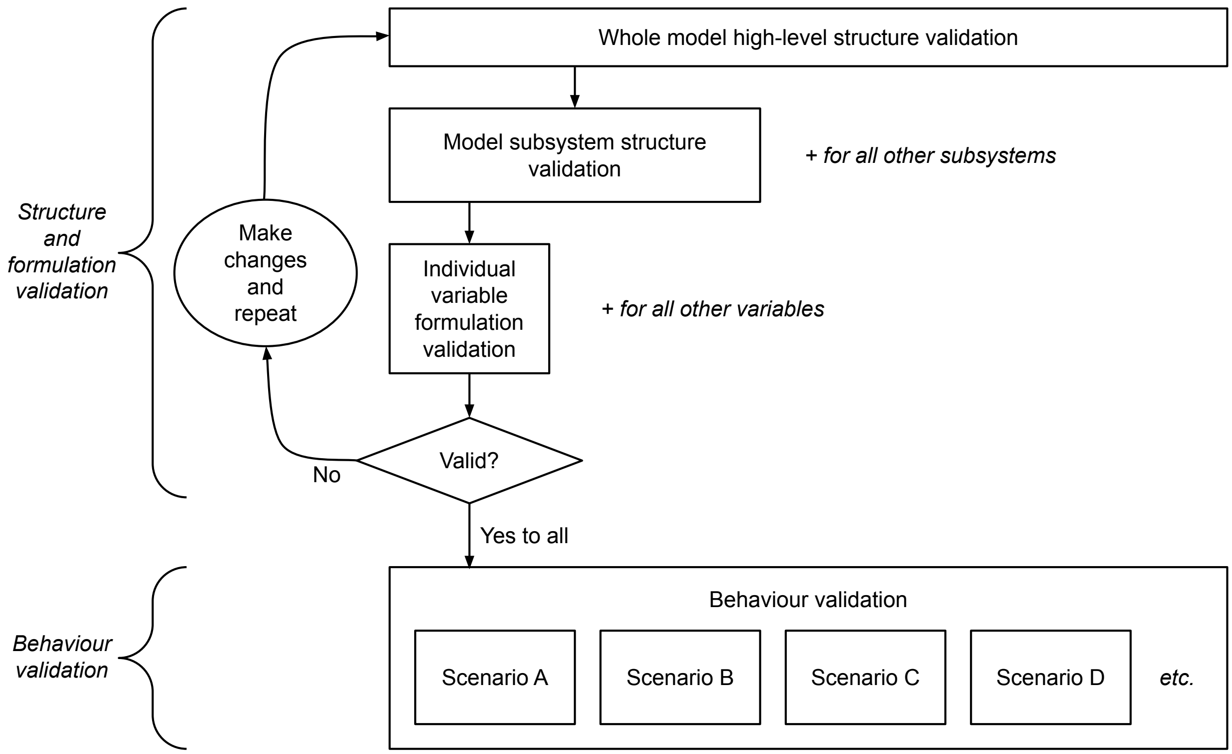

Figure 2-11: Model validation process

- Is the level of aggregation at a structural level appropriate to the model's fidelity and complexity?
- Does the model fit within the pre-agreed scope? Are there key aspects within the scope that are omitted? Or does the model comprise aspects that are outside the scope?

The formulation of the model considers the equation for each individual variable. The key questions to consider for the formulation of each variable in the model are:

- Does the equation seem logical?
- Does the equation consider all potential factors that would influence this variable?
- Is the level of complexity in the equation appropriate for the fidelity and complexity of the model?

Because the structure and the formulation of the model are intrinsically linked, their validation can take place concurrently.

Iteration can also occur during the validation process, most likely during structural and formulation validation. Feedback can results in changes to the model, which then need to be validated again.

Behavior validation

Once structure and formulation validation are complete, behavior validation can begin. Behavior validation involves assessing the plausibility of the model output for different scenarios. Behavior validation involves the steps:

1. Decide which scenarios to investigate
2. Decide how to formulate each scenario
3. Assess the output of each scenario by comparing it to historical data, or comparing it to expert opinion

Since the structure and formulation of the model have already been validated, discrepancy between the model's actual and expected output is either due to something omitted in the model, something overlooked in the structural and formulation validation, or a genuine system behavior that is unexpected.

If the behavior validation seems to indicate that an important dynamic has been omitted from the model, or that something has been overlooked in the structural and formulation validation, this should be addressed by adding in what is missing, or modifying part of the model. This then requires structural and formulation validation to be repeated for that section of the model, followed again by behavior validation.

If the system behavior produced in behavior validation cannot be explained by structural or formulation issues with the model itself, then it is possible that it is a genuine behavior of the system. This can then form the beginning of model experimentation, and wraps up the model validation phase of work.

2.3.6.2 Stakeholders involved

Different stakeholders may be able to contribute to different parts of the validation process. Some stakeholders may have a strong technical knowledge of certain aspects and may be able to comment in detail on certain parts of the formulation. Others may have a broader expertise and could comment on the overall model structure. Others still may have extensive experience in situations that the model is intending to show, and may be well-positioned to comment on the model behavior. Also, commenting on model behavior does not require knowledge of system dynamics or the model's construction, provided the results are communicated effectively.

Having aspects of model validation be accessible to different audiences can be an advantage as this can help broaden the model's legitimacy. However, it highlights the need to effectively communicate the desired level of fidelity and complexity of the model. An expert in a certain aspect of the model would likely seek high levels of fidelity in the model for their area of expertise, at the expense of complexity. Additional levels of complexity may be desired to precisely match the model's behavior to reality, despite this being superfluous to the model's utility as a decision tool.

Balancing the model's fidelity and complexity during the validation process is key for the modeling team. Although different stakeholders can add value for specific aspects of model validation, having some stakeholders be present for the whole process is key to ensuring maintaining an appropriate level of fidelity and complexity across the model and throughout the process.

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Chapter 3

Results

As the contexts and methods in this thesis are distinct, the results are presented separately. Section 3.1 presents the results from applying the multi-mode information aggregation method in the Uganda context, while Section 3.2 presents the results from applying the system dynamics model in the Nigeria context.

3.1 Uganda context

Regarding the Uganda project, the main focus of this document is on the *process* of information aggregation, rather than its actual results. However, some key results are presented here merely to illustrate the types of insights the information aggregation process ultimately produce.

3.1.1 Content of Update Reports

The Uganda project produced four update reports, released in sequence. Each update report presented insights from the period since the previous update report.

3.1.1.1 Update Report 1

Produced early in the analysis, the first update report presented a few key hypotheses [31]. Access to agricultural inputs was expected to reduce due to transportation restrictions, although this impact would be mitigated by the fact that the initial most strict restrictions were occurring between planting seasons. Export volumes were expected to drop, and increased transportation costs were expected to have ripple effects through the supply chain. Households which rely strongly on non-farm income were expected to be significantly impacted to movement restrictions limiting access to the labor market. Access to credit was also expected to be restricted, particularly if banks reduced lending due to the increased uncertainty caused by the pandemic.

3.1.1.2 Update Report 2

Now based on more information that had been collected through the information aggregation process, the second report made further assessment of what was happening, and prediction of future impacts [32]. It was assessed that input availability had likely decreased due to border closures, and importers reducing imports further to increase their liquidity. It was expected that demand for inputs would also decrease, which would ultimately reduce farmer incomes. This is illustrated in Figure 3-1.

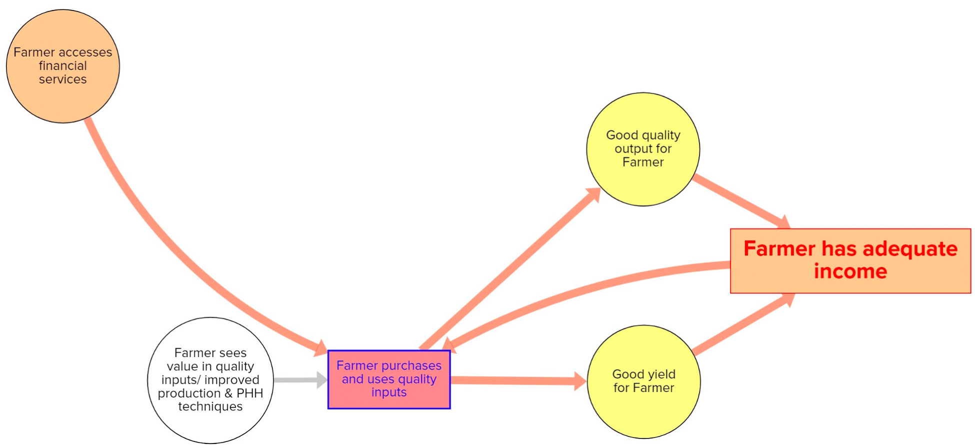


Figure 3-1: Impact on quality inputs demand and farmer income. Shock status is denoted by element colour: Red indicates *Impacted to the point of being non-functional*, Orange indicates *Significantly impacted*, Yellow indicates *Somewhat impacted*, White indicates *Impact unknown* [32]

3.1.1.3 Update Report 3

The third update report noted some important impacts for commodity distribution [33]. The increase of transportation costs, reduction in wholesale demand, and restriction of movement across borders all likely reduced trader profitability. One important assessment was that small traders, who are often women, would be particularly negatively affected. This potential outcome was identified by several sources of information that the information aggregation process highlighted. The examples of these information sources, aggregated and shown in screenshots of the system map, are shown in Figures 3-2 and 3-3.

Figure 3-2 shows the facts (under 'STATUS EXPLANATION' on the left) that are associated with the element `Traders face delays at border`. Along with other elements, it has been implied that the downstream element `Collectors / traders are connected to international / regional markets` has been *Somewhat impacted*. It has only been *Somewhat impacted* as opposed to *Significantly impacted* because international market access was not strongly impacted for formal traders, but was strongly impacted for informal traders.

Figure 3-3 shows the facts that are associated with the element `Cross-border trade limited to cargo vehicles`. The facts associated with this element support an assessment drawn from the element `Traders face delays at border`: that collector

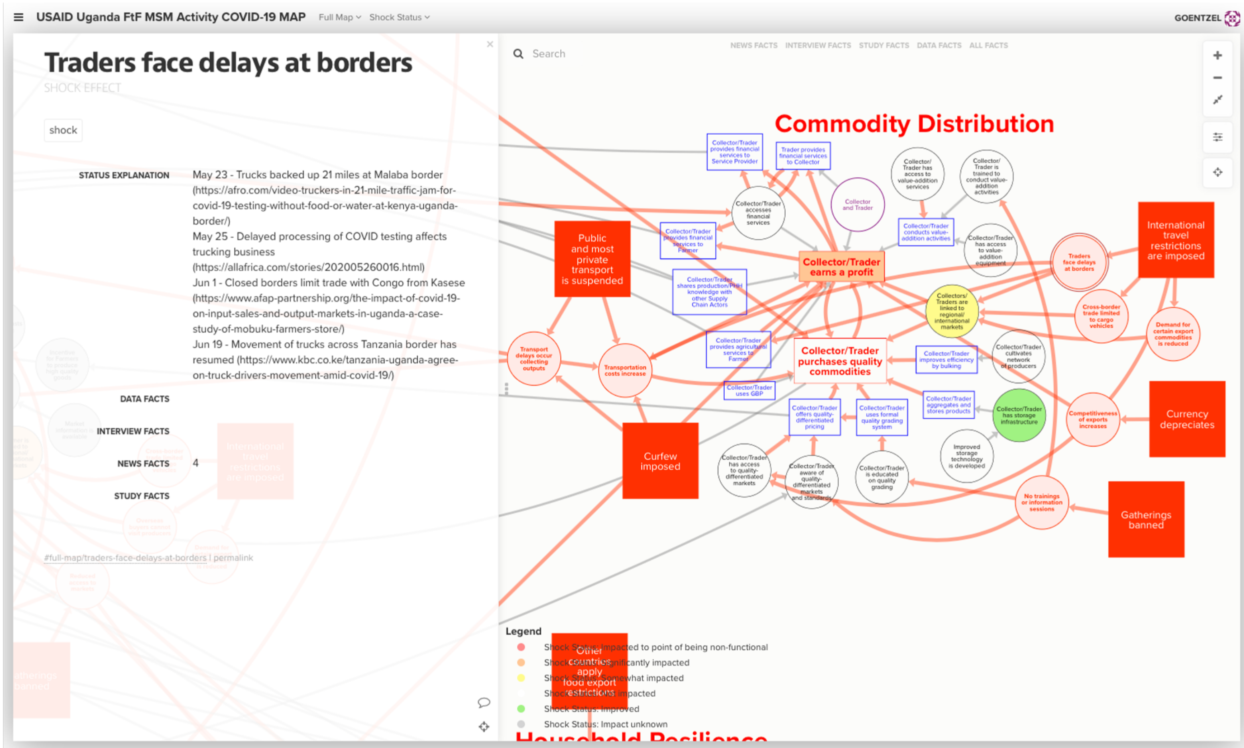


Figure 3-2: Screenshot of system map for element `Traders face delays at border` [87]

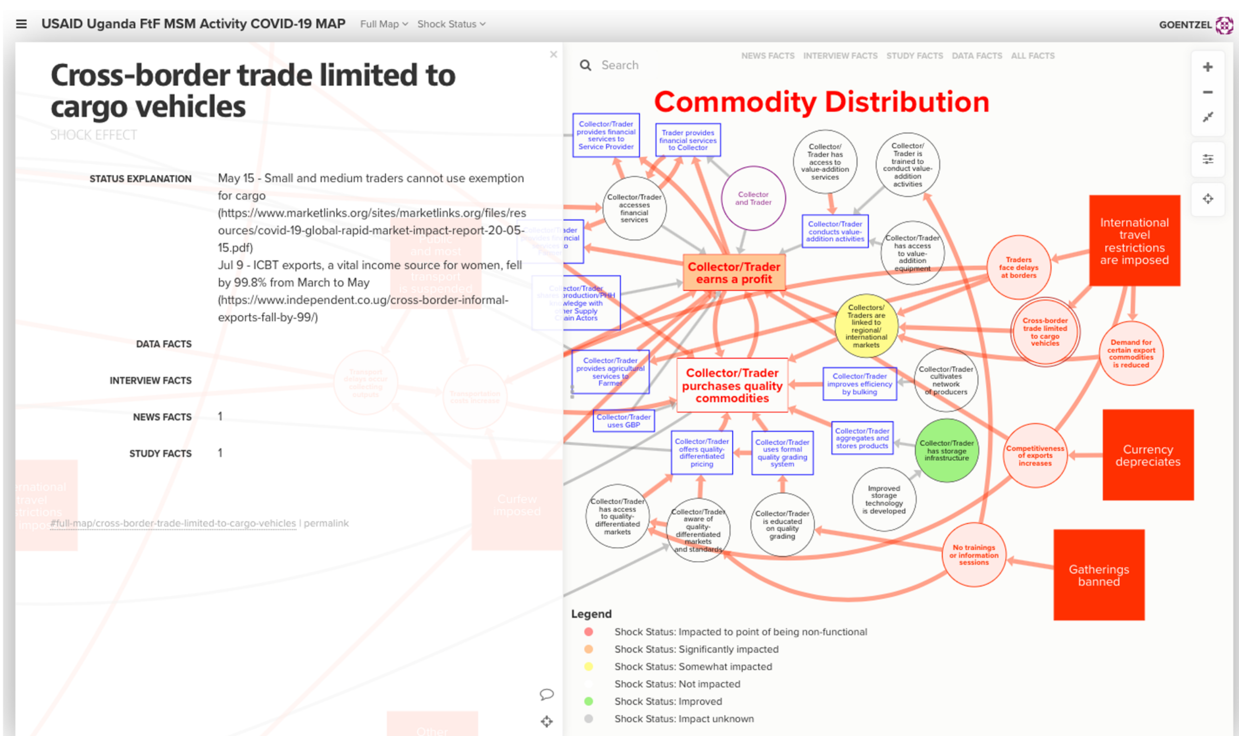


Figure 3-3: Screenshot of system map for element `Cross-border trader limited to cargo vehicles` [87]

/ trader profitability would be impacted significantly. There is also a fact associated with `Cross-border trade limited to cargo vehicles` that can further refine this assessment. The most recent fact associated with the element is that *"ICBT exports, a vital income source for women, fell by 99.8% from March to May"*, drawn from an Independent article [76]. ICBT stands for informal cross-border trade, which is the international trade that is not recorded but customs, typically conducted by small traders. This helps confirm that only cargo vehicles, who would be more likely to have a permit to trade internationally, are the only ones that can get across the border.

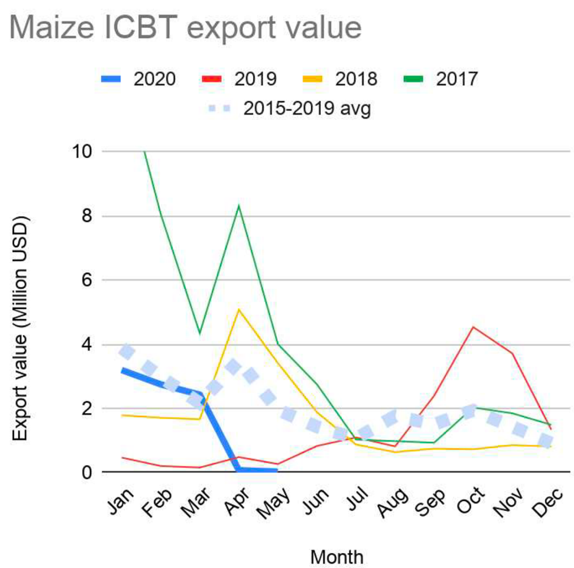


Figure 3-4: Informal cross-border trade during the COVID pandemic [33]

This statistic was investigated further for publication in the update report. Figure 3-4 shows the change in ICBT value over time. Informal cross-border trade, which normally accounts for a 1-4 million USD per month (roughly a third of maize export value), fell to zero as border restrictions were introduced. This further solidified the assessment that small traders, who are often women, would be disproportionately affected by the COVID pandemic and corresponding government restrictions (specifically, by the delays faced at borders, and cross-border trade being limited to cargo vehicles).

3.1.1.4 Update Report 4

The fourth and final update report provided updates on the specific predictions made in the previous reports [34]. This was greatly facilitated by the information aggregation process, which naturally showed how parts of the market system had changed over time.

3.1.2 Information gaps and sentinel indicators

The information aggregation process identified parts of the system where information was lacking (information gaps), and parts of the system where regularly gathering information could help provide early indication of changes in the system (sentinel indicators).

Figure 3-5 shows the Farmer Practices subsystem, with the colour of the element outlines indicating how many facts were assigned to the element. We can see that we have a lot of information for some elements (*e.g.*, `Farmer has adequate income` and `Farmer purchased and uses quality inputs`), but little information for others (*e.g.*, `Good yield for farmer`). A preliminary conclusion to draw from this example is that more information about farmer yields may be important to better understand the system behavior.

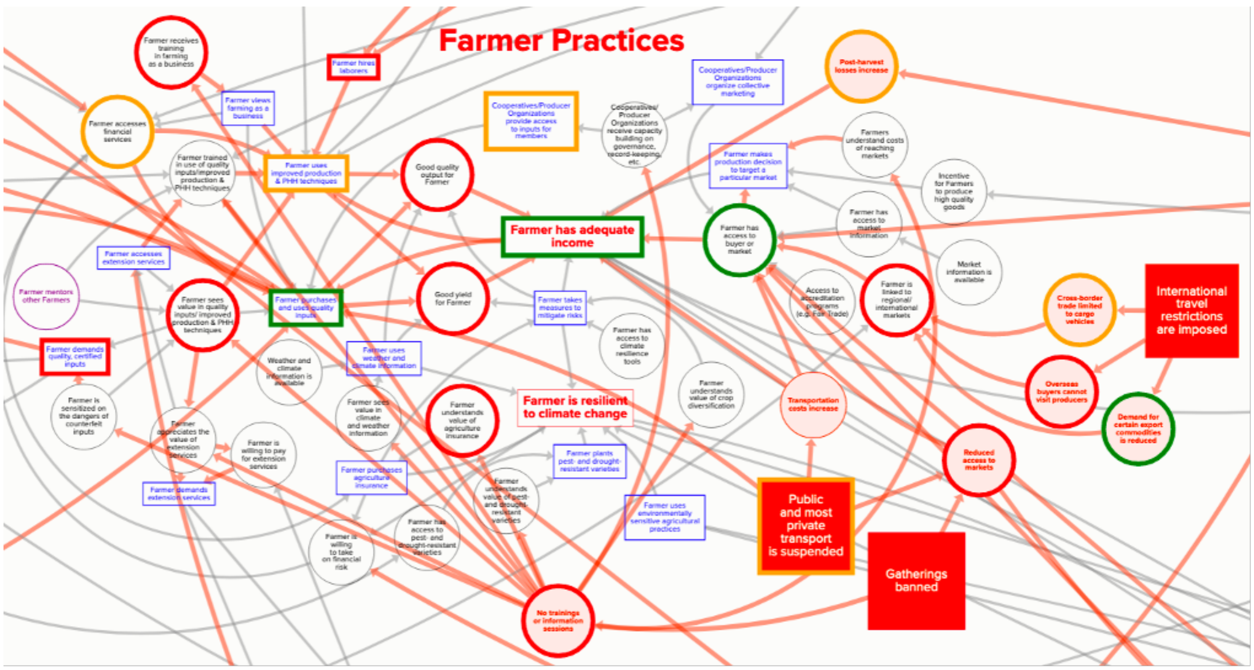


Figure 3-5: Information availability in Farmer Practices subsystem: *Green* bold outline indicates 4 or more facts, *Orange* bold outline indicates 2-3 facts, *Red* bold outline indicates 1 fact, *Thin* outline indicates no facts [34]

We can make a similar analysis on a broader scale in the system map. Figure 3-6 shows the whole system map, with the colour of the element outlines indicating how many facts were assigned to the element. Although we are too zoomed out to see the detail of the subsystems in this figure, we can see some patterns on a subsystem level. For example, the Regulatory and Agricultural Services subsystems have nearly no facts, while the core supply chain subsystems (Inputs Importing and Manufacturing, Input Distribution, Farmer Practices, and Commodity Distribution) all have a healthier number of facts. At a high level, this could indicate that collecting more information about the non-supply chain subsystems could be important for assessing system health. This is discussed in more detail in Update Report 4.

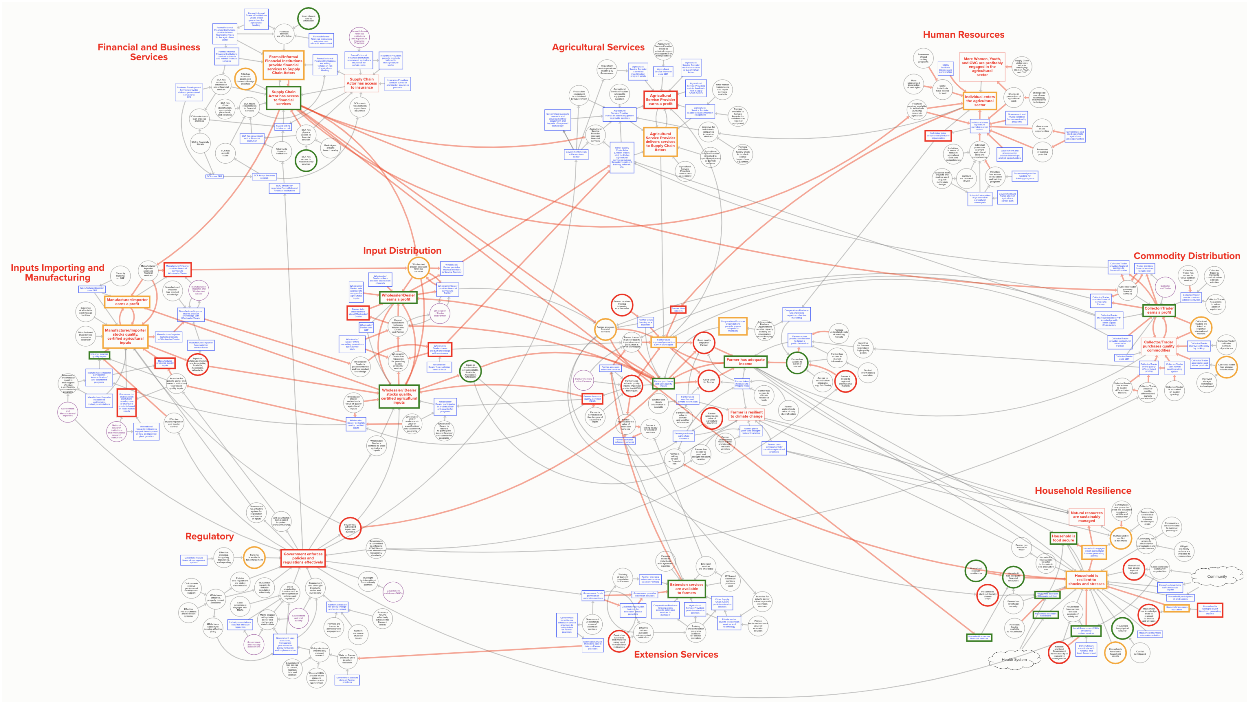


Figure 3-6: Information availability in whole system map: *Green* bold outline indicates 4 or more facts, *Orange* bold outline indicates 2-3 facts, *Red* bold outline indicates 1 fact, *Thin* outline indicates no facts [34]

Nineteen sentinel indicators were recommended to measure the impact of the shock on the system over time. The purpose, information source, and collection interval of the indicator was also recommended. A couple of examples are shown in Table 3.1.

Sentinel Indicator	**Purpose**	**Information Source**	**Collection Interval**
Access to / use of credit	Formal or informal loans may increasingly be used as a coping mechanism	UBoS-LSMS high frequency phone surveys	Quarterly
Availability of extension services at sub-county level	Indication of how significantly access to extension services has been reduced	Key informant interviews	After each planting period

Table 3.1: Example sentinel indicators [34]

3.2 Nigeria context

3.2.1 ICRC staff validation

Model validation was conducted with ICRC Geneva staff from the Economic Security Unit (EcoSec, part of the Assistance Division), and the Logistics Division. Validation was conducted with the method described in Section 2.3.6. Thus, model validation was split into two parts, conducted sequentially:

1. *Structure and formulation validation:* The structure (the level of aggregation, supply chain actors modeled, and the flows between them) and formulation (the individual equations used to each variable) were validated by the staff in a three week process.
2. *Behavior validation:* Once the structure and formulation validation was complete, various scenarios were run with the model. The results were validated with the staff.

3.2.1.1 Structure and formulation validation

Structure: High-level

The structure of the model was validated first at a high level by discussing the actors in the model, and the flows between them.

The model actors discussed are listed below. For a reminder of nomenclature and acronyms, see Tables 2.9, 2.10, 2.11, and 2.12.

- SA Farmer
- HA Trader
- HA Wholesaler
- HA Retailer
- AA Farmer
- AA Trader
- AA Wholesaler
- AA Retailer
- HA Humanitarian actor
- HA Importer

When discussing the model actors, the main considerations were their geographic scope and the group(s) of actual actors they were intended to represent. The main challenges were to clearly define the geographic areas that each model actor covered. In reality, each model actor represents a group of actual actors that is geographically disparate and potentially changing.

The flows between actors (material, financial, and information) were discussed at a high level. Again, the main challenge was regarding geographic distinctions. A particularly difficult flow to define was `SA F-T volume`, which is the flow from the Source Area Farmer to the Host Area Trader. The difficulty arises form the mis-match in geography between the two actors: the Source Area is the whole country of Nigeria, while the Host Area is Borno State. The traded volume depends on national stocks and state demand. A clearer definition of `SA F-T volume` resulted from feedback in the structural validation phase.

The structural validation phase also generated feedback regarding imports. Previously, imports were not considered in the model. Feedback led to the addition of the `HA W import rate` variable, and variables for import price calculation.

Population dynamics were also discussed in the structural validation. It was a challenge to reconcile the complex geographic dynamics of population displacement with the simple binary model, where people can simply switch between being in the Affected Area and the Host Area. Structural validation discussions did not lead to significant changes in the existing model, but did highlight potential areas for future work. The one small change structural validation brought was the addition of the variable `Intervention pull factor` and other variables to calculate it. Together, these variables account for additional population movement due to the pull of humanitarian interventions.

Formulation: AA Population Dynamics

On the first pass of model validation, the AA Population Dynamics subsystem did not include the `Intervention pull factor` and variables used to calculate it. ICRC staff noted during model validation that sometimes interventions implemented in a certain area can cause increased displacement towards that area. ICRC staff also noted that cash assistance may result in more displacement than in-kind assistance. These aspects were incorporated into the subsystem, and the subsystem was re-validated.

ICRC staff also noted that for other contexts it may be useful to model different population group movements. This was not incorporated into the current model, but was noted as a potential development to make the model more generalizable.

Formulation: AA Production and Consumption

ICRC staff feedback for this subsystem did not necessitate any formulation changes.

Formulation: SCA Supply and Price

On the first pass of model validation, the ability of the wholesaler to import was not yet implemented. ICRC staff noted that exchange rates can potentially have an effect on prices and supply. This feedback led to additional variables being created to capture import prices, and a simplified version of importing behavior.

ICRC staff also enquired whether this formulation would produce hoarding behaviors by SCAs. It was noted that this behavior may arise from SCA forecasting.

Formulation: SCA Cash

On the first pass of model validation, credit along the supply chain was not yet implemented. ICRC staff noted that trust along the supply chain can be key to supply chain performance, particularly in conflict settings. This led to additional formulation being added for SCA supply chain credit. After this additional formulation was implemented, the SCA cash part of the model was re-validated.

Formulation: SCA Retained Earnings

ICRC staff feedback for this part of SCA behavior did not necessitate any formulation changes.

Formulation: SCA Demand

ICRC staff feedback for this part of SCA behavior did not necessitate any formulation changes. However, some clarification was requested for how the SCA forecasts. It was clarified that since forecasting is based on revenue, SCAs will attempt to increase their stocks if the price they sell at increases, or if they are facing increased demand.

Formulation: SCA Supply Chain Credit

This aspect of SCA behavior was implemented after the first pass of formulation validation. On the second pass of formulation validation, ICRC staff feedback for this part of SCA behavior did not necessitate any formulation changes.

Formulation: SCA External Credit

ICRC staff feedback for this part of SCA behavior did not necessitate any formulation changes.

Formulation: SA Production

ICRC staff feedback for this subsystem did not necessitate any formulation changes.

Formulation: Humanitarian Actor

ICRC staff noted that often in-kind distributions only occur during the lean season, with sourcing occurring after the harvest. It was not necessary to change any model formulation to accommodate this. However, it did highlight the need to produce input parameters externally, such as with a Python script. This greatly facilitates inputting time-varying input parameters.

Formulation: Consumer Demand

ICRC staff noted that the demand system is very simple, and did not capture potentially important aspects such as cross-price elasticities. In response to this, another consumer demand subsystem was developed based on the Linear Expenditure System. However, the original formulation was deemed sufficient for the current model. Future versions of the model that incorporate multiple commodities will need a more sophisticated consumer demand subsystem.

Formulation: Imports Cost

This part of the model was added based on ICRC feedback. Further feedback regarding this part of the model did not necessitate any formulation changes.

Formulation: Imports Volume

ICRC staff noted that this behavior is quite simple, but should be sufficient for the model in its current state.

3.2.1.2 Behavior validation

Note that the scenarios assessed during model behavior validation are different than the scenarios developed later for response option analysis (Section 3.2.5).

Scenario 0: baseline

In this scenario, the model produced behavior that largely aligned with the behavior expected by ICRC staff. However, staff did note that the demand is often higher than the supply. It was explained that this is because the safety stock level in the baseline is set to zero, so any demand fluctuation could lead to gaps in supply.

Scenario 1: increased trust along the supply chain

This scenario investigated the effect of increasing supply chain credit time from zero to one month. The model produced behavior that aligned with the behavior expected by ICRC staff.

Scenario 2: quicker leadtimes

This scenario investigated the effect of halving all leadtimes. The model produced behavior that aligned with the behavior expected by ICRC staff.

Scenario 3: increased transportation costs

This scenario investigated the effect of doubling all transportation costs. The degree to which this increased retail prices was somewhat unexpected to ICRC staff. Upon further investigation in the model, this behavior aligned with their expectations.

Scenario 4: cash aid to IDPs

This scenario investigated the effect of giving IDPs cash assistance. The degree to which this suddenly increased retail prices was somewhat unexpected to ICRC staff. However, once it was remarked that this scenario represented an *instantaneous* increase in cash assistance for *all* IDPs, model behavior aligned with their expectations.

Scenario 5: in-kind aid to IDPs

This scenario investigated the effect of giving IDPs in-kind assistance sourced from the wholesaler. The degree to which this suddenly increased retail prices was unexpected to ICRC staff, given that the demand jump should be occurring at the wholesaler. This level of surprise was somewhat reduced when it was noted that this scenario represented an *instantaneous* increase in in-kind aid for *all* IDPs. Further discussion of how prices in the model are calculated better aligned the model behavior with their expectations. No formulation changes resulted from this discussion. However, it did highlight a key weakness in the model: when the supply chain is modeled as a single aggregated flow (*i.e.,* all material that passes through the wholesaler also passes through the retailer), price variations upstream can have very strong effects on prices downstream.

Scenario 6: allowing imports

This scenario investigated the effect of allowing unlimited imports. The model produced behavior that aligned with the behavior expected by ICRC staff.

3.2.2 Other validation techniques

Other than validating the model with the ICRC HQ staff, the model was also validated with some standard tests for a system dynamics model: a dimensional consistency check, extreme value tests, and a time step check [72].

Dimensional consistency check

Powersim has a built-in feature to ensure dimensional consistency across the model. This was used throughout the model construction; it was ensured that the dimensions automatically assigned to variables matched the dimensions they are intended to have.

Extreme value tests

A few extreme value tests were conducted.

Setting the level of conflict to 1 (its maximum value) resulted in `AA population` gradually dropping to zero.

Setting `SA F production` to zero resulted in all prices growing exponentially, and all traded volumes dropping to zero.

Setting all safety stock values to 5 (equivalent to an SCA stocking 500% more than they expect to sell) resulted in all gaps between supply and demand dropping to zero.

Time step check

The time step is set to 0.0625 months (about two days), which is half of the shortest time constant in the model (`HA R-C leadtime` at 0.125 months). When the time step was halved (to 0.03125 months), no significant changes were noted in the model output. When the time step was doubled (to 0.125), some changes were noted in the model output. Thus, a time step of 0.0625 months was deemed to be appropriate.

3.2.3 Comparison with historical data

The output of the model was compared with historical data for January 2017 up to when the most recent data was available at the time of writing (March 2021). Although some historical data was available for later months, March 2021 was the most recent time that all historical datasets were available, with the limiting dataset being the IOM DTM, which is typically only released every two months about 2-3 months after the measurement time.

The model was run first with no modifications, and later run with modifications to inputs that represent hypotheses of what was happening to uncertain input parameters at the time. The following sections outline these runs.

For each run, the retail price, wholesale price, and IDP population from the model was compared to historical data. For more information on the data source of the prices and population, see Sections 2.3.4.5 and 2.3.4.3, respectively. The model fit was assessed using Thiel statistics [72], where the mean squared error is broken down into three components:

- U^M: the bias
- U^S: the unequal variation
- U^C: the unequal co-variation

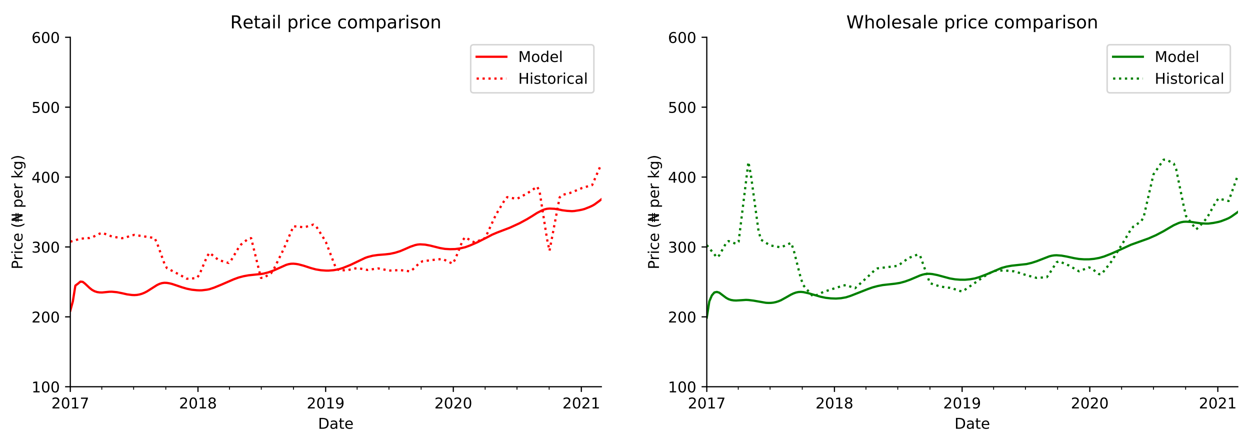
The R^2 value is also calculated.

3.2.3.1 Baseline run

The model fit for a baseline run with no modifications to the inputs is presented in Table 3.2. A comparison between the modeled and historical retail price, wholesale price, and IDP population is shown in Figures 3-7a, 3-7b, and 3-8 respectively.

	Retail price	Wholesale price	IDP population
U^M	0.33	0.24	0.02
U^S	0.00	0.07	0.04
U^C	0.67	0.69	0.94
R^2	0.38	0.32	0.73

Table 3.2: Model fit statistics: baseline



(a) Retail price

(b) Wholesale price

Figure 3-7: Price comparison: baseline

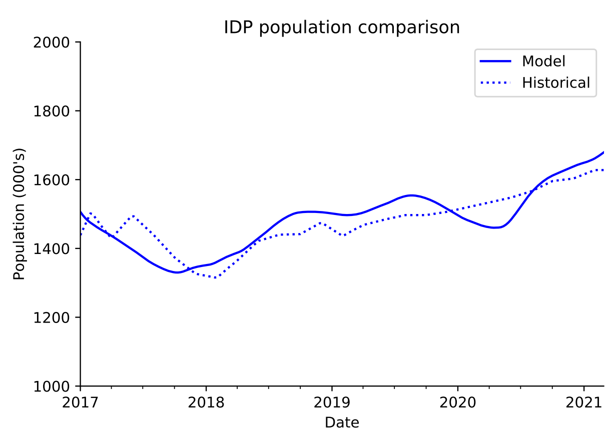


Figure 3-8: IDP population comparison: baseline

The model fit shows relatively low bias (low U^M) for IDP population, relatively low bias for wholesale price, and slightly higher bias for retail price. This suggests that there is a systematic error in the difference between the wholesale and retail prices, *i.e.*, a systematic error relating to the retailer's margin.

The R^2 value for both prices is quite low. This makes sense looking at the plots — for both prices, the model predicts a relatively consistent price increase throughout the run (tracking headline inflation), while the historical price stays relatively constant and only jumps during 2020. This suggests two things: some changes in the supply chain may have led to gradual cost decrease to offset the headline inflation during 2017-2019, and another change in the supply chain led to a cost increase in 2020. We can use the model to hypothesize what these changes could have been.

3.2.3.2 Run with increased leadtimes during 2020

One hypothesis for supply chain changes is increased leadtimes during 2020. Due to the COVID-19 pandemic, the Nigerian government implemented a range of transportation restrictions, possibly leading to increased leadtimes.

According to the Oxford COVID-19 Government Response Tracker [37], the Nigerian government had a policy to 'restrict movement' from 29 March 2020 to 30 June 2020 and from 14 August 2020 to 10 September 2020, and a policy to 'recommend movement restriction' from 1 July 2020 to 13 August 2020, from 11 September 2020 to 8 March 2021, and from 25 May 2021 to 6 June 2021. We can hypothesize that policies of 'restrict movement' and 'recommend movement restriction' led to all leadtimes in the model to increase by 50% and 20%, respectively, as shown in Figure 3-9.

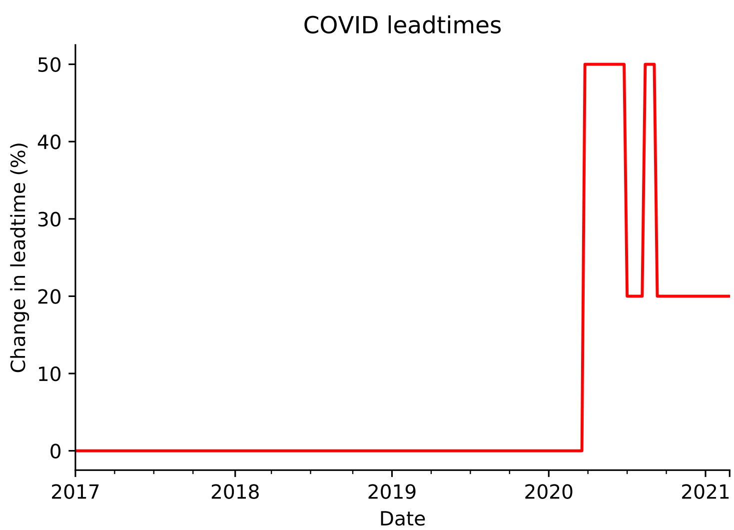


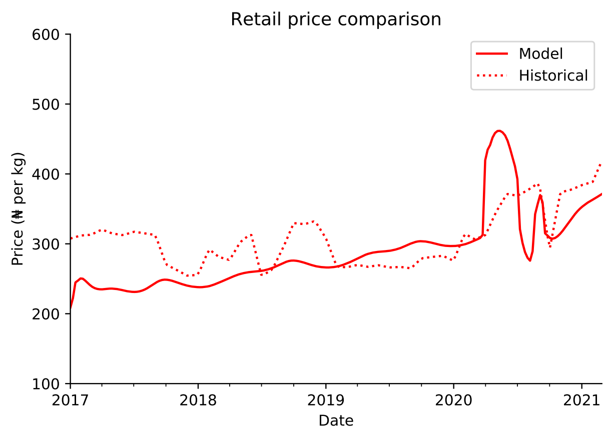
Figure 3-9: Leadtime changes due to COVID

The model fit statistics for this run are presented in Table 3.3. A comparison between the modeled and historical retail price and wholesale price is shown in Figures 3-10a and 3-10b respectively. IDP population is not shown since there is no change from the baseline run.

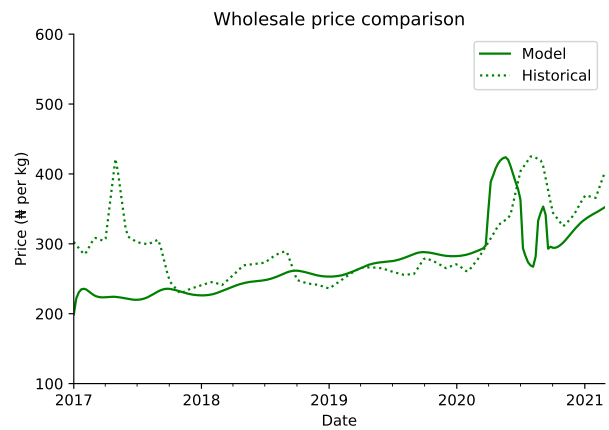
	Retail price	Wholesale price	IDP population
U^M	0.16	0.14	0.02
U^S	0.08	0.00	0.04
U^C	0.76	0.85	0.94
R^2	0.30	0.22	0.73

Table 3.3: Model fit statistics: COVID leadtimes

The Thiel statistics for this run show an improvement from the Thiel statistics for the baseline run. The bias (U^M) for both prices has reduced (from 0.33 to 0.16 for retail and from 0.24 to 0.14 for wholesale). This indicates that when historical information about the leadtimes in the supply chain is incorporated into the model, it does a better job of predicting the average prices. This improves the model's credibility.



(a) Retail price



(b) Wholesale price

Figure 3-10: Price comparison: COVID leadtimes

In a more qualitative way, in Figure 3-10 we can also see clearly the spike in wholesale and retail prices due to the increased leadtimes. Although the timing doesn't line up perfectly with the price spike in the historical data, the approximate shape of the increase is reasonable, particularly for the wholesale price.

The price increase and decrease occur earlier in the model than they do in the historical data. This suggests that the model predicts prices to change more rapidly than they do in reality. This could be because the model omits household stocks. Household stocks being included in the model would lead to more of a buffer — retail and subsequently wholesale demand may only increase after household stocks have been depleted.

3.2.4 Forecasting input data

Before running the model for a time in the future when input data is not available, the input data needed to be forecasted. For more information on how input data is used in the model, see Section 2.3.4.

Inflation data

The inflation data from the Nigeria National Bureau of Statistics was forecasted using an exponential fit:

$$y = A \exp(Bx) + C$$

where y is the price index, x is the date, A, B, and C are parameters to fit the curve. This model was chosen because it assumes that the *rate* of inflation will remain constant. A different curve was fit for the three different prices indices used, with data from January 2017 to May 2021 being used. The curve fits for the three price indices used in the model are shown in Figure 3-11, with extrapolation of the curve through to March 2022.

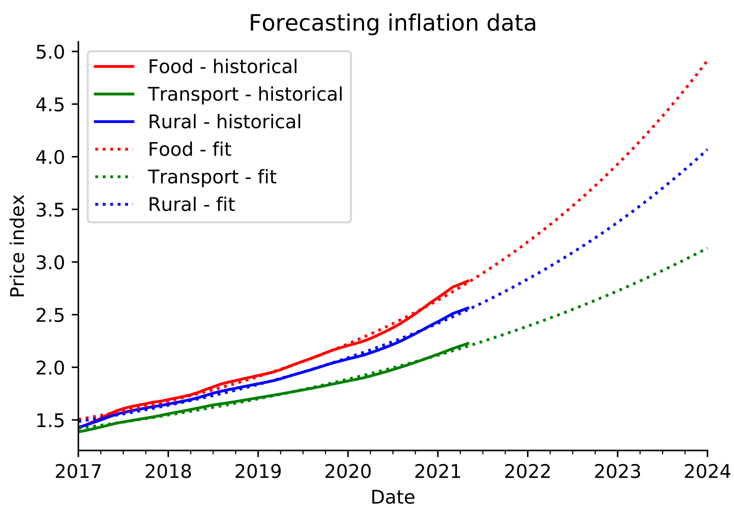


Figure 3-11: Inflation data projection

Conflict data

Conflict data from ACLED was assumed to be constant at the average conflict level for January 2017 to May 2021, shown in Figure 3-12. Although in reality the conflict level, as measured by deaths per month in Borno state, varies significantly from month to month, this does not significantly affect the number of IDPs if the *average* conflict level is the same. This is because there is both a time lag in conflict producing a perception of danger in the area (`Perceived danger in the area`), and another lag in this perceived danger actually producing displacement.

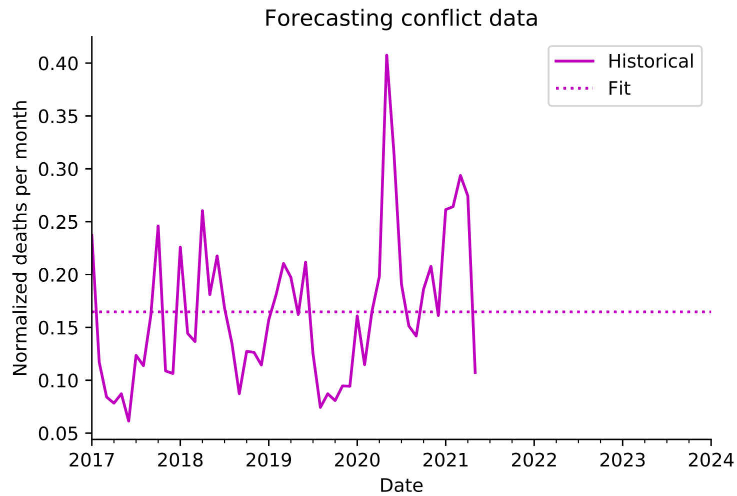


Figure 3-12: Conflict data projection

Production data

Production data was forecasted using a linear fit for the annual production volumes. Seasonality is assumed to remain the same (*i.e.*, the harvest occurs at the same time every year) and is not shown here. The forecast for annual production volume is shown in Figure 3-13.

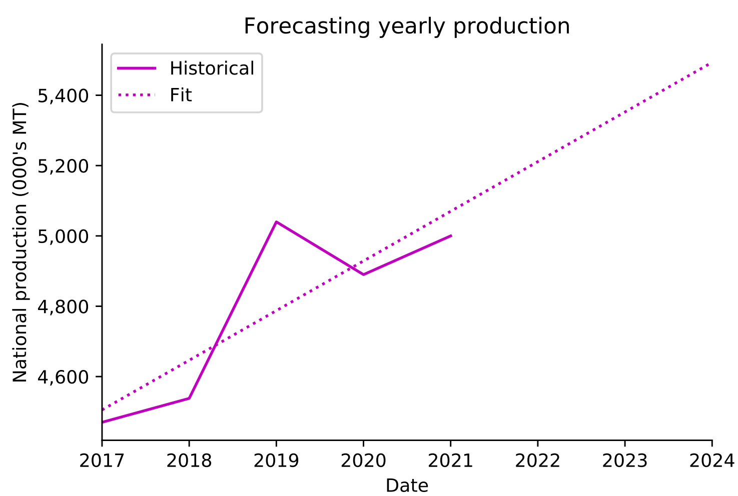


Figure 3-13: Production data projection

Import prices

The price of Thai B rice was forecasted using a linear fit, shown in Figure 3-14. Although this does not nearly capture the complexity in the variation of the price, there is no immediately obvious pattern to the price variation, and building a more accurate forecast is beyond the scope of this project.

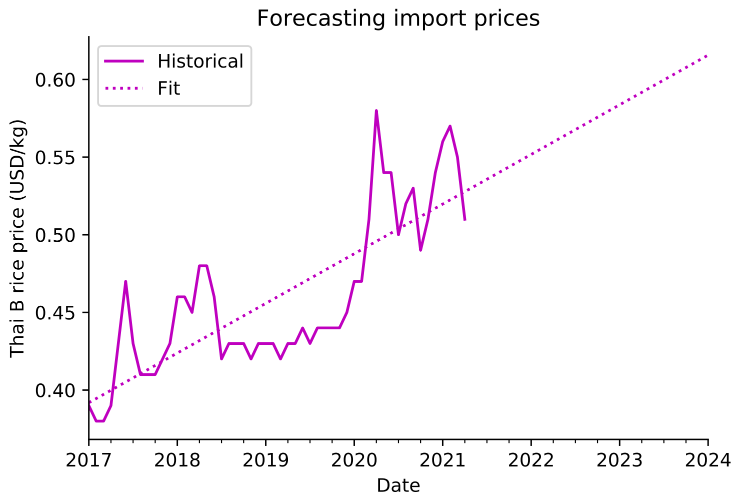


Figure 3-14: Import price projection

Exchange rate

The exchange rate was assumed to remain constant at the most recent value (21 June 2021), as shown in Figure 3-15. This is because based on historical values, the exchange rate tends to increase to a certain value, then remain around this value for a long time.

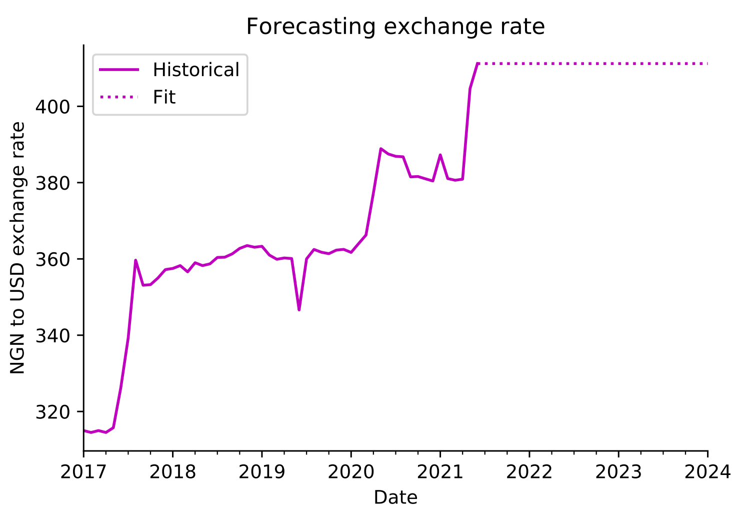


Figure 3-15: Exchange rate projection

3.2.5 Response option analysis

The model was also used to forecast outcomes under different scenarios and response options. These scenarios and response options were developed with the ICRC HQ staff.

The model was run for three scenarios:

- *Scenario 0:* **Baseline.** All input parameters are projected as outlined in Section 3.2.4.
- *Scenario 1:* **Increased conflict.** The projected `Deaths per month` is doubled starting in January 2022. All other input are projected as outlined in Section 3.2.4.
- *Scenario 2:* **Increased conflict with increased leadtimes.** The projected `Deaths per month` is doubled starting in January 2022. The wholesaler, retailer, and consumer leadtimes (`T-W/W-R/R-C leadtime`) are all doubled starting in January 2022. All other input are projected as outlined in Section 3.2.4.

For each of these scenarios, four different response options (ROs) were tested:

- *RO-0:* **Do nothing.** No humanitarian action at any time.
- *RO-1:* **Food aid to IDPs.** Starting in January 2022, the humanitarian actor distributes rice (standard food ration of 50 kg per 6 person household [40]) to all IDPs every month for the full two years. The food is continually sourced from the Wholesaler, and there is no leadtime between sourcing and distributing the food.
- *RO-2:* **Cash aid to IDPs.** Starting in January 2022, the humanitarian actor distributes cash (survival minimum expenditure basket of NGN 37,500 per 6 person household [40]) to all IDPs every month for the full two years.
- *RO-3:* **Cash aid to IDPs and HP.** Starting in January 2022, the humanitarian actor distributes cash (survival minimum expenditure basket of NGN 37,500 per 6 person household [40]) to all IDPs and all HP every month for the full two years.
- *RO-4:* **Cash aid to IDPs and HP, with credit to traders.** Starting in January 2022, the humanitarian actor distributes cash (survival minimum expenditure basket of NGN 37,500 per 6 person household [40]) to all IDPs and all HP every month for the full two years. In addition to this, each supply chain actor can borrow up to their yearly revenue at zero interest rate from the humanitarian actor.

Each of these scenarios and response plans span the years 2022 and 2023, but the model run began one year prior (*i.e.,* the model was run from January 1, 2021 to December 31, 2023). Although annual planning remains in the norm for the ICRC, the organization is increasingly looking to longer-term planning. Of course, the projections made by this simulation become increasingly uncertain further in the future.

3.2.5.1 Main performance metrics

The main metrics used to assess different scenarios-response plan combinations are outlined below.

IDP and HP purchasing gap

The purchasing gap is the fraction of a household's daily rice needs that is it *not* purchasing at a given time. A purchasing gap of 0% indicates the household is able to access and afford all the rice it needs, as defined by the variable `Rice needs per capita`. Conversely, a purchasing gap of 100% indicates that the household is not purchasing any rice at all. There are many existing food security indicators (*e.g.,* HDDS, FCS, HHS, FIES [46]), some of which can be estimated from the purchasing gap with some assumptions about household behavior. However, the purchasing gap was chosen for this analysis as it best fits with the output of the SD model.

The purchasing gap is split into two causes: income and market. Purchasing gap due to income indicates that the market is able to supply all the rice that the household *demands*, but this demand is lower than the household's *needs* because of the price relative to their income. Purchasing gap due to market indicates that the market is *not* able to supply all the rice that the household demands. It is possible for both causes to be happening at the same time.

A *time-averaged* purchasing gap is the average purchasing gap of a certain population over run time of the model. A *population-averaged* purchasing gap is the weighted average purchasing gap of the two populations (IDP and HP) over time. The *total* purchasing gap is the sum of the income and market purchasing gap.

Note that IDP and HP purchasing gaps are already averaged across the three income groups that make up each population. See Section 2.3.4.13 for how a population group is split into income groups.

Note also that since the model does not consider household stocks, a household's *purchasing* gap does not necessarily equal a household's *consumption* gap. The model assumes that whatever is purchased is consumed immediately.

Humanitarian spending

The humanitarian spending is the amount the humanitarian actor spends on in-kind assistance, cash assistance, and credit to traders. Note that in the model, the humanitarian actor is an aggregate of all humanitarian actors in the region.

The spending to credit traders, the amount a humanitarian actor 'spends' is the maximum amount that the humanitarian actor is owed at any point in time. This is equivalent to assuming that the supply chain actors never pay the humanitarian actor back, and get to choose their borrowing amount (up to the credit limit specified by the humanitarian actor).

3.2.5.2 Summary of response option analysis

Figure 3-16 shows a comparison of all scenarios and response options, plotting the time- and population- averaged total purchasing gaps against the total humanitarian spending.

We can take a more granular view of this summary by looking at each scenario individually, shown in the following sections.

3.2.5.3 Scenario 0: Baseline

Figure 3-17 shows the five possible response options (including the do-nothing response) for Scenario 0, with the purchasing gap disaggregated by population group. We can see that Response Option 1 greatly reduces the purchasing gap for IDPs, but increases the

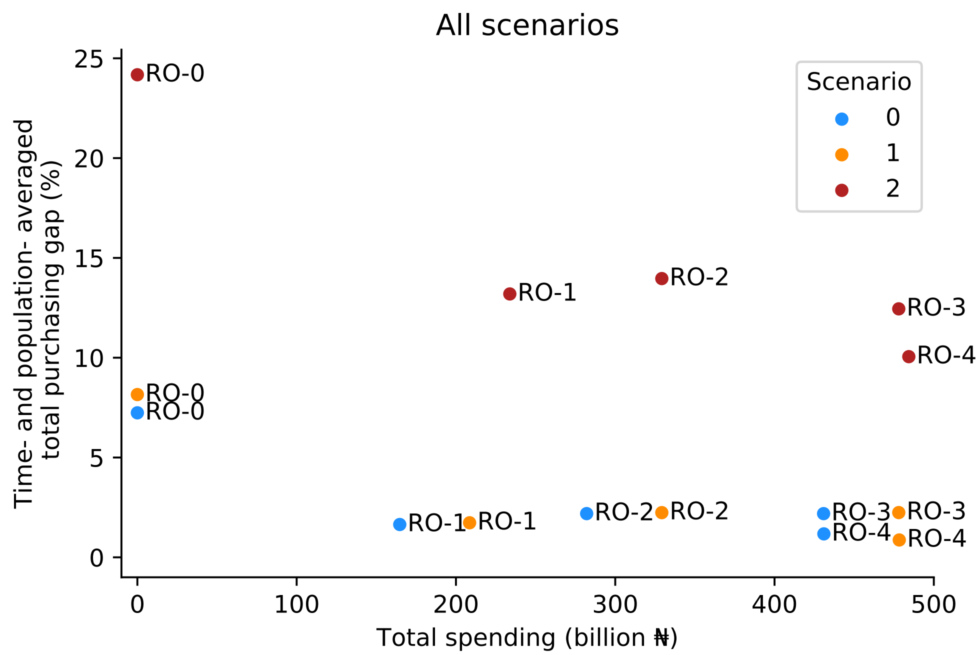


Figure 3-16: Comparison of all scenarios and response options ('RO-' labels indicate response option)

purchasing gap for HP. Outcomes for HP and IDP are roughly the same for Response Option 2. Response Options 3 and 4 have nearly identical spending, but Response Option 4 has a reduced purchasing gap for both IDP and HP.

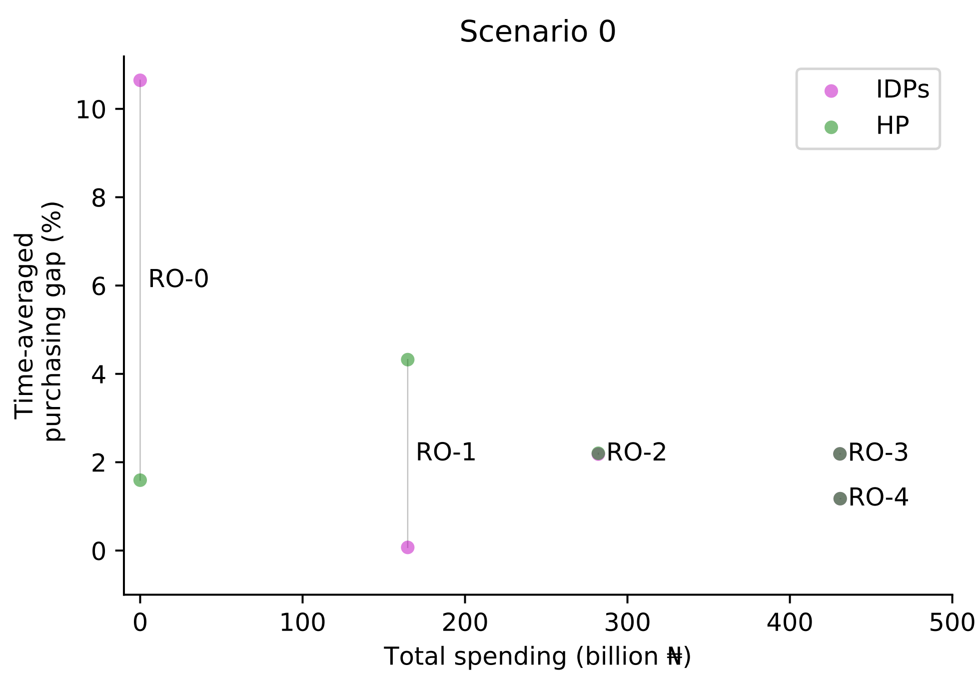


Figure 3-17: Comparison of response options for Scenario 0

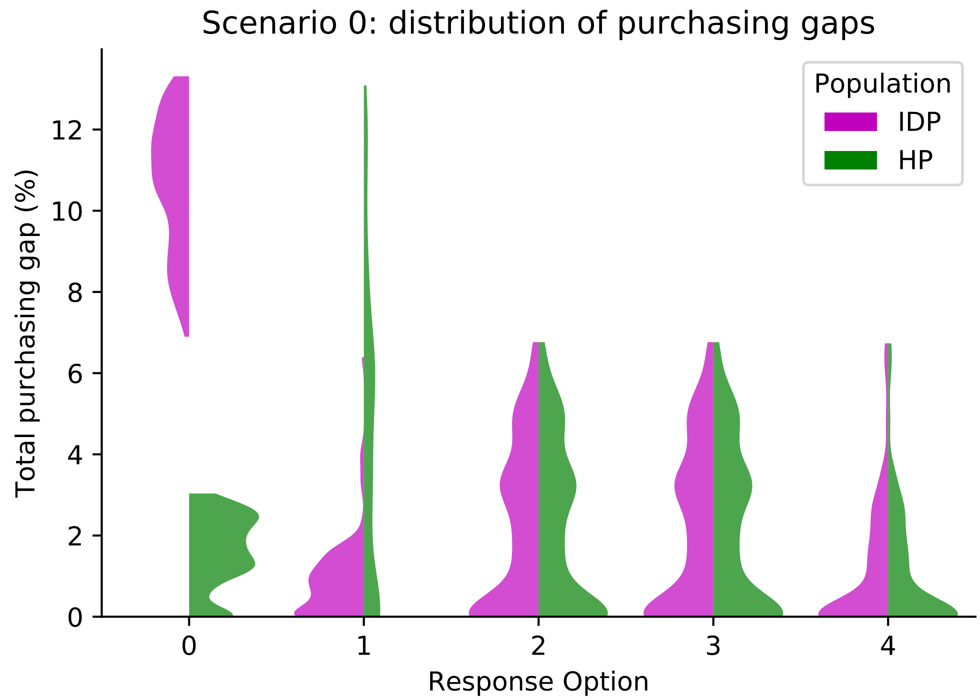


Figure 3-18: Distribution of purchasing gap for Scenario 0

What we don't see in Figure 3-17 is the distribution of outcomes for both populations, we only see the time-averaged value. Figure 3-18 shows the distribution of purchasing gaps throughout the simulation time for IDP and HP populations, for each response option. The shapes indicate the fraction of time that each population group spends at different purchasing gap levels. Here we see that for RO-0, the IDP population *always* has a higher purchasing gap than the HP. For RO-1, the HP has a broad distribution of purchasing gaps over the simulation time. This means that the purchasing gap varies widely over time. Although their time-averaged purchasing gap is just above 4% (from Figure 3-17), from Figure 3-18 we can see that sometimes it ranges all the way above 12%. Conversely, the IDPs consistently have a low purchasing gap for RO-1. For RO-2, RO-3, and RO-4, the distributions for the two populations are similar. The causes of these purchasing gap distributions are explored further in the following sections, response option by response option.

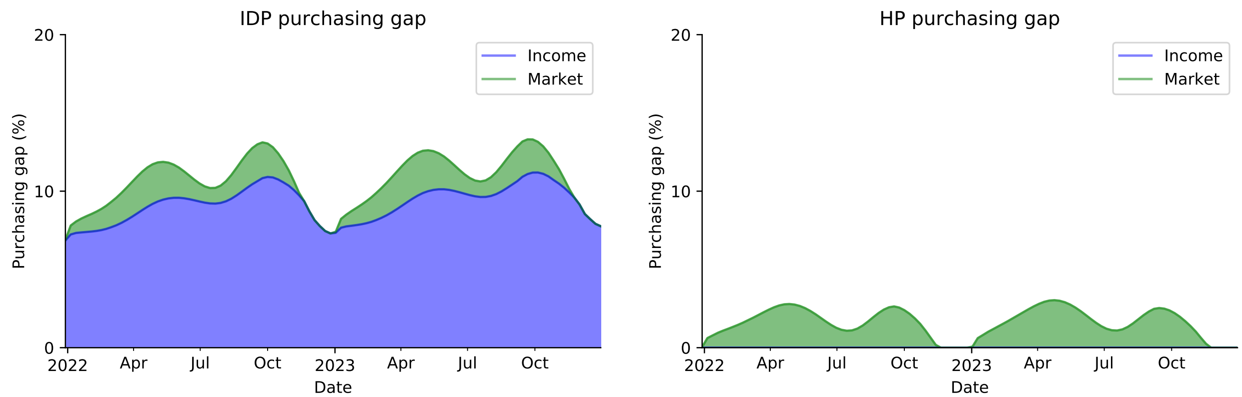
Response Option 0: Do nothing

The outcomes for IDPs and the HP are shown in Figure 3-19. The average outcomes are shown in Table 3.4. The humanitarian spending in this response costs nothing, since there is no humanitarian response.

Notably, there is almost always a purchasing gap due to the market. This indicates that the supply chain does not fully supply the market's demand during most of the year, only during the period after the main harvest (after October). A combination of two properties

Source	Average purchasing gap (%)	
	IDP	HP
Income	9.2	0.0
Market	1.4	1.6
Total	10.6	1.6

Table 3.4: Scenario 0, RO-0: time-averaged purchasing gaps



(a) IDP purchasing gap

(b) HP purchasing gap

Figure 3-19: Scenario 0, RO-0: purchasing gaps

of the supply chain is leading to this behavior. Firstly, the baseline scenario assumes that all supply chain actors do not keep any safety stock. This means that the supply chain will be in equilibrium only when the demand is exactly met by the supply. Any additional demand will not be immediately met. Although the IDP population is relatively constant, the demand is not since prices are varying due to seasonal production. Secondly, prices are also continually increasing, and supply chain actors have no credit access. Although in the baseline scenario they are forecasting by one month, they are only able to spend what they are currently earning.

Another point to note is that IDPs have a significant time-averaged purchasing gap (9.2%) due to income, whereas the host population does not. This is because host population incomes are higher than IDP incomes.

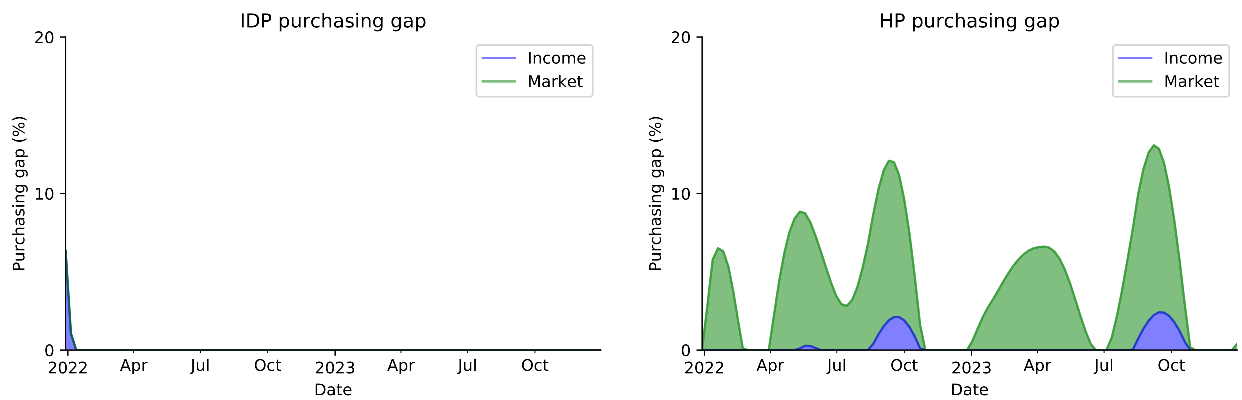
Response Option 1: In-kind assistance to IDPs

The outcomes for IDPs and the HP are shown in Figure 3-21. The average outcomes are shown in Table 3.6. The humanitarian spending in this response costs NGN 164.7 billion, all of which is spent on in-kind assistance procurement.

Notably, the purchasing gap for the host population has increased significantly, both due to income and market. This is because humanitarian procurement from local wholesalers is putting pressure on the supply, which reduces availability (leading to the market

	Average purchasing gap (%)	
Source	IDP	HP
Income	0.1	0.3
Market	0.0	4.0
Total	0.1	4.3

Table 3.5: Scenario 0, RO-1: time-averaged purchasing gaps



(a) IDP purchasing gap

(b) HP purchasing gap

Figure 3-20: Scenario 0, RO-1: purchasing gaps

component of the purchasing gap) and consequently increases prices (leading to the income component). The market recovers somewhat later in the year, but market-caused purchasing gaps are still occurring in 2023, long after the in-kind procurement began.

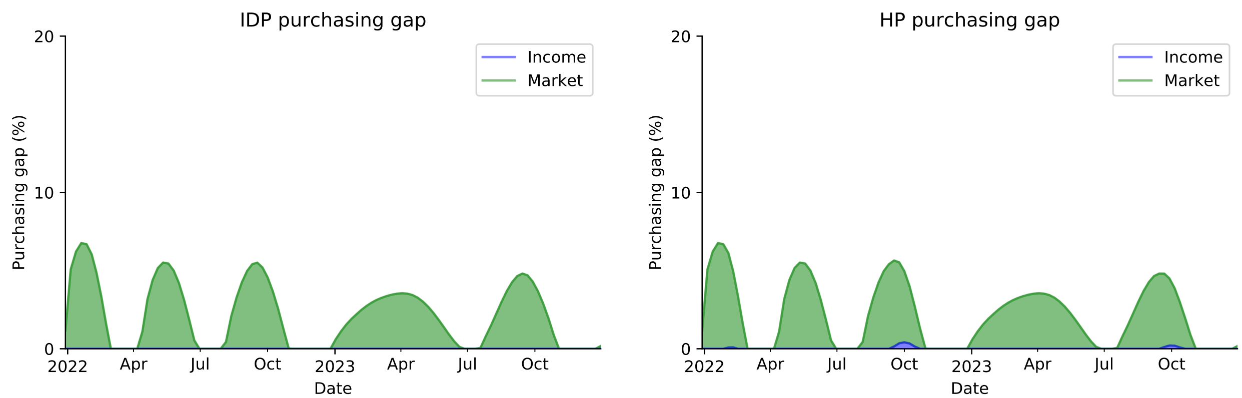
The purchasing gap for IDPs has reduced to zero, since the bulk of their rice needs are being provided to them at no cost.

Response Option 2: Cash assistance to IDPs

The outcomes for IDPs and the HP are shown in Figure 3-21. The average outcomes are shown in Table 3.6. The humanitarian spending in this response costs NGN 282.1 billion, all of which is spent on cash assistance.

	Average purchasing gap (%)	
Source	IDP	HP
Income	0.0	0.0
Market	2.2	2.2
Total	2.2	2.2

Table 3.6: Scenario 0, RO-2: time-averaged purchasing gaps



(a) IDP purchasing gap

(b) HP purchasing gap

Figure 3-21: Scenario 0, RO-2: purchasing gaps

The cash assistance provided the the IDPs has caused much less supply chain disruption than the in-kind assistance in RO-1. The time-averaged total purchasing gap for IDPs has improved from RO-0 (from 10.6% to 2.4%), but is still not as good as with Response Option 1 (0.1%). However, the time-averaged total purchasing gap for the HP has increased from RO-0 (from 1.6% to 2.4%). This is because the additional demand on the market by increased IDP purchasing is causing greater fluctuations in the retail supply.

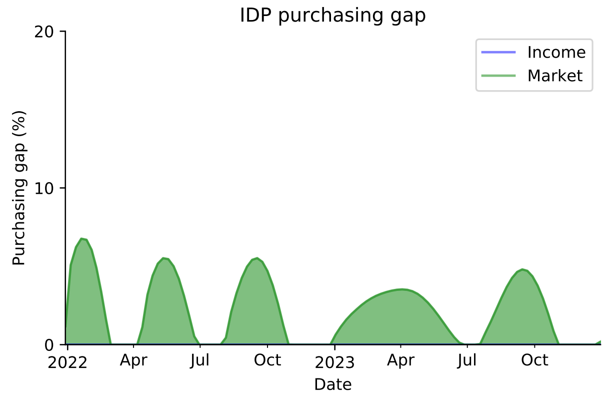
Response Option 3: Cash assistance to IDPs and HP

The outcomes for IDPs and the HP are shown in Figure 3-22. The average outcomes are shown in Table 3.7. The humanitarian spending in this response costs NGN 430.8 billion, all of which is spent on cash assistance.

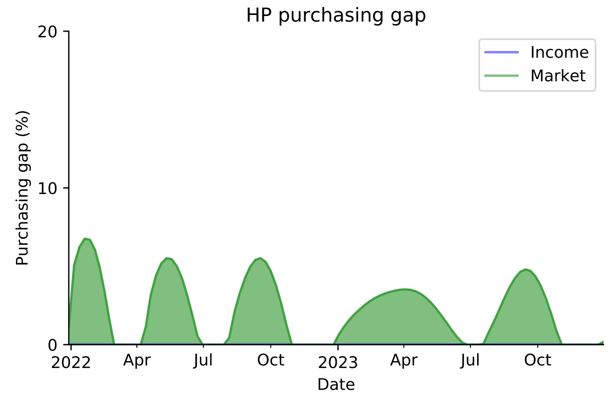
	Average purchasing gap (%)	
Source	IDP	HP
Income	0.0	0.0
Market	2.2	2.2
Total	2.2	2.2

Table 3.7: Scenario 0, RO-3: time-averaged purchasing gaps

The outcomes for this response option are nearly identical to those for RO-2, except for that the humanitarian spending has increased by 52%. This is because cash assistance is now being distributed to a much larger population. However, the host population does not need any additional cash for purchasing rice; they already have sufficient income for their rice needs. In fact, their purchasing gap is still worse than with RO-0 (it has increased from 1.6% to 2.2%), since they gain nothing from the additional cash, but are affected by the supply chain disruption. Of course, in reality, the additional cash they receive would be used for other things, but this is not captured in the model. Thus, the beneficiary outcomes



(a) IDP purchasing gap



(b) HP purchasing gap

Figure 3-22: Scenario 0, RO-3: purchasing gaps

appear identical between RO-2 and RO-3. This highlights the weakness of a model that does not consider other essential commodities, and thus assigns no value to additional income.

Response Option 4: Cash assistance to IDPs and HP, with credit to traders

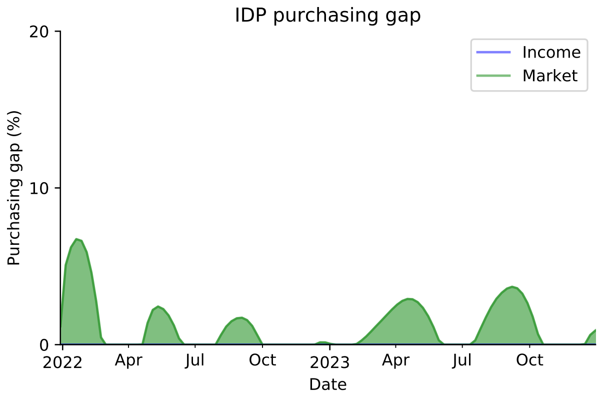
The outcomes for IDPs and the HP are shown in Figure 3-23. The average outcomes are shown in Table 3.8. The humanitarian spending in this response costs NGN 431.0 billion, of which NGN 430.8 billion was spent on cash assistance and NGN 0.2 billion was spend on SCA credit.

	Average purchasing gap (%)	
Source	IDP	HP
Income	0.0	0.0
Market	1.2	1.2
Total	1.2	1.2

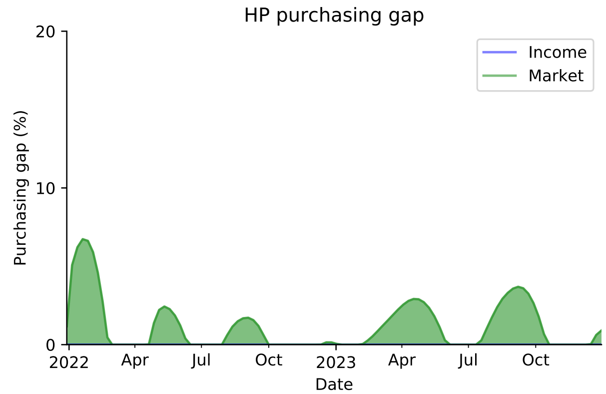
Table 3.8: Scenario 0, RO-4: time-averaged purchasing gaps

Compared to RO-3, there is an improvement of purchasing gap for both IDP and HP (both 2.2% to 1%) with a virtually no increase in spending (0.04% increase). This extra spending is for credit to supply chain actors. In theory, this money is not even spent by the humanitarian actor, since it is paid back by the supply chain actors shortly after it is lent. However, the model accounts for the lent money as an expenditure. The efficiency of spending is further explored in Section 3.2.6.

The very small amount of spending on SCA credit may seem surprising. However, the impact of credit *availability* has a significant impact SCA behavior, whether the credit is actually used. A SCA adjusts its ordering based on, among other things, how close its cash



(a) IDP purchasing gap



(b) HP purchasing gap

Figure 3-23: Scenario 0, RO-4: purchasing gaps

level is to its credit limit. With no credit available, a SCA's credit limit is NGN 0. When credit is available, it has a much higher credit limit. This means a SCA will let its cash get much lower before significantly curtailing its ordering. Thus, changes of commodity availability in the supply chain can actually change without *any* spending on credit, since humanitarian spending on credit is only accounted for if SCA cash goes below zero.

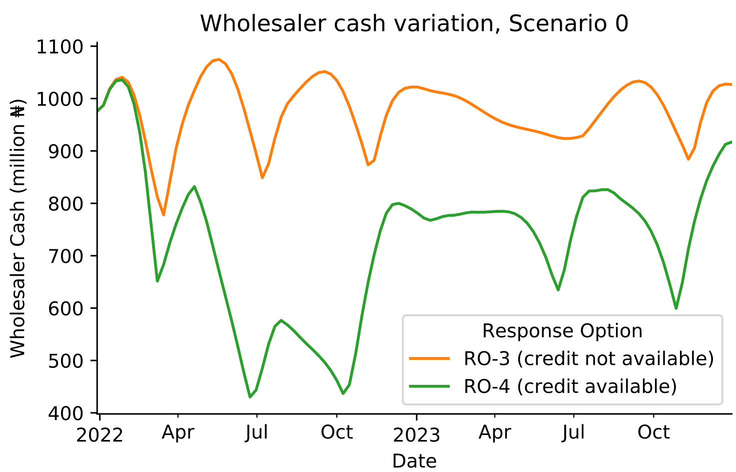


Figure 3-24: Scenario 0: changes in wholesaler cash with and without credit

This is illustrated in Figure 3-24, which shows the wholesaler cash level with RO-3 and RO-4. The cash level varies less, and is consistently higher with RO-3 than with RO-4. This is because the wholesaler is allowing its cash levels to go lower, because it knows it has significant amounts of credit available. The ultimate effect is that more cash is being used for purchasing in the supply chain, improving availability and thus improving outcomes. Note that the wholesaler never actually goes into debt (humanitarian credit spending is on a different SCA).

3.2.5.4 Scenario 1: Increased conflict

A summary of the outcomes for the five different response options in Scenario 1 is shown in Figure 3-25.

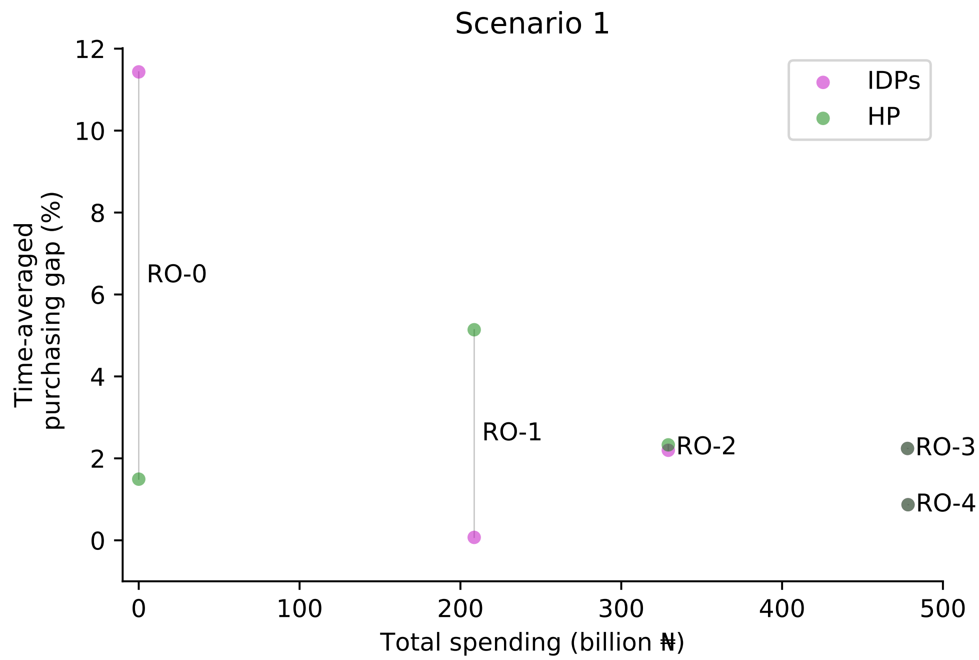


Figure 3-25: Comparison of response options for Scenario 1

The outcomes in Scenario 1 are fairly similar to those in Scenario 0. The summary figure, Figure 3-16, shows this. The causes for the various outcomes in Scenario 1 are the same as they were in Scenario 0. Notably, despite the level of conflict doubling, the market is largely able to cope with the increased demand. The main difference between the scenarios is that Scenario 1 has higher budgets. This is because the increased conflict has led to more displaced people.

	Average purchasing gap (%)	
Source	IDP	HP
Income	10.1	0.0
Market	1.3	1.5
Total	11.4	1.5

Table 3.9: Scenario 1, RO-0: time-averaged purchasing gaps

Figure 3-26 shows the distribution of purchasing gaps for Scenario 1, all response options. Table 3.9 shows the time-averaged purchasing gaps for RO-0. These show another difference between Scenarios 0 and 1. The IDP income-related purchasing gap is slightly higher in Scenario 1 than in Scenario 0 (time-averaged 10.1% instead of 9.2%). This is because the

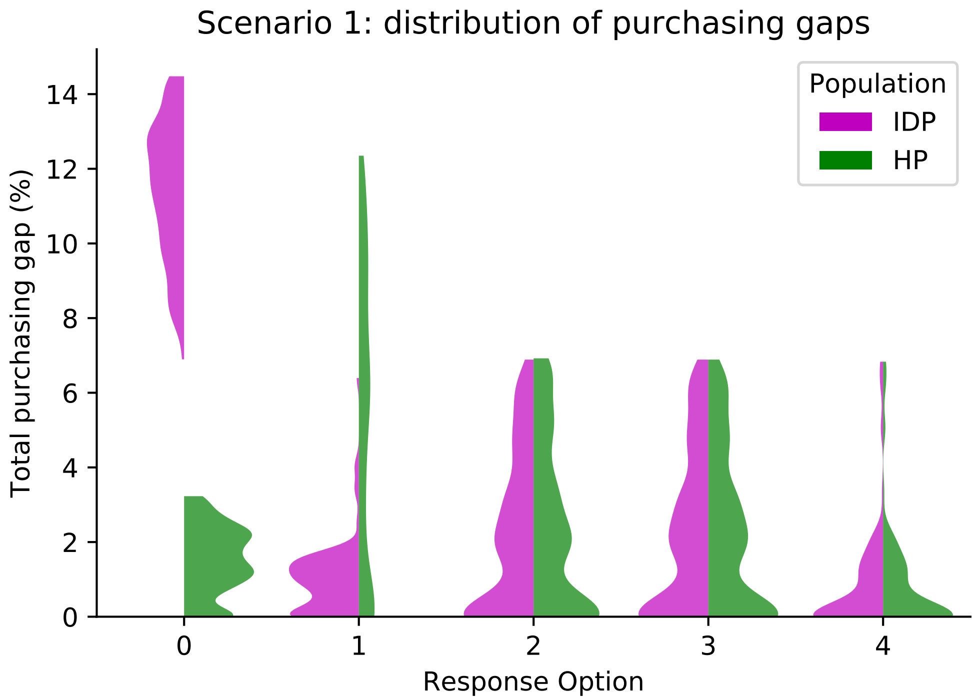


Figure 3-26: Distribution of purchasing gap for Scenario 1

additional demand from the increased number of IDPs has pushed prices up. However, this additional demand has not impacted the availability of food, since the market-related purchasing gap for both IDPs and HP has remained roughly the same from Scenario 0.

For brevity, the purchasing gap varying in time is not shown for any of the responses in Scenario 1, since the plots are fairly similar to those for Scenario 1.

3.2.5.5 Scenario 2: Increased conflict with increased leadtimes

A summary of the outcomes for different response options in Scenario 2 is shown in Figure 3-27. Note the change in scale from previous figures.

The most significant difference between Scenario 2 and Scenarios 1 and 0 is that the purchasing gaps are much higher, which is more clearly visible in the comparison figure (Figure 3-16). This is because the added supply chain disruption of all leadtimes doubling severely impedes the market's ability to supply enough food to the retail market, whose demand has also increased due to increased displacement.

Figure 3-28 shows the distribution of purchasing gaps for Scenario 2. Again, note the change in scale from previous similar figures. This figure shows the relatively long tail of purchasing gaps: while the *average* gaps have gone up (shown in Figure 3-27), the *worst* gaps have gone up much more. Most notably, the worst HP purchasing gap in RO-1 is nearly 100%. In response options 2-4, the bulk of the time for each population is spend with a purchasing gap less than 20%. However, there are times that it ranges above 50%. In

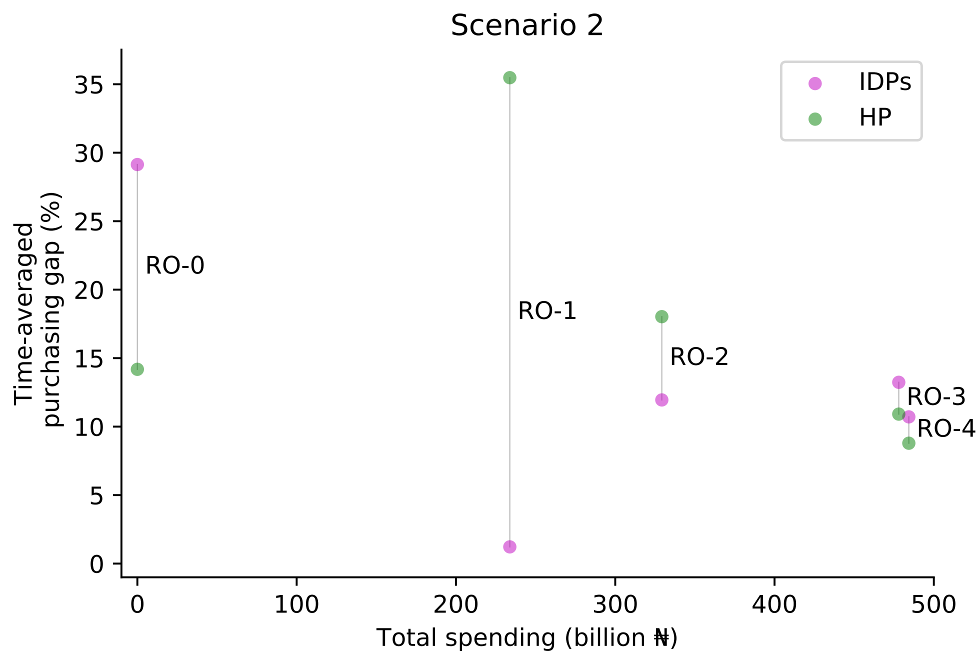


Figure 3-27: Comparison of response options for Scenario 2

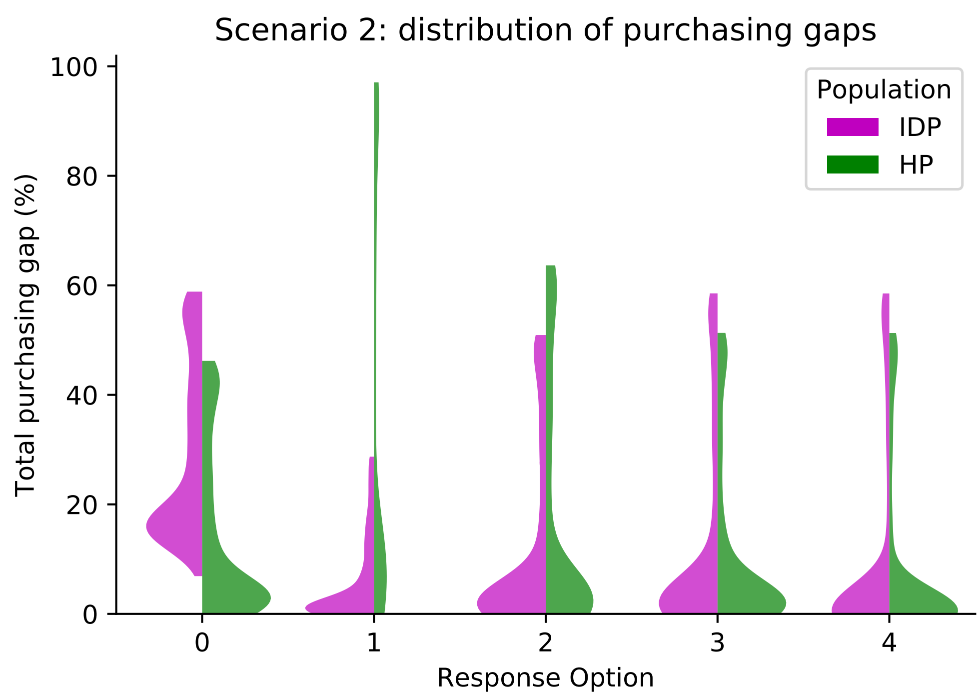


Figure 3-28: Distribution of purchasing gap for Scenario 2

situations like these, understanding household storage practices and capabilities becomes quite important. If a high purchasing gap is experienced for a relatively short amount of time, this may not be an issue if the household has adequate storage (and the commodity has a long enough shelf life). However, if the household has little ability to store the commodity, then purchasing gaps quickly become consumption gaps, which is a more severe problem.

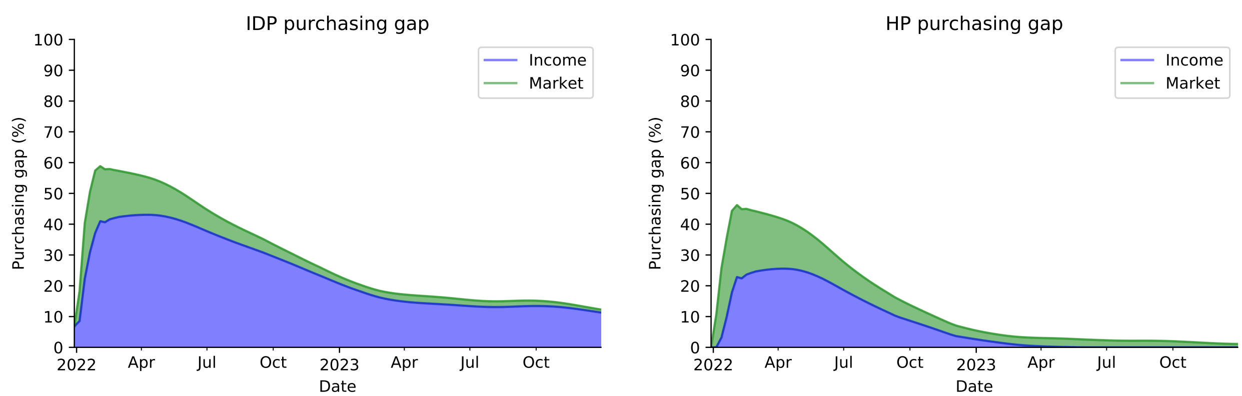
The causes of these purchasing gap distributions are explored in the following sections.

Response Option 0: Do nothing

The outcomes for IDPs and the HP are shown in Figure 3-29. The average outcomes are shown in Table 3.10. The humanitarian spending in this response costs nothing, since there is no humanitarian response.

	Time-averaged purchasing gap (%)	
Source	IDP	HP
Income	24.0	7.7
Market	5.1	6.5
Total	29.1	14.2

Table 3.10: Scenario 2, RO-0: time-averaged purchasing gaps



(a) IDP purchasing gap

(b) HP purchasing gap

Figure 3-29: Scenario 2, RO-0: purchasing gaps

Looking at Figure 3-29, we can see how much the purchasing gap for both IDP and HP varies with time. Unlike previous scenarios, where the bulk of the variation was due to seasonality, most of the purchasing gap variation here is due to the significant disruption caused by the doubled leadtimes. For the first time, we see a significant purchasing gap due to income for HP, indicating that prices have increased significantly.

A comparison of the prices between scenarios for RO-0 is shown in Figure 3-30. This shows how much more prices are affected by leadtime and conflict doubling (Scenario 2) than just conflict doubling (Scenario 1). However, it important to note that although conflict levels instantaneously doubled in Scenarios 1 and 2, this did *not* instantaneously

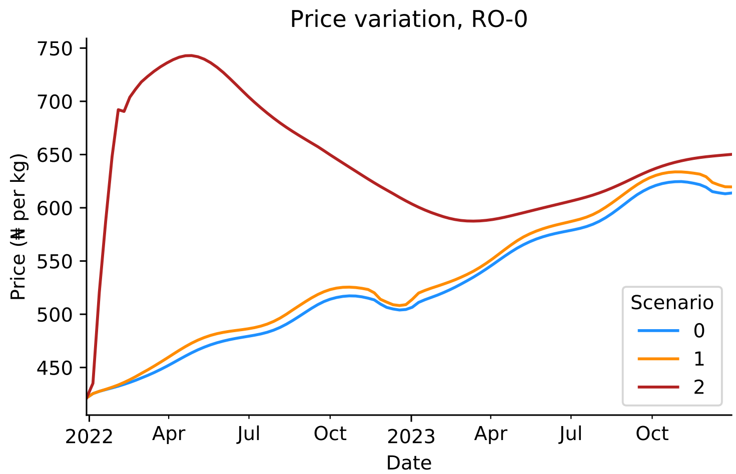


Figure 3-30: RO-0: Comparison of retail prices across scenarios

double the consumer demand (the demand on the retailer). Because there is a delay in the movement of people, this change happened gradually. Also, retail demand did not come close to doubling, because a doubling of conflict only leads to an increase of IDPs based on how many have already been displaced, not a doubling. IDPs also only make up part of the consumer demand, with the HP making up a significant fraction.

The significant difference in outcomes between Scenarios 1 and 2 highlights the need to better understand how conflict actually affects supply chains. Had it been assumed that the only effect of conflict was increased displacement, its impact would have been severely underestimated. At the same time, modeling a scenario where leadtimes double instantaneously may be an overestimate of conflict's impact. A doubling of all leadtimes effectively means that every supply chain actor instantaneously attempts to double its stocks to account for the doubled leadtime. It is perhaps unrealistic that this would happen, as supply chain actors could potentially find different sources from which to restock. This is an issue with modeling the supply chain for a large region (in this case, a whole state) in aggregate; by assuming that all leadtimes vary together, the complexity of every actual actual actor's supply chain is lost.

The impact of leadtime variations is further discussed in Sections 3.2.7.1 and 3.2.8.

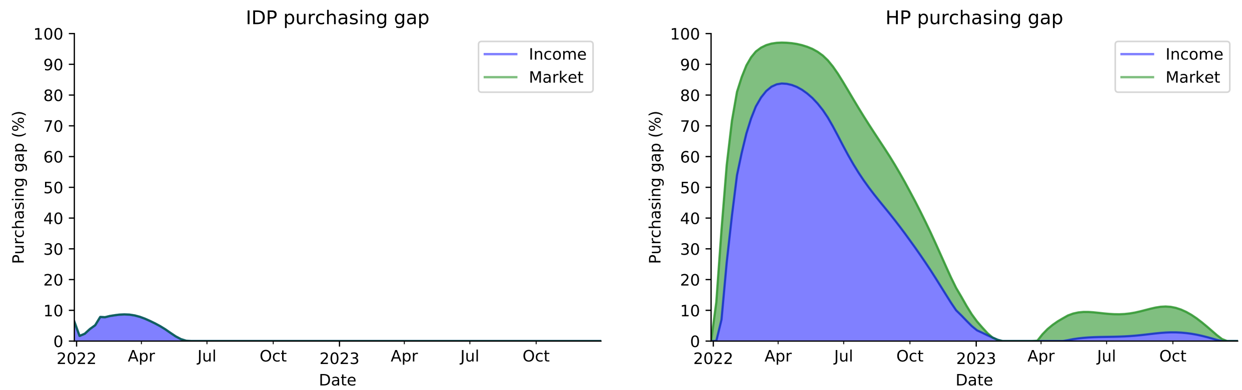
Response Option 1: In-kind assistance to IDPs

The outcomes for IDPs and the HP are shown in Figure 3-31. The average outcomes are shown in Table 3.11. The humanitarian spending in this response costs NGN 233.8 billion, all of which is spent on procurement for in-kind assistance.

We can clearly see an even greater increase in HP purchasing gap when humanitarian purchasing further impacts the supply chain. The total HP purchasing gap increases to nearly 100% during the first year of humanitarian purchasing, but decreases to 0% once the main harvest of that year has made it through the supply chain into the consumer market.

	Time-averaged purchasing gap (%)	
Source	IDP	HP
Income	1.2	24.9
Market	0.0	10.6
Total	1.2	35.5

Table 3.11: Scenario 2, RO-1: time-averaged purchasing gaps



(a) IDP purchasing gap

(b) HP purchasing gap

Figure 3-31: Scenario 2, RO-1: purchasing gaps

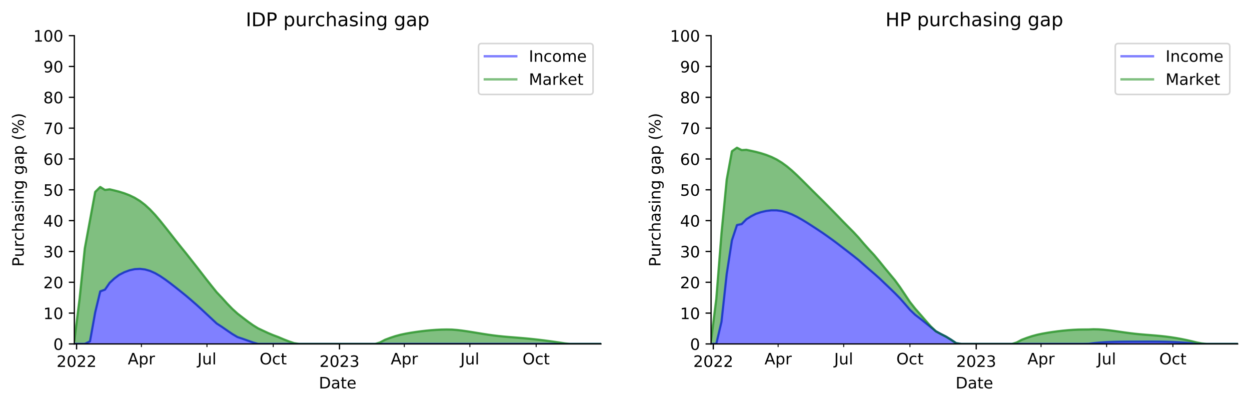
In this scenario, it is unrealistic that a humanitarian actor would procure locally; the severe impact on food availability should be easily predictable without any modeling. However, this scenario - response option combination shows how severe the impact of such a response could be.

Response Option 2: Cash assistance to IDPs

The outcomes for IDPs and the HP are shown in Figure 3-32. The average outcomes are shown in Table 3.12. The humanitarian spending in this response costs NGN 329.2 billion, all of which is spent on cash assistance.

	Time-averaged purchasing gap (%)	
Source	IDP	HP
Income	4.5	12.1
Market	7.4	6.0
Total	11.9	18.0

Table 3.12: Scenario 2, RO-2: time-averaged purchasing gaps



(a) IDP purchasing gap

(b) HP purchasing gap

Figure 3-32: Scenario 2, RO-2: purchasing gaps

Compared to RO-0 and RO-0, RO-2 is more equitable, *i.e.,* there is less of a discrepancy of purchasing gaps between IDPs and HP. This is because the lower income of IDPs has been more than cancelled out by the cash assistance they are receiving. However, this cash assistance amount is still insufficient, as evidenced by the remaining income-caused purchasing gap (4.5%).

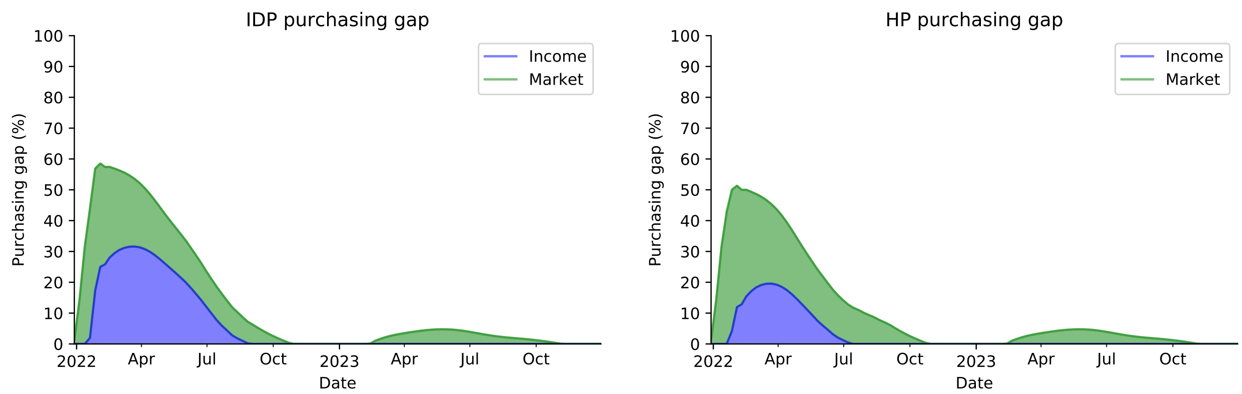
Response Option 3: Cash assistance to IDPs and HP

The outcomes for IDPs and the HP are shown in Figure 3-33. The average outcomes are shown in Table 3.13. The humanitarian spending in this response costs NGN 478.0 billion, all of which is spent on cash assistance.

	Time-averaged purchasing gap (%)	
Source	IDP	HP
Income	5.9	2.7
Market	7.4	8.2
Total	13.2	10.9

Table 3.13: Scenario 2, RO-3: time-averaged purchasing gaps

RO-3 shows a couple interesting changes compared to RO-2. Despite still receiving the same amount of cash assistance, the IDP income-caused purchasing gap has increased from 4.5% to 5.9%. This is because there is now additional consumer demand from the HP, who are now also receiving cash assistance. This pushes up prices, as shown in Figure 3-34. Because of this, the HP now again has a lower purchasing gap than IDPs. Also, the market-caused purchasing gap for both populations is now greater than their income-caused purchasing gaps.



(a) IDP purchasing gap

(b) HP purchasing gap

Figure 3-33: Scenario 2, RO-3: purchasing gaps

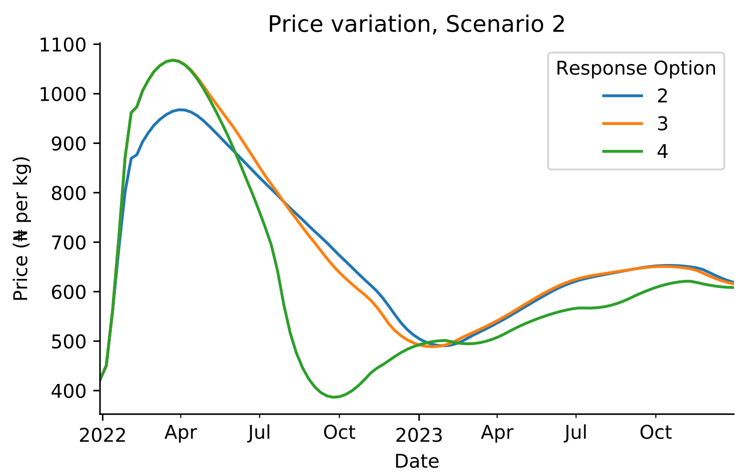


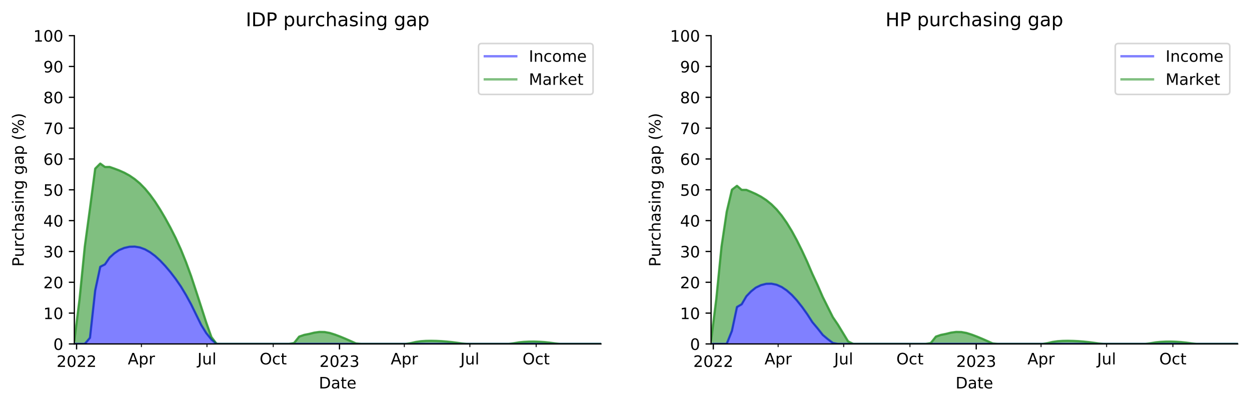
Figure 3-34: Scenario 2: Comparison of retail prices across responses

Response Option 4: Cash assistance to IDPs and HP, with credit to traders

The outcomes for IDPs and the HP are shown in Figure 3-35. The average outcomes are shown in Table 3.14. The humanitarian spending in this response costs NGN 484.3 billion, of which NGN 478.0 billion is spent on cash assistance and NGN 6.3 billion is spent on SCA credit.

	Time-averaged purchasing gap (%)	
Source	IDP	HP
Income	5.2	2.5
Market	5.5	6.3
Total	10.7	8.8

Table 3.14: Scenario 2, RO-4: time-averaged purchasing gaps



(a) IDP purchasing gap

(b) HP purchasing gap

Figure 3-35: Scenario 2, RO-4: purchasing gaps

By providing credit to traders, the market- and income-caused purchasing gaps for both population groups decrease. This is because supply chain actors are able to more quickly response to increased demand. This is also clear from the retail price variation, shown in Figure 3-34. The retail price still spikes to the same level as with RO-3, but decreases more quickly afterward, recovering after the first season harvest. The amount lent to traders is shown in Figure 3-36. Notably, traders only start to use credit after the price peak in April 2022. This is because downstream prices increased faster than the upstream prices, because the demand pressure was coming from downstream. As the prices increased, traders were able to cover their expenses. It is only when the retail supply caught up to the retail demand that prices began to come down again. This is when traders needed credit to re-stock.

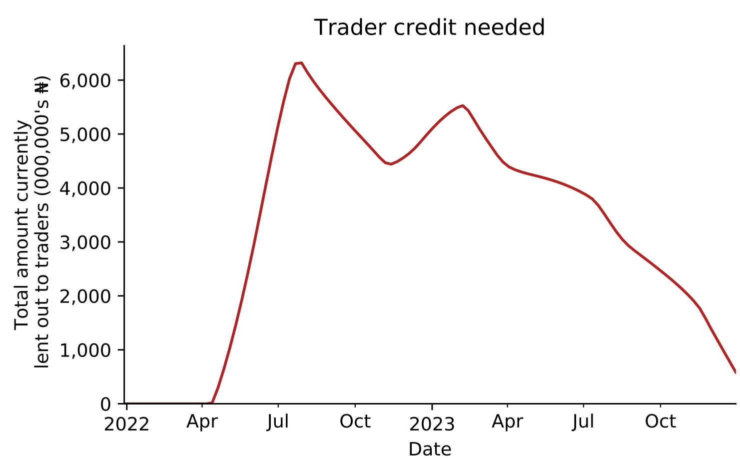


Figure 3-36: Scenario 2, RO-4: trader credit

A key takeaway from this is that the initial price spike could not be avoided with credit provision. This spike occurred because of constraints on how much rice could be moved through the supply chain (caused by the suddenly doubled leadtimes). However, had the retail price been controlled by some sort of government action during this period, credit may have been needed by traders earlier to cope with increased upstream prices.

Most notable about the difference between RO-3 and RO-4 is the relatively small amount of extra humanitarian spending needed to lower purchasing gaps (also observed in Scenarios 0 and 1). We can compare differences in response plans by calculating their efficiency, which is done in Section 3.2.6.

Again, we might note that the amount spend on SCA credit is quite low (although not as extreme as in Scenario 0). Again, this because SCA behavior is already affected significantly by the *availability* of credit, without the SCA actually borrowing anything.

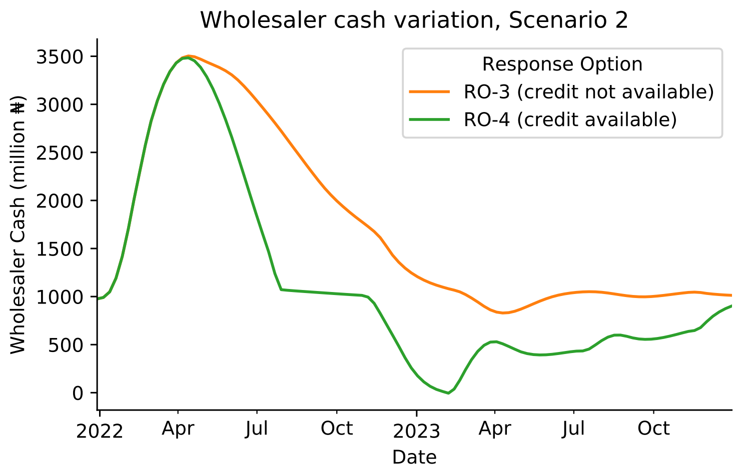


Figure 3-37: Scenario 2: changes in wholesaler cash with and without credit

Figure 3-37 shows the cash level of the wholesaler with RO-3 and RO-4. Similar to Scenario 0 (shown in Figure 3-24), the cash level varies more and is lower on average with RO-4 than with RO-3. This behavior is enabled by the significant amount of credit available, freeing up more cash for purchasing. Unlike in Scenario 0, in Scenario 2, the wholesaler does actually use some of its available credit in RO-4 (early in 2023).

3.2.6 Efficiency

The efficiency is defined as the percentage points reduction of the purchasing gap between two response plans, divided by the difference in spending between the two plans:

$$\text{Efficiency of RO-}x\text{ to RO-}y = -\left(\frac{\text{Purchasing gap for RO-}x - \text{Purchasing gap for RO-}y}{\text{Total cost for RO-}x - \text{Total cost for RO-}y}\right)$$

This is effectively the marginal impact of one naira on the purchasing gap. A higher efficiency indicates that one naira will reduce the purchasing gap more than for a low efficiency.

Table 3.15 shows the efficiency of RO-0 to RO-3 and of RO-3 to RO-4 in Scenarios 0 and 2. RO-1 and RO-2 are not included, since they involve responses that only serve IDPs, so are less useful for a comparison. Scenario 1 is not included due to its similarity to Scenario 0.

	Efficiency (% pts per billion NGN)	
Response Options	Scenario 0	Scenario 2
RO-0 to RO-3	0.012	0.025
RO-3 to RO-4	5.879	0.379

Table 3.15: Response efficiencies

The efficiency for RO-3 to RO-4 is much higher than the efficiency for RO-0 to RO-3 for both scenarios (by a factor of 502 for Scenario 0 and 15 for Scenario 2). This means that for Scenario 0, if cash assistance is already being provided to IDPs and HP at the SMEB level, further money is 502 times better at reducing the purchasing gap if it is spent on trader credit instead of cash assistance.

3.2.7 Sensitivity analysis

A sensitivity analysis was conducted for the following groups of input variables:

- `T-W/W-R/R-C leadtime`
- `T/W/R equilibrium earnings fraction`
- `IDP/HP income`
- `T/W/R safety stock`
- `T/W/R forecast time`
- `HA production`

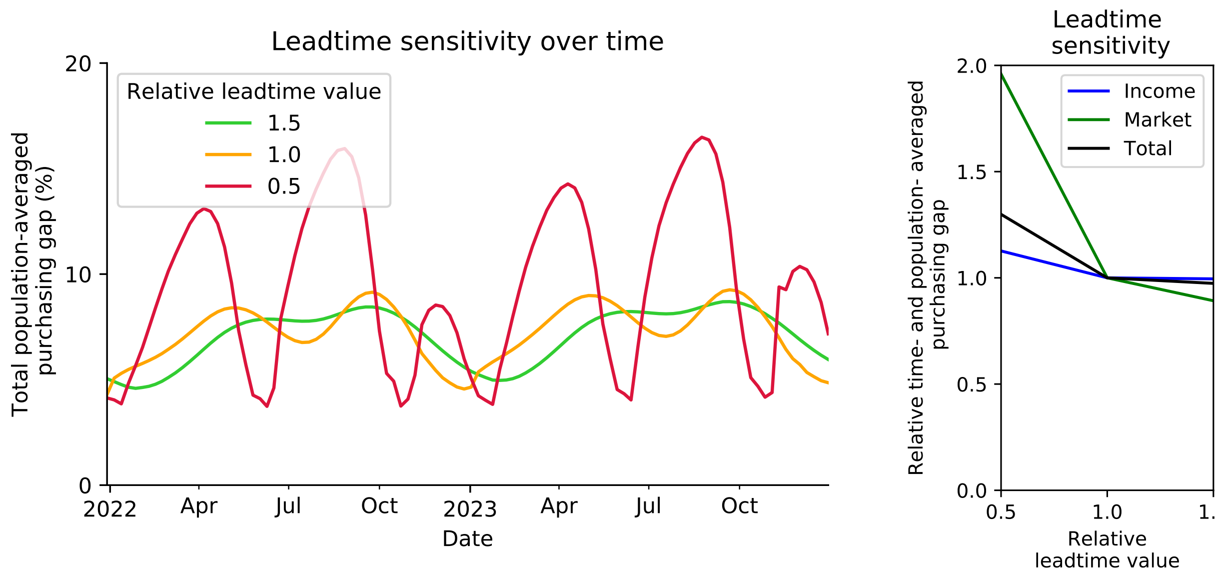
The model was run for each of these groups variables (except safety stock) at a factor of 0.5, 1.0, and 1.5 times their usual values. All variables in one group were varied together, *i.e.,* the relative impact of the wholesale vs. retail leadtime was not investigated. Since safety stock's usual value is 0% and would not expected to be negative, it was run at 0% and two higher values.

Note that unlike in Scenario 2, where leadtimes were increased as a step function at the beginning of 2022, for sensitivity analysis the groups of variables were set at their new values for the entire simulation, not just from 2022 onwards.

Unless stated, all other variables were set as for Scenario 0, RO-0.

3.2.7.1 Leadtime

Figure 3-38 shows the sensitivity of the population-averaged purchasing gaps to the leadtimes.



(a) Variation over time

(b) Relative value, time-averaged

Figure 3-38: Sensitivity of purchasing gap to leadtimes

From Figure 3-38a, we can see that there is much more variability in the supply chain with short leadtimes. From Figure 3-38b, we can see that the time-averaged purchasing gap also increased with short leadtimes, mainly driven by the market availability. This could initially seem counterintuitive. However, we first need to consider that supply chain actors have no safety stock for this analysis. Actors only attempt to order as much as they forecast, but no additional amount if their forecast is off. We then need to consider what the leadtime means for the stock levels of a supply chain actor. These are shown for the retailer in Figure 3-39. An actor holds enough stock to cover their leadtime, so a decreased leadtime requires less stock. Conversely, a longer leadtime requires more stock. Since the model does not limit stock levels, the actors are able to stock as much as they need to, which effectively buffers against the demand variations. Thus, a scenario with longer leadtimes can be interpreted as the ability of actors to hold more stock. A key takeaway from this is that interventions to increase supply chain actor inventory capacity could be effective at reducing the level and fluctuation of the purchasing gap.

3.2.7.2 Earnings fraction

Figure 3-40 shows the sensitivity of the population-averaged purchasing gaps to the equilibrium earnings fractions of the SCAs. Recall that the equilibrium earnings fraction of a SCA is the fraction of their revenue that they retain (*i.e.,* their income) when the market is in equilibrium.

From Figure 3-40 we can see that increased earnings fractions lead to increased total purchasing gaps. This is because increased earnings fractions along the supply chain lead to increased margins, and subsequently increased prices. Figure 3-40b shows that the

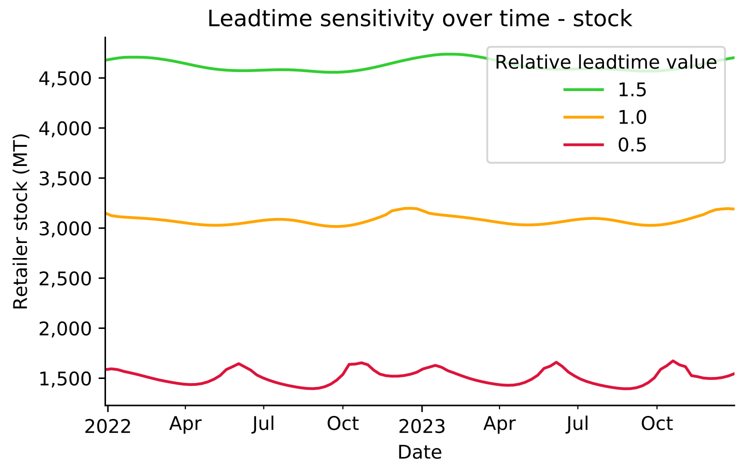
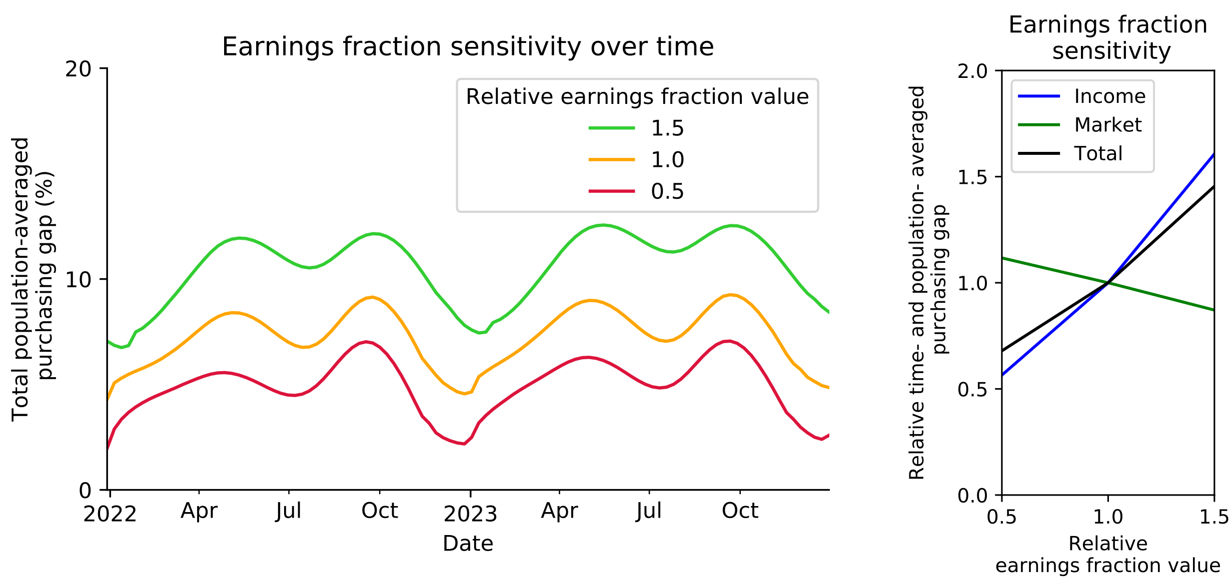


Figure 3-39: Sensitivity of retailer stock to leadtimes



(a) Variation over time

(b) Relative value, time-averaged

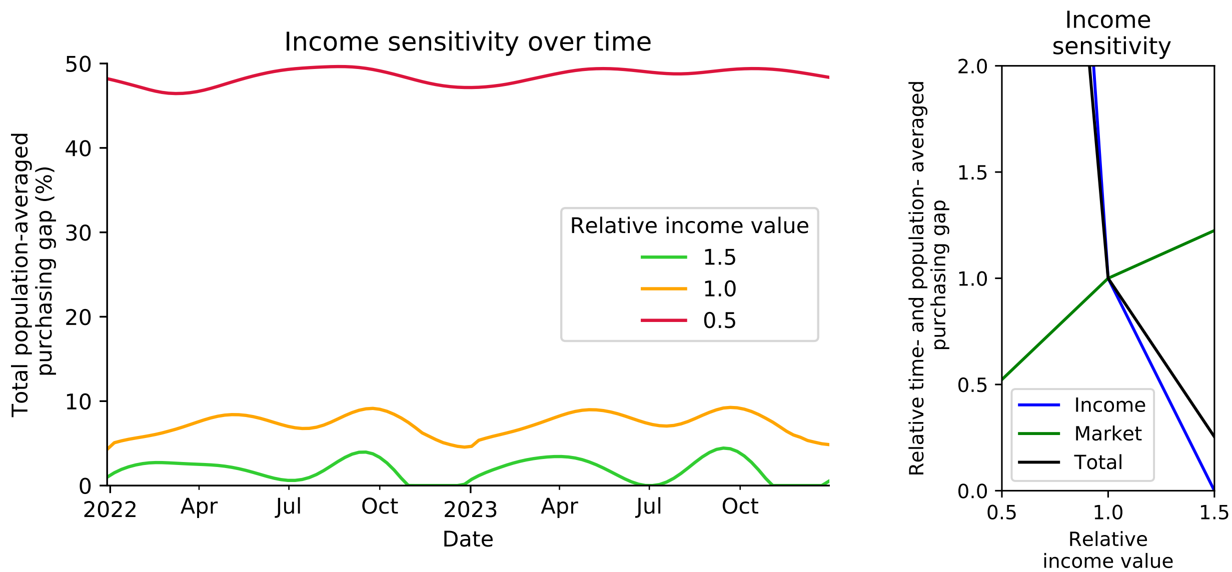
Figure 3-40: Sensitivity of purchasing gap to earnings fractions

increased purchasing gap is due to income effects, which confirms that increased prices are driving the gap.

This highlights a weakness of the model, by considering the supply chain actors as distinct from the IDPs and HP. In reality, increased earnings by SCAs could lead to increased incomes for the IDPs and HP and could potentially offset some of this price increase. However, this effect is potentially quite far out of the model's scope, as doing this effectively could necessitate modeling more of the economy as a whole.

3.2.7.3 Income

Figure 3-41 shows the sensitivity of the population-averaged purchasing gaps to the IDP and HP income.



(a) Variation over time

(b) Relative value, time-averaged

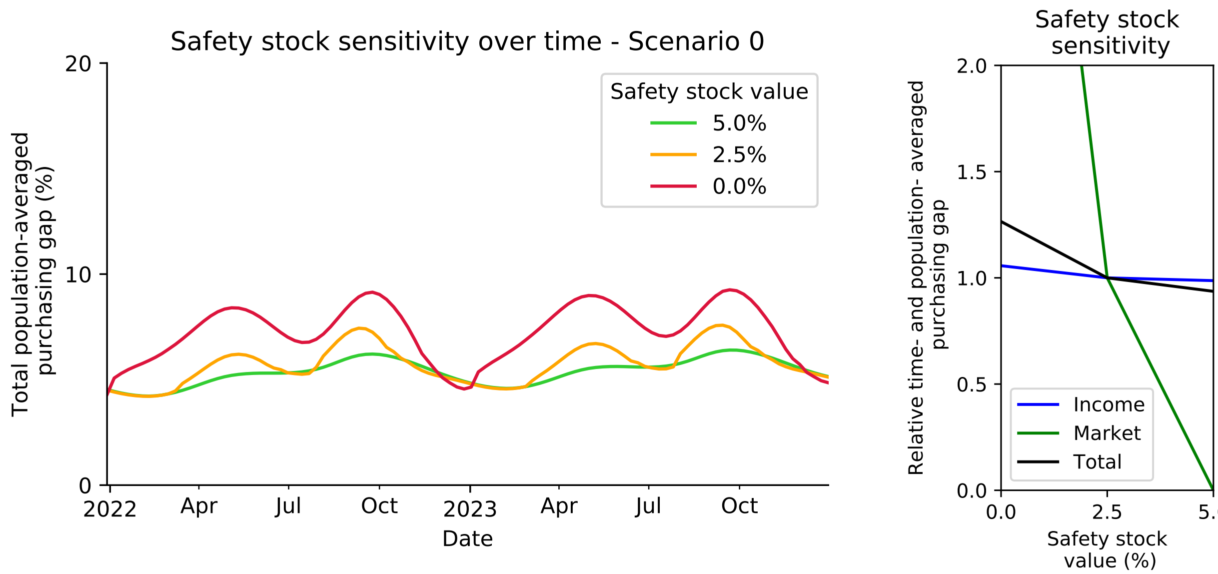
Figure 3-41: Sensitivity of purchasing gap to income

In Figure 3-41 we can see a highly asymmetric sensitivity: increases in income reduce the purchasing gap mildly, but decreases in income increase the purchasing gap strongly. This is because above a certain value, the consumer demand is inelastic to consumer income. Because rice is a staple food, the household is assumed to not purchase any above a certain amount (set by `Rice needs per capita`). Figure 3-41b shows that the increase in purchasing gap at low income is due entirely to income. It also shows that as income increases, the market-caused purchasing gap increases. This shows that although consumers are demanding more, this increased demand is not fully satisfied by the market.

3.2.7.4 Safety stock

Since safety stock is set to 0% in the usual model runs, its sensitivity analysis is treated differently. Figure 3-42a shows the sensitivity of the purchasing gap to safety stock levels, in Scenario 0.

As the safety stock level increases, the purchasing gap decreases. From Figure 3-42b, we can see that this is almost entirely due to the market availability improving. With a safety stock of 5%, the market-caused purchasing gap is zero. This may seem to be a fairly small safety stock level to ensure there is always sufficient rice in the consumer market, but recall that in Scenario 0 there is little demand variation due to a relatively stable IDP population.

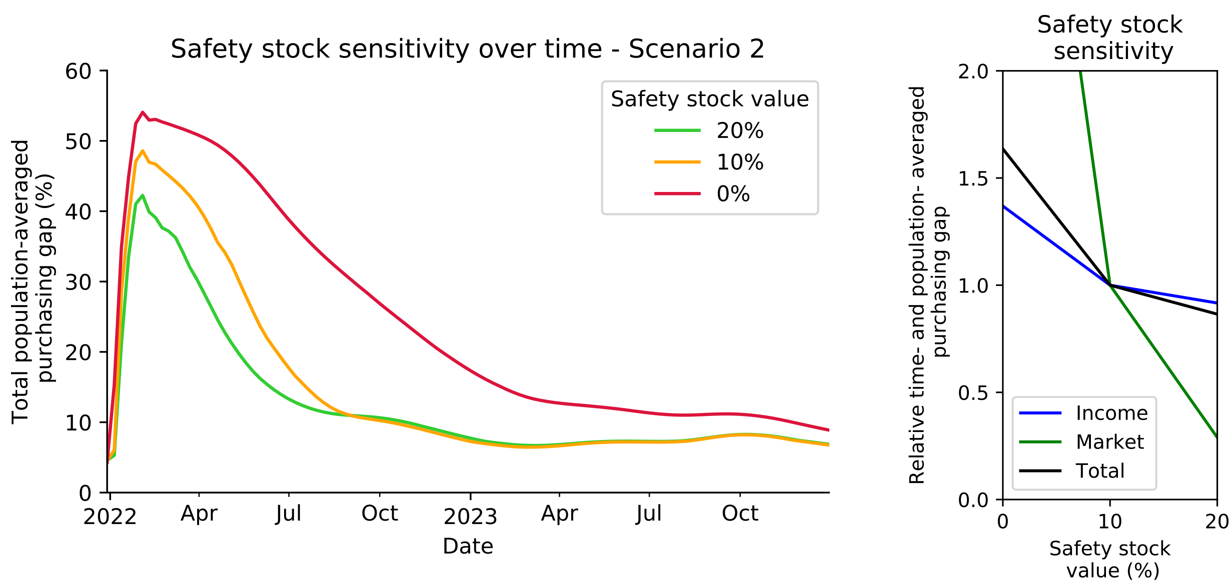


(a) Variation over time

(b) Relative value, time-averaged

Figure 3-42: Scenario 0: sensitivity of purchasing gap to safety stock

Figure 3-42a shows the sensitivity of the purchasing gap to safety stock levels, in Scenario 2.



(a) Variation over time

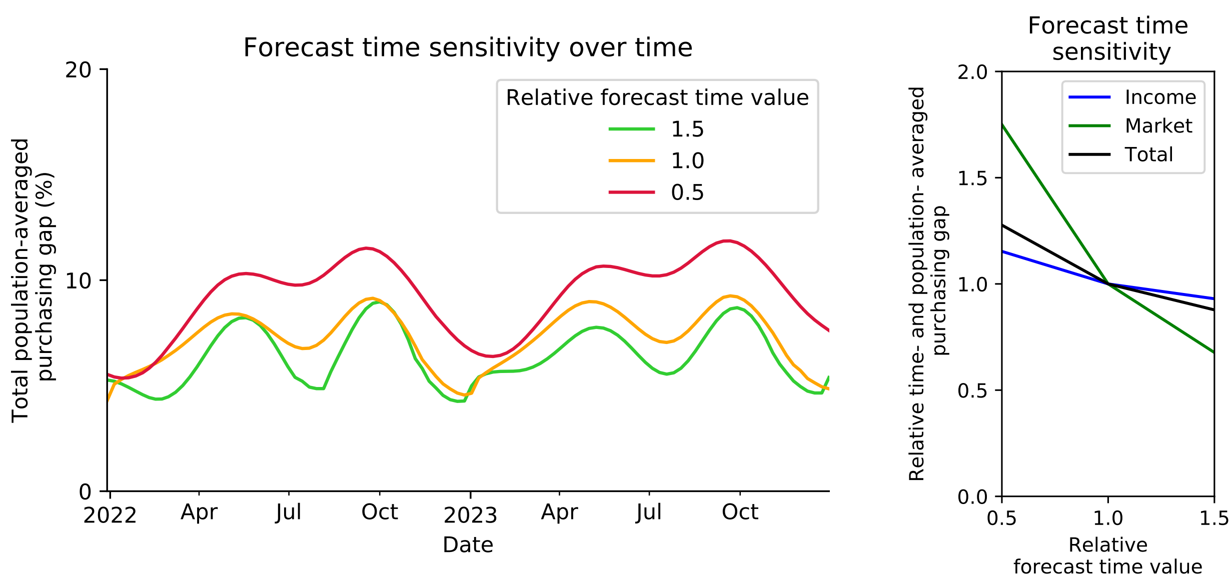
(b) Relative value, time-averaged

Figure 3-43: Scenario 2: sensitivity of purchasing gap to safety stock

As with Scenario 0, there is a reduction of purchasing gap as the safety stock increases. From Figure 3-43b, we can see that this is again mostly from improved market availability. However, unlike Scenario 0, increasing safety stock beyond 5% continues to reduce the purchasing gap. From Figure 3-43a, we can see that increasing the safety stock from 0% to 10% reduces the purchasing gap peak in early 2022, allows for a quicker recovery in April-June 2022, and keeps the purchasing gap consistently lower in 2023. Increasing the safety stock further to 20% reduces the peak and quickens the recovery even more, but does not further lower the purchasing gap in 2023. This is because the purchasing gap in 2023 has become entirely income-caused, which further safety stock will not mitigate. A key takeaway from this analysis is that a safety stock that is sufficient for low demand variation may not be nearly sufficient for high demand variation.

3.2.7.5 Forecast time

Figure 3-44 shows the sensitivity of the population-averaged purchasing gaps to the forecast time.



(a) Variation over time

(b) Relative value, time-averaged

Figure 3-44: Sensitivity of purchasing gap to forecast time

As the forecast time increases, the purchasing gap decreases. As SCAs attempt to order enough for the future, it is less likely that they will be out of stock. We can see the effect that this has on the retail price, shown in Figure 3-45.

At a higher forecast time, the price is able to drop more sharply after periods when it increases. This is happening because SCAs forecast based on the *revenue*, not just the volume. As the price they are selling at increases, SCAs anticipate increased revenue in the future, and attempt to order more. As the availability increases, the price stabilizes. Thus, this analysis shows the value of market information in stabilizing prices and reducing purchasing gaps.

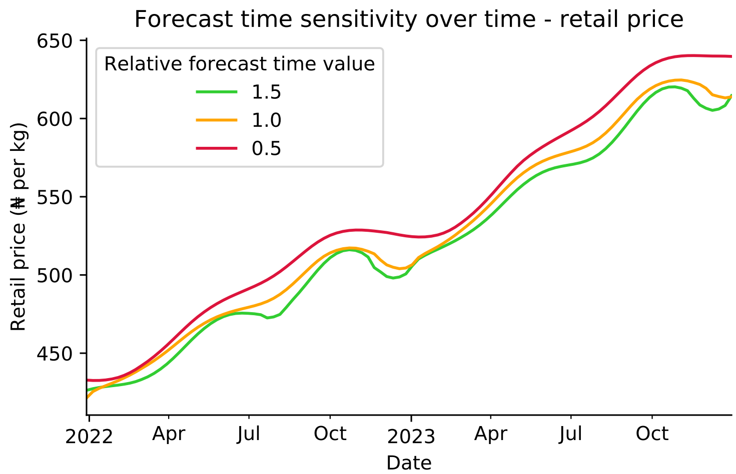
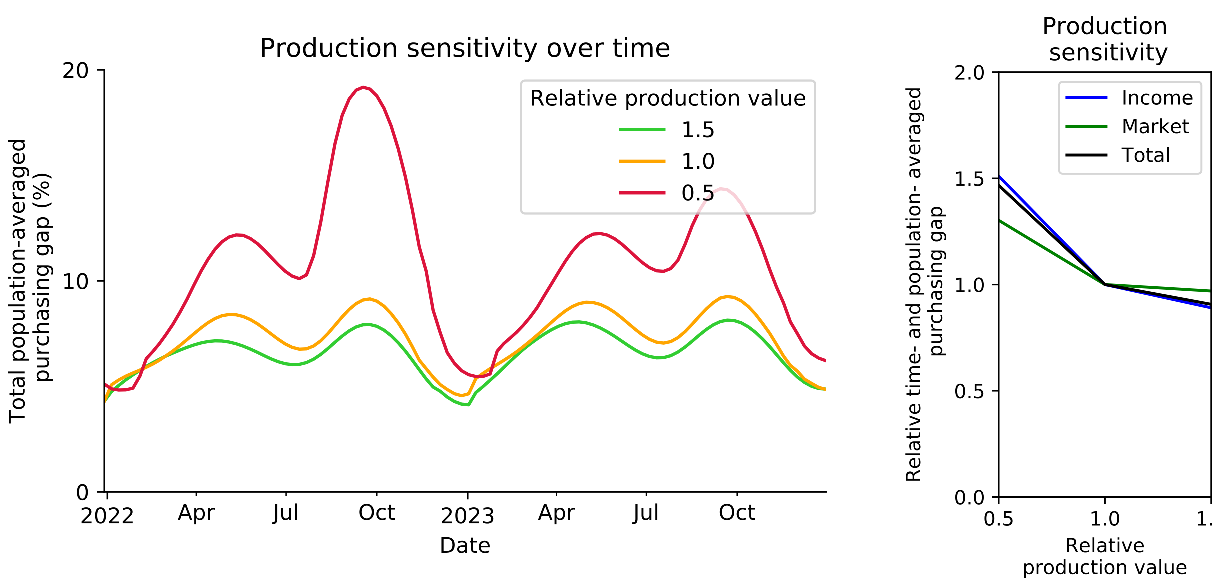


Figure 3-45: Sensitivity of retail price to forecast time

3.2.7.6 Production

Figure 3-46 shows the sensitivity of the population-averaged purchasing gaps to the national (SA) production.



(a) Variation over time

(b) Relative value, time-averaged

Figure 3-46: Sensitivity of purchasing gap to production

The sensitivity to production is asymmetric, with greater losses for low production than gains for high production. The purchasing gap increases significantly during the lean season with lower production, as there is reduced availability all along the supply chain. There is less of a gain as production increases, as other supply chain effects dominate the outcomes.

3.2.8 Variability analysis

In all model runs up to this point, all input variables have been deterministic. Many remained constant, and other were projected as described in Section 3.2.4. The variability analysis investigated the impact of stocastically varying leadtimes.

For variability analysis, the wholesaler and retailer leadtimes (`T-W/W-R leadtime`) were assumed to follow a log-normal distribution. This distribution was chosen because it only takes positive values (only positive leadtime are possible), and the probability density function drops to zero as the value drops to zero (very short leadtimes are less likely than very long leadtimes). Figure 3-47 shows this distribution with a mean of 1 month and a standard deviation of 0.1 months. With such a small standard deviation the distribution is nearly symmetric.

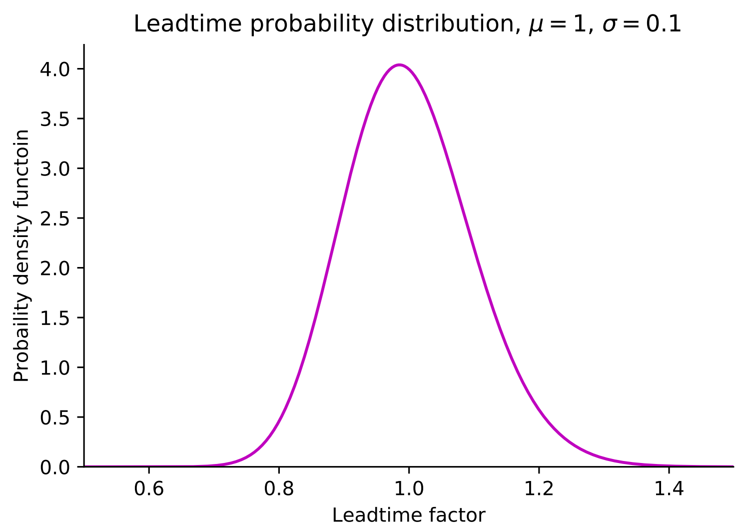


Figure 3-47: Leadtime probability distribution

The consumer leadtime (`R-C leadtime`) was not varied. This is because its value is already relatively small, and further reduction to the value may push it close enough to the model timestep to introduce inaccuracies.

A new value for the stocastically varying leadtimes was generated at the beginning of every month, with the leadtime remaining constant at that value for the rest of the month.

3.2.8.1 Run comparison

The model was run three times for each standard deviation (5% and 10%), each time with a different seed for random number generation. A comparison of the three runs with a standard deviation of 10% is shown in Figure 3-48. The three runs show similar patterns of variation.

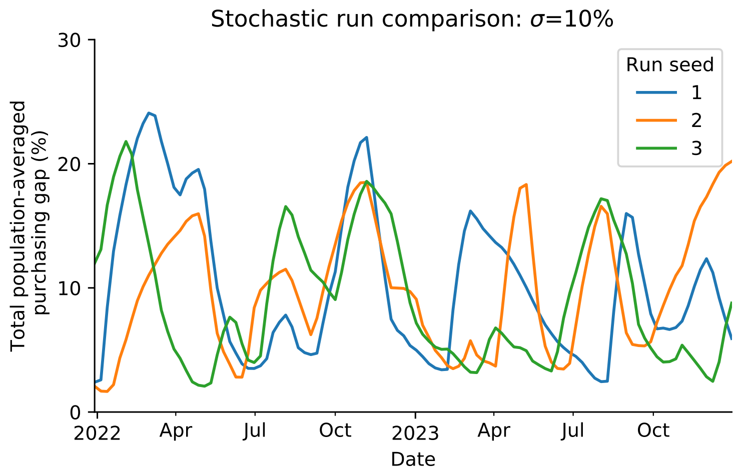
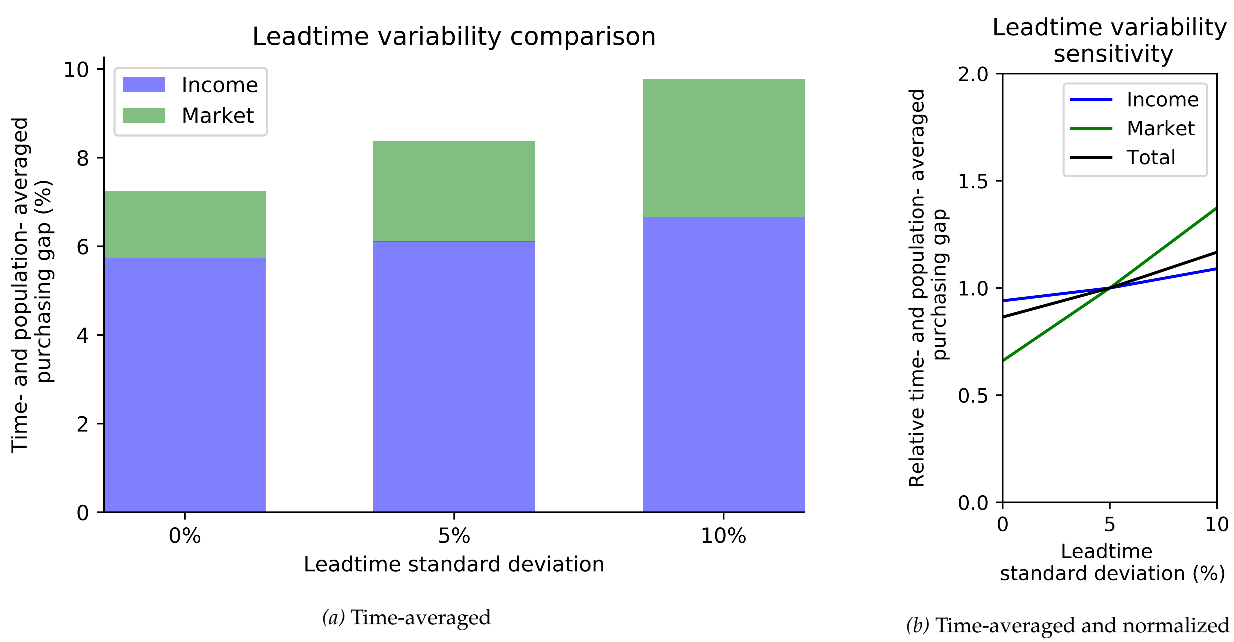


Figure 3-48: Comparison of stocastic leadtime runs

3.2.8.2 Variability comparison

Figure 3-49 shows the change in time- and population- averaged purchasing gap for different leadtime variabilities.



(a) Time-averaged

(b) Time-averaged and normalized

Figure 3-49: Sensitivity of purchasing gap to leadtime variation

The time- and population- averaged purchasing gap becomes worse as leadtime variability increases, due to both income and market. Figure 3-50 is a histogram showing how the distribution of the population-averaged purchasing gap changes with leadtime variability. From this we can see that as the leadtime variability increases, so does the variability of the purchasing gap. With a leadtime standard deviation of 0%, the population-averaged purchasing gap is always between 4% and 10%. With a leadtime standard deviation of 5%, the gap between 2% and 17%. With a leadtime standard deviation of 10%, the gap ranges between 1% and 25%. This broadening of the distribution is not visible from a plot like Figure 3-49, where the purchasing gap is time-averaged.

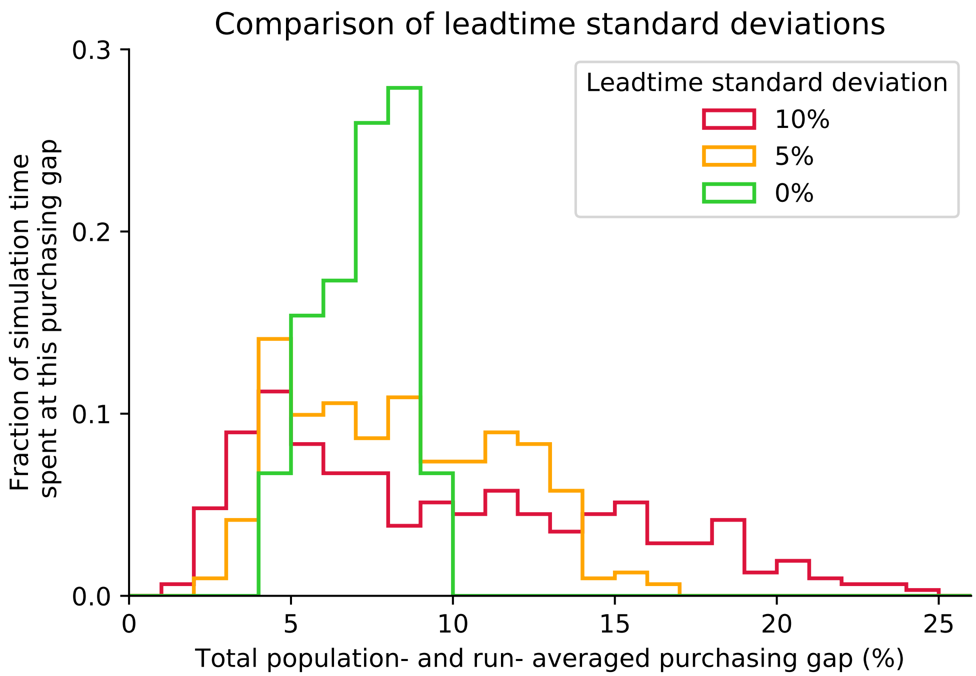


Figure 3-50: Leadtime variability effect on purchasing gap variability

At a glance, it appears that the leadtime variation has an unexpectedly large effect on the purchasing gap. A leadtime standard deviation of 10% is relatively small, yet causes the maximum population-averaged to increase from 10% to 25%, compared to a leadtime standard deviation of 0%. However, it is important to remember that the model aggregates all leadtimes, and assumes that they vary together. All leadtimes doubling in the model is equivalent to every single route into and around Borno state doubling at the same time. As discussed before in Section 3.2.5.5, this illustrates a weakness of how the model aggregates complexity.

3.2.9 Information gaps relating to the MAG

Similar to how information gaps can be shown on a system map, information gaps can also be shown on the SD model itself. Figure 3-51 shows part of the SD model, with each variable coloured by the extent to which it is addressed in the MAG. Note that this figure shows gaps in information provided by a theoretical MAG output, *not* the actual information gaps in the model.

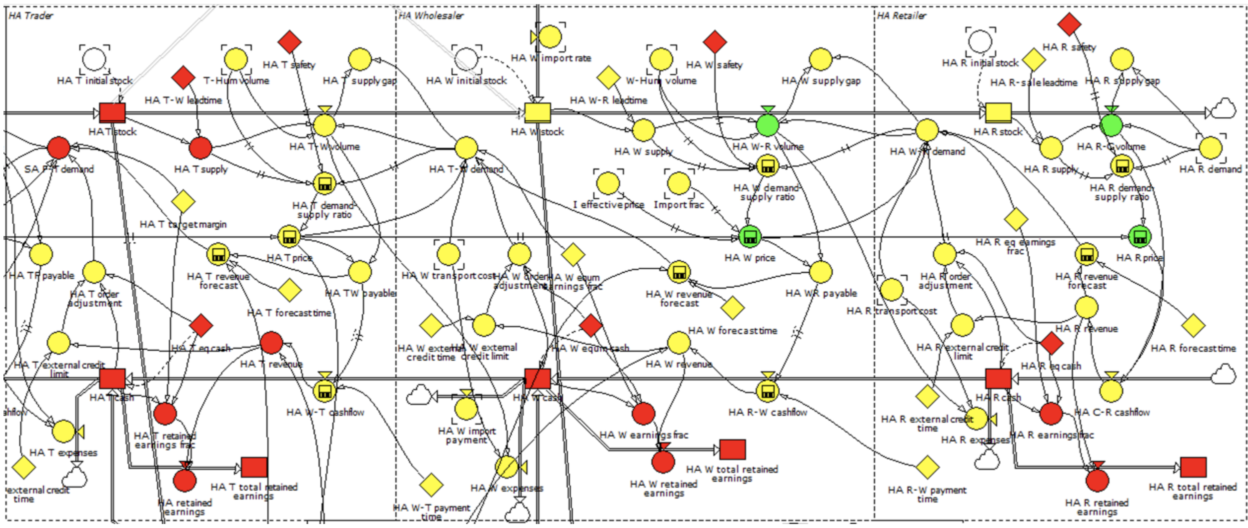


Figure 3-51: Information gaps in the SD model relative to a theoretical MAG output. Red: variable not covered in the MAG, Yellow: somewhat covered in the MAG, Green: covered in detail in the MAG

We can see that the downstream end of the supply chain is generally better covered than the upstream end. For all SCAs, the business model is not covered at all (largely due to the fact that this is a hard thing to measure).

Chapter 4

Discussion

4.1 Overview

The research contribution of this thesis is broadly two-fold: developing methods that can ultimately be applied in other contexts, as well as specific results for the specific contexts in this project. The first method aimed to quickly make sense of how a crisis has impacted a market system, and the second method aimed to synthesize existing data to project outcomes under different scenarios and response options. The results that have been produced can be both intrinsically useful (as results that can be applied to contemporary decision-making in the real world), and instrumentally useful (in that they demonstrate the applicability of the methods). The results had a practical impact for collaborating organizations while also revealing some general insights that could potentially relevant for other contexts.

Together, these methods and results aimed to answer the research questions, reproduced here:

- How can we synthesize information from a varied range of sources to generate an understanding of a complex market system in a crisis?
- How can we improve our understanding of the behavior of an essential commodity supply chain in a crisis with analytical modeling?
- How can we leverage our understanding of a market system or supply chain in a crisis to evaluate response options or interventions, and shape additional ones?

This chapter first discusses the results in each context and their implications for the methods that produced them, and their real-world contexts (Section 4.2). It then goes into a brief analysis of the salience, credibility, and legitimacy of the methods for decision-making (Section 4.3). It wraps up by outlining some potential areas of future work (Section 4.4).

4.2 Implication of results

4.2.1 Uganda context

We can see some benefits from having a structured sense-making process. For example, the impact of the COVID pandemic on rural traders was noted and corroborated by several sources (Section 3.1.1.3). This assessment was further refined by more incoming information, to identify that smaller traders, particularly women, would likely be disproportionately affected.

We can also see that by systematically mapping where we are getting information in a crisis, we can also identify *a)* data gaps where collecting more information would be useful to refine the assessment, and *b)* sentinel indicators that can be monitored in the future to keep track of the system (Section 3.1.2).

As is also the case for the Nigeria context, the output of the methods in the Uganda context need more processing to be operationable. In other words, the results may show what is going on, but not necessarily what should be done about it. This requires more knowledge of the policy levers or potential interventions that an organization has at its disposal. More involvement from staff within the organization could help improve the design of the information aggregation, making it better tailored to specific responses an organization could provide. It may also help with communicating results in a way that decision-makers can easily interpret.

4.2.2 Nigeria context

Much of the validity of the results from the Nigeria context rests the results of the model validation. The model validation involving feedback from the ICRC staff (structure, formulation, and behavior validation; Section 3.2.1) was straightforward to conduct and resulted in a model that is plausible to those involved in the validation. Further validation with historical data (Section 3.2.3) showed plausible model behavior, with the Thiel statistics improving with as more historical data was incorporated into the model. However, this comparison with historical data highlighted challenge in modeling supply chains and markets. Much of the relevant data is difficult to access (*e.g.*, commercial information from supply chain actors), and the most consistently available data — prices — are influenced by so many factors that modeling their behavior with any precision requires a very complex model. Unfortunately, such a complex model would be impossible to provide accurate input data for due to the first issue (difficulty in accessing commercial data), and the resources required in collecting data from the many actors in such a complex system. Thus, we must find a compromise between fidelity and complexity when modeling a complex system, which the SD model in this project aimed to do.

The results from running the SD model in different scenarios for response option analysis (Section 3.2.5) showed how the model can be used to quickly compare different response options in different scenarios. A strength of the model is that it can be quickly run for any number of scenario-response option combinations to compare outcomes.

A key high-level result was that if cash assistance is being provided, market support (in the form of credit for supply chain actors) can improve target population outcomes further with relatively little extra spending (Section 3.2.6). Specifically, it was found that extra spending a certain scenario would be 502 times more effective if it were spent on SCA credit than on more cash assistance (Table 3.15). The model suggests that very little spending is needed on SCA credit because the mere *availability* of credit changes SCA behavior sufficiently to change outcomes noticeably, whether the SCA actually uses the credit or not. In other words, if credit is available, actors will tolerate more risk (*i.e.,* they will tolerate having less cash; see Figures 3-24 and 3-37), which allows for quicker spending on procurement. This improves food availability and affordability downstream in the supply chain, ultimately benefiting the target population. The ability to increase stocks quickly is important if cash assistance increases demand. However, it is important to note that this proposed mechanism is only as valid as the model's formulation for supply chain actor behavior. Because it is difficult to know exactly how credit availability influences SCA behavior, this explanation is still just a hypothesis.

The results of the response option analysis provided fairly straightforward results for target population outcomes and estimates for humanitarian spending when the scenario and response option are prescribed. However, it requires a bit more work to go the other way, *i.e.,* develop specific components of response options from the model output. This is to be expected, as the model was never intended to design a response. Even the response option components explicitly considered in the response option analysis only provided high-level estimates for humanitarian spending. For example, spending on supply chain actor credit was simply calculated as the amount of credit that supply chain actors actually used. However, as described in the paragraph above, the availability of credit is important, whether it is used or not. It is unclear how this should be accounted for in the hypothetical budget of a humanitarian organization. This issue also arises with other potential interventions that are addressed in less detail in this thesis. For example, it was noted that increasing the forecast time helps keeps prices down and improves target population outcomes (Section 3.2.7.5). This provides a general indication that improved availability of market information is helpful, but does not provide particularly operationable recommendations. While some basics about how to increase the forecast time may be apparent (*e.g.,* providing information about population movements), it is hard to quantify how much this actually increases the forecast, or the humanitarian spending needed for such an intervention. These two examples highlight the importance of involving logistics and programming staff in model construction and use. A knowledge of the target population *and* the mechanisms to potentially support them is key in interpreting model results. Better integration of the model with an organization's workflow and actual programme design process can ensure that results are relevant and useful.

Much of the focus in the Nigeria context was on creating a model and using it to predict outcomes, with less attention given to how scenarios were formulated for input to the model. This was partially by design of the project (Figure 2-1). However, some model results highlighted the need for more nuanced input data to the model. For example, in the response option analysis, target population outcomes were generally similar in Scenarios 0 and 1 (steady conflict level, and doubling conflict level, respectively), but became much worse in Scenario 2 (doubling conflict level with doubling leadtimes). This is best seen in Figure 3-16. While considering these different scenarios has been useful, additional nuance in formulating scenarios (*i.e.,* more specific mechanisms regarding how conflict affects the supply chain) may be more informative. This highlights the importance of the multi-mode aggregation method developed in the Uganda context, which could quickly provide many useful indications of how the supply chain is affected.

4.3 Impact on decision making

Much of the value of this project rests on its ability to meaningfully aid decision-making. One useful framework to evaluate how research can influence decision making is presented in Cash et al. 2002 [16], where it is argued that salience, credibility, and legitimacy are all required for information from research to be used in decision making. The authors define salience as *"relevance of information for an actor's decision choices, or for the choices that affect a given stakeholder"*; credibility as *"whether an actor perceives information as meeting standards of scientific plausibility and technical adequacy"*; and legitimacy as *"whether an actor perceives the process in a system as unbiased and meeting standards of political and procedural fairness"*.

The next three sections evaluate these attributes for the methods in this project. The main focus is on the SD model, since this is the method that is closer to the actual decision-making process.

Salience

By attempting to include relevant actors in developing the methods for this project, the salience was potentially improved. For example, the logistics and EcoSec staff within ICRC may have somewhat different perspectives on salient information for their decision-making, but including them both in the model development process should mitigate any discrepancy. However, there is still a question of how representative the views of the staff included in the model construction are, and how much their own view of salient information translates across the organization.

A better understanding of the workflow of humanitarian organizations could bolster this project's salience. While this project suggests methods that could aid decision-making, it is hampered by the lack of information about how decisions are actually made in such organizations. It is possible that incremental modifications to existing processes may be much more effective than the more involved methods described in this document. There are many elements described in this document that could be applied piecemeal to organizational processes; such an application of these methods may be more realistic than a wholesale adoption of everything this document describes. Ultimately, it is hard to create salient model without better understanding what matters to those who might use the model results.

Credibility

The credibility of the SD model was attempted to be strengthened with the various validation steps. However, this may only make the model credible to those involved in the validation, unless if others in the organization treat the credibility of those in the validation as a proxy for their own credibility.

As noted above in Section 4.2.2, improving the SD model credibility with more comparison to historical data is difficult, because the available data (prices) are the result of many more factors than are included in the model, and more pertinent historical data is difficult to access.

In the Uganda context, the credibility of the output of the information aggregation process is only as good as the sources that serve as its input. However, the information aggregation process at least makes this credibility transparent by clearly tracing each prediction or assessment back to a collection of specific sources.

Legitimacy

Legitimacy of the methods can suffer due to information availability. Information is difficult to access in crisis, particularly in a conflict. Almost by definition, the areas where there is the highest risk of famine (or other severely negative conditions) will be where it is hardest to collect data from. This is potentially a big weakness in attempting to model food security situations. Attributing relatively complete data to parts of the model lend those parts a relatively high amount of credibility. This credibility can overshadow other parts of the model where data is less available, or doesn't lend itself as well to the modeling method. A numerical model has a tendency to equate salience to credibility, meaning that people may only look at parts that can be well modeled, *i.e.,* the parts with data.

By reducing things to a technical model, it only draws attention to parts that are easily reduced to a numerical model, and well covered with data. This can be an issue with food insecurity. As was remarked in a commentary about declaring famine: *"Almost by definition, the risk of famine is highest in the most difficult-to-reach places"* [59].

This means that highlighting data gaps (especially ones for particular geographies or demographics) becomes even more important. If anything, the parts lacking data should draw *even more* attention than the parts with complete data.

A final legitimacy issue is the complete lack of input from the affected population. On one hand, the methods in the project are aimed at decision-makers within humanitarian and development organizations, so they are the key audience regarding legitimacy. If they regard the methods and results as legitimate, then perhaps this is sufficient. On the other hand, the methods in this project attempt to suggest what is the best way to support people in need. While some analysis may only be possible from a removed position, it seems overly academic and technocratic to claim any relevance with methods that are so distant from the people they are ultimately intended to help. A mitigating factor to this issue is how these methods are integrated in the decision-making process of a humanitarian actor. A humanitarian actor is better poised to integrated feedback from affected populations to make a more considered judgement on assistance modality. By no means are the methods in this project intended to be used standalone to guide programming.

4.4 Further work

There is a range of future work that would build on the existing methods to make them more robust to different contexts, more accurate, and potentially more relevant to decision-makers.

Connecting the two methods

This thesis developed two complementary methods for the processing and analysis of market system information. Unfortunately, since these two methods focused on different contexts, they were never connected. Developing a method to bridge the qualitative-quantitative gap between multi-mode information aggregation and system dynamics would be useful to *a)* make better use of existing information to predict dynamic market system behavior, and *b)* increase the body of information that a system dynamics model can use as an input.

Parallel models for different commodities

Running parallel models for different commodities would be relatively straightforward to implement. With a generalizable model, different supply chain parameters can be set for the different commodities. The volumes and costs can also be aggregated along the supply chain where appropriate (*e.g.,* transportation — commodities can be transported together, which could capture important aspects like backhaul utilization, and limits in capacity). The volumes and costs can also be aggregated at the consumer. This is conceptually important, as it captures a more systems-level view of food security. A consumer can substitute one commodity for another as prices change. However, this would require a more complex consumer demand subsystem which allows for switching between commodities (see Section 2.3.4.13).

Developing a more holistic model that considers other commodities could be useful at an earlier stage of response analysis. The MAG's first driving question is *"Which market systems should the assessment focus on?"*. Modeling multiple commodities simultaneously could help show which commodities are more critical to the target population.

Parallel models for different geographic areas

Similar to creating parallel models for different commodities, creating different parallel models for different geographic areas would make the model consider the supply chain in a more holistic way. Trade conditions in other regions will influence the region of concern, and modeling the supply chain even more broadly would help capture these effects. It may also allow for more real-world data to be leveraged for model validation and input.

Household stocks

Modeling household stocks would allow households to buy when the retail price is low and save the commodity for later. This would need to consider shelf life, and any late-stage processing such as milling. It may also be difficult to get data on this. However, it may be significant, as household stocks are mentioned in multiple WFP Market Monitors for Borno and Yobe States as a cause for certain outcomes.

Incorporating HEA

Household Economy Analysis (HEA) considers different income and food sources and spending patterns for households, and how they change during a crisis. This can be incorporated into the consumer demand subsystem of the model, with several different household types being modeled. Household demand would thus be a function not only of income and access, but also other important factors. HEA also lends itself well to system dynamics modeling, as household assets are central aspect. Thus, not only food stocks, but also productive assets could be modeled.

Refining stock levels

Currently, there is no limit on how much a SCA can stock, and there is no expense incurred for inventory. This is at odds with some fundamental supply chain management theory, and indeed at odds with reality. Considering stock limits and costs would make the model reflect reality more accurately, and would give a more meaningful interpretation to leadtime changes (see Sections 3.2.7.1 and 3.2.8). It may also identify more options for market facilitation activities.

Long term effects on production

Conflict can have long term effects on the agricultural productivity of a region, beyond simply interruptions in the production due to people being displaced. The estimation of production levels are currently relatively simple, and could be improved by considering long-term effects. However, this would stretch the model's scope further, and may not add that much value for short- or medium-term response option analysis.

Other economic factors

Other economic data could be included, such as unemployment and underemployment. This could better inform the consumer demand subsystem.

Compare against similar markets

Comparing the behavior of similar markets could be more useful for teasing out the differences in how the supply chain behaves. This could uncover which types of backlogs are actually important. For example, one market could have a price spike while another similar one doesn't. Comparing the supply chains could maybe isolate the fact that the price spike was caused by transportation access issues, for example. Unfortunately, this is lost when all markets in Borno state are aggregated, when realistically the supply chains for these different markets could be quite different. Modeling different markets independently could help determine the characteristics of their supply chains.

Integration with other markets

Currently, transportation costs are exogenous. A more accurate model may consider some elasticity, where transportation costs increase as transportation demand increases.

Reduction of model complexity

The balance between complexity and fidelity has been discussed throughout this thesis. A significantly less complex model may be worth investigating, if the reduced complexity allows for more effective communication with decision-makers in humanitarian organizations. A less complex model also allows for simpler modification and potentially quicker validation. These potential gains may be worth the resulting reduction in fidelity.

Chapter 5

Conclusions

This project developed methods to synthesize and analyze information about market systems in a crisis to guide response. Two separate but related methods were developed and used in different contexts: multi-mode information aggregation for the COVID-19 pandemic impact on the Ugandan maize market system, and system dynamics for the displacement crisis impact on the rice supply chain in Borno State, Nigeria.

In the Uganda context, the information aggregation process drew on 259 unique sources, processing information into 444 unique and specific facts about the impact of the crisis on the market system. This organized information was layered onto a system map to provide a continually updating assessment of the market system. Several key conclusions were drawn from this assessment throughout the process, which were used inform USAID/Uganda's response to support the market system during the crisis. One key assessment was that rural traders would face reduced revenues, and within this group, female traders in border areas would be disproportionately affected.

In the Nigeria context, a system dynamics model of the supply chain for rice in Borno State was developed with the input of ICRC programming and logistics staff, drawing on existing tools for market analysis as well. The model used existing secondary data as input, forming a more complete and evolving assessment of supply chain behavior during the crisis. The model was validated with ICRC staff, and with comparison to historical data. The model was used to evaluate different response options under different hypothetical ways the crisis could play out (scenarios). A key finding was that when cash assistance is being provided to the target population, relatively small amounts of additional spending on market support (in the format of credit to traders) can improve target population outcomes significantly. The model was also used to test the sensitivity of target population outcomes to different supply chain parameters, identifying new potential avenues for humanitarian intervention.

These methods, and the results they produced, show how diverse information can be used to create a more complete and evolving understanding of market systems in a crisis.

While many existing methods produce snapshots of a market system at a specific time, the methods developed here recognize and incorporate the dynamic nature of market systems, allowing for more effective interventions to be identified or selected. These methods also consider the complexity of market systems, incorporating data from many sources to create as full as picture as possible of the market system. This can enable humanitarian organizations to better account for, and leverage, the behavior of market systems to improve their programming.

Appendix A

Detailed SD Model Formulation

This appendix describes the formulation of the SD model for the Nigeria context in detail.

Each page addresses a subsystem, or part of a subsystem, from the model. The numbers in the descriptions on the left correspond to the variables labeled on the screenshot of the model on the right.

AA Population Dynamics

Overview: The number of IDPs depends on how much conflict there is, and how much aid is being supplied in the host area.

1. Deaths in the region lead to perceived danger in the area (measured on a scale of 0 to 1).

2. The displacement rate depends on the perceived danger and the intervention pull factor (both ranging from 0 to 1). As the perceived danger increases, the displacement rate increases and more people become IDPs. As the pull factor increases, displacement also increases. As the pull factor contribution increases, the relative importance of interventions in determining displacement rates increases:

$$disp\ rate = \left(\begin{array}{l} perceived\ danger \times (1 - pull\ factor\ contribution) + \\ \qquad intervention\ pull\ factor \times pull\ factor\ contribution \end{array} \right) \times \frac{AA\ population}{time\ to\ leave}\ [\text{people/mo}]$$

3. The return rate also depends on the perceived danger and intervention pull:

$$return\ rate = \left(\begin{array}{l} 1 - perceived\ danger \times (1 - pull\ factor\ contribution) - \\ \qquad intervention\ pull\ factor \times pull\ factor\ contribution \end{array} \right) \times \frac{IDP\ population}{time\ to\ return}\ [\text{people/mo}]$$

4. The pull factor is made up of cash and food pull (both ranging from 0 to 1):

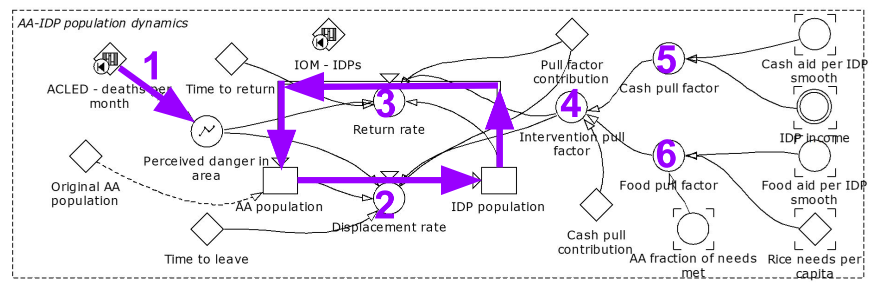
$$pull\ factor = cash\ pull\ factor \times cash\ pull\ contribution + food\ pull\ factor \times (1 - cash\ pull\ contribution)\ [\text{dmnl}]$$

5. Cash pull is proportional to the cash aid relative to income:

$$cash\ pull\ factor = \min\left(\frac{cash\ aid\ per\ IDP}{IDP\ income}, 1 \right) [\text{dmnl}]$$

6. Food pull is proportional to the food aid relative to the per capita consumption in the affected area:

$$food\ pull\ factor = \min\left(\frac{food\ aid\ per\ IDP}{AA\ fraction\ of\ needs\ met \times rice\ needs\ per\ capita}, 1 \right) [\text{dmnl}]$$



AA Production and Consumption

Overview: Conflict reduces subsistence production.

1. The production rate can meet all the AA population needs when there is no danger (ie. the production takes the loss rate into account), but reduces as danger increases:

$$production = \left(\frac{needs \times (1 - perceived\ danger) \times}{(1 + loss\ rate) \times seasonal\ factor} \right) [\text{kg/mo}]$$

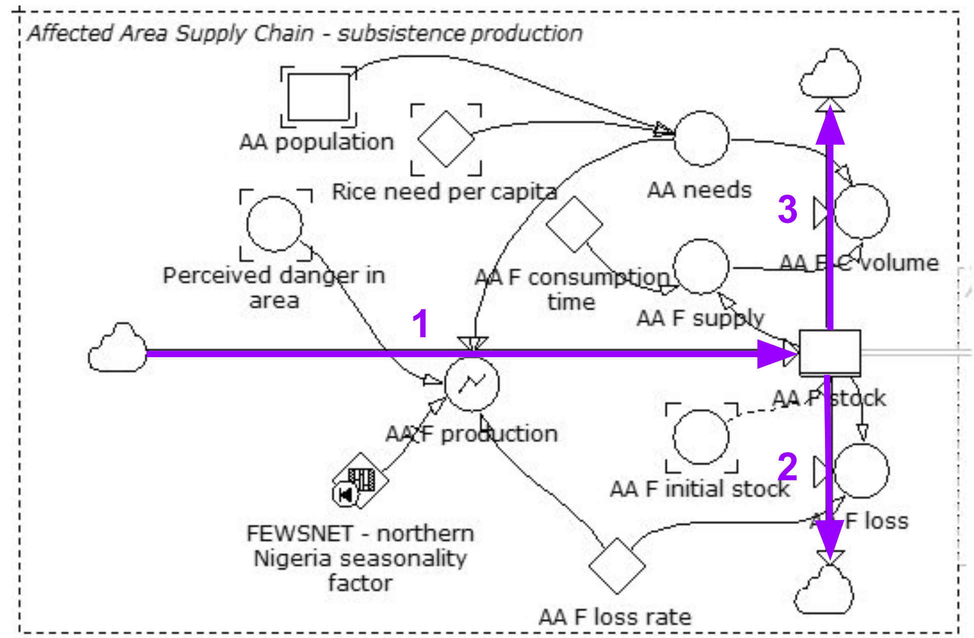
2. Food that has been produced is lost in PHH losses (for example, at a rate of 30% per year):

$$loss = stock \times loss\ rate\ [\text{kg/mo}]$$

3. Food is consumed (consumption = FC volume) at the rate of needs, unless low levels of stock limit consumption:

$$FC\ volume = \min(needs, supply)\ [\text{kg/mo}]$$

$$supply = \frac{stock}{consumption\ time}\ [\text{kg/mo}]$$



Notes: the seasonal factor is close to 0 in non-harvest months (Jan-Mar, Jun-Aug) and close to 2 in harvest months (Apr-May, Sep-Dec). The seasonal factors are set so that the average seasonal factor across a whole year is 1.

Supply Chain Actor (SCA) Overview

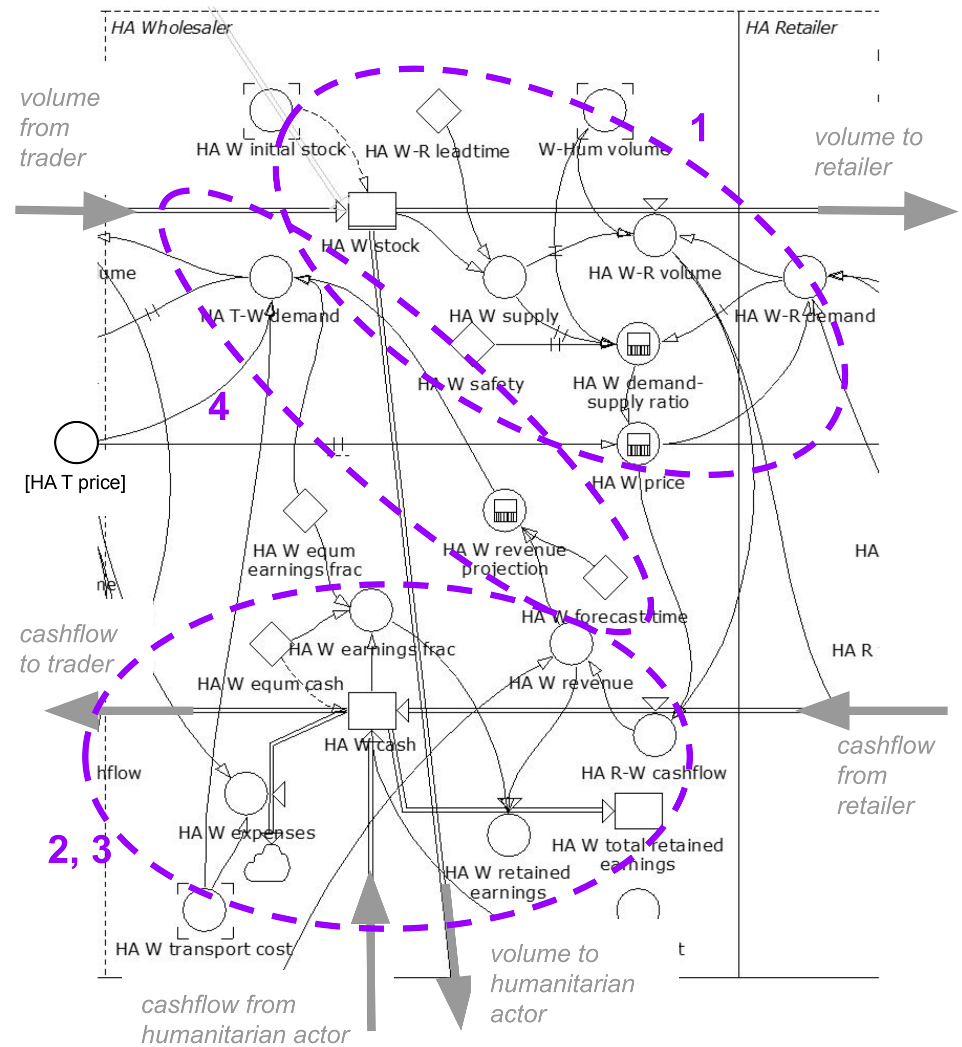
There are three SCAs in the model:

- Trader
- Wholesaler
- Retailer

They all behave in the same way, except for that the retailer does not sell to the humanitarian actor.

The next slides outline how the SCAs work, using the **Wholesaler** as an example:

1. SCA: Supply, Price
2. SCA: Cash
3. SCA: Retained Earnings
4. SCA: Demand



SCA: Supply, Price

Overview: Price and traded volume depend on supply and demand.

1. The total supply is limited by the available stock, and the leadtime:

$$W\ supply = \frac{W\ stock}{WR\ leadtime}\left[\text{kg/mo}\right]$$

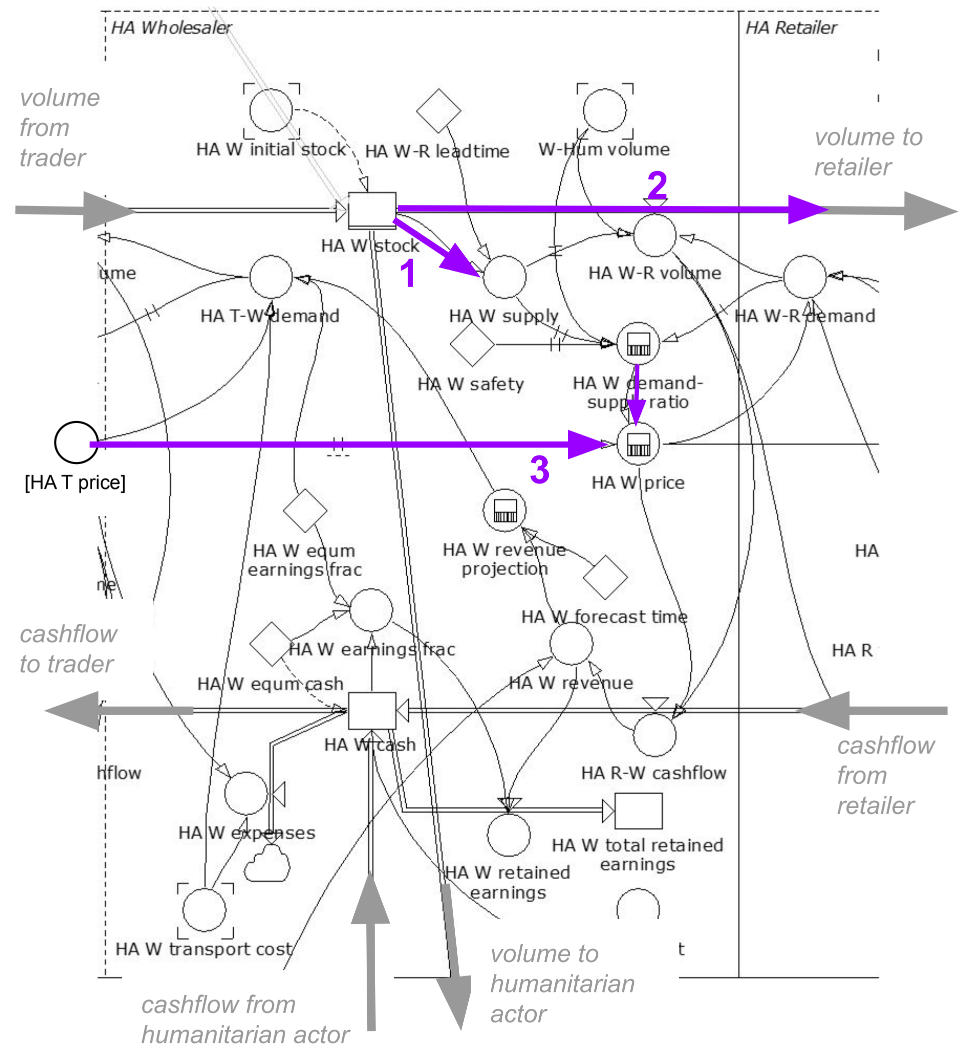
2. The volume from the wholesaler to the trader is equal to the retailer's demand, limited by available supply (the supply that is not already being sold to the humanitarian actor):

$$WR\ volume = \min(\ WR\ demand,\ W\ supply - WHum\ volume\ )\ \ [\text{kg/mo}]$$

3. The wholesale price depends on the demand-supply ratio, the trader price, the wholesaler's expenses (currently just the transport cost), and the equilibrium earnings fraction. The safety stock (*HA W safety*) is the amount of buffer stock the market has (a safety of 1.2 indicates that in equilibrium, the market has 20% more rice available than the demand). There are also delays, which means that the W price does not adjust immediately to changes in demand, supply, and upstream price.

$$W\ price = \text{delay}(\ T\ price + W\ transport\ cost\ ) \times \text{delay}\left(\frac{WR\ demand}{WR\ supply} \times W\ safety\right) \times \frac{1}{1 - W\ equm\ earnings\ frac}\ [\text{NGN/kg}]$$

Notes: the delay function is a bit complex to write out here, but essentially means that the W price lags the demand:supply ratio and T price by a certain timescale (currently set to 0.5 months). When imports are allowed, the import price is also incorporated to the wholesale price (see later slides regarding imports).



SCA: Cash

Overview: The wholesaler's cash depends on various cashflows.

1. The wholesaler has two cash inputs / revenue flows: from the retailer and from the humanitarian actor.

$$RW\ cashflow = W\ price \times WR\ volume\ [\text{NGN/mo}]$$
$$HumW\ cashflow = W\ price \times WHum\ volume\ [\text{NGN/mo}]$$

2. The wholesaler has three cash outputs. Two are expenses (materials cost paid to the trader; and other expenses, which currently only incorporates transport). The other output is the wholesaler's retained earnings (discussed on the next slide)

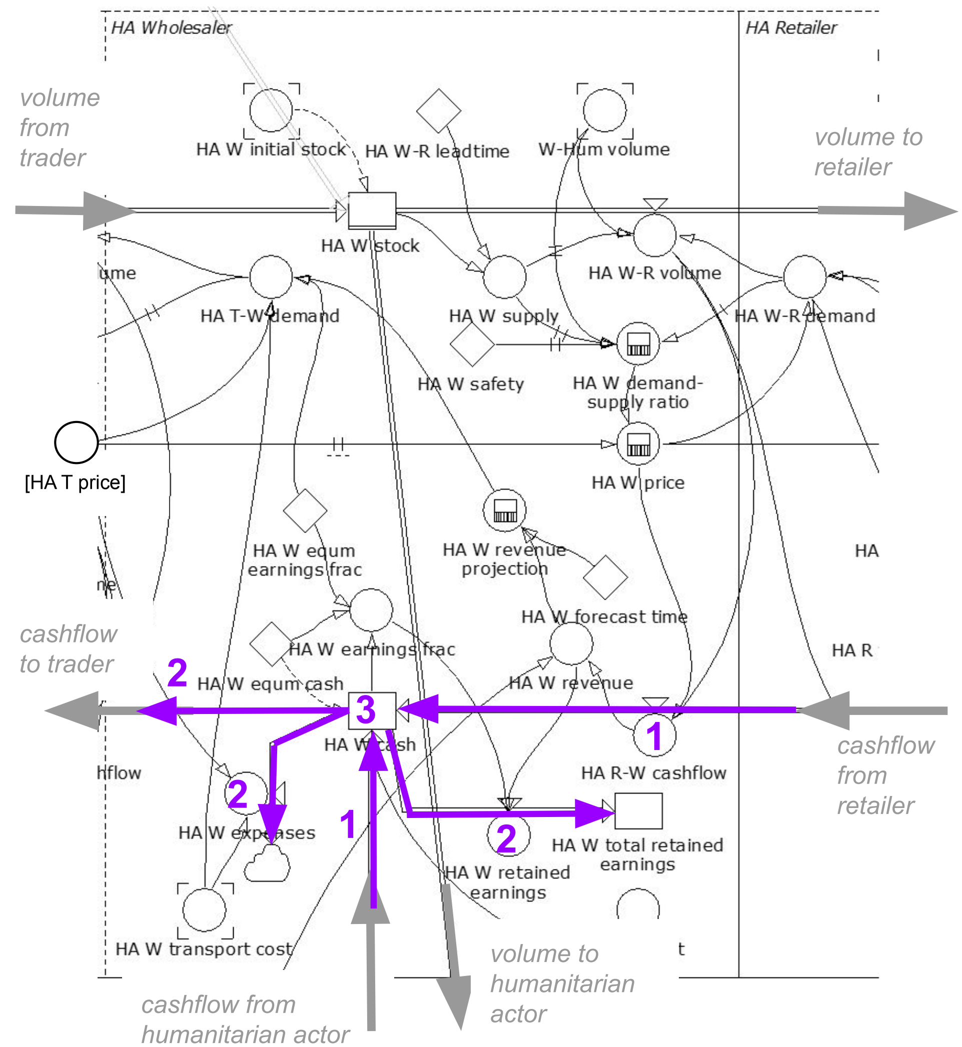
$$WT\ cashflow = T\ price \times WT\ volume\ [\text{NGN/mo}]$$
$$W\ expenses = W\ transport\ cost \times WT\ volume\ [\text{NGN/mo}]$$
$$W\ retained\ earnings = W\ revenue \times W\ earnings\ frac\ [\text{NGN/mo}]$$

3. The wholesaler's cash is the net of all these cashflows:

$$W\ cash = \int \begin{pmatrix} RW\ cashflow + HumW\ cashflow - WT\ cashflow \\ - W\ expenses - W\ retained\ earnings \end{pmatrix} dt\ [\text{NGN}]$$

If cash dips below zero, the wholesaler is deemed to be in debt.

Notes: recall that this model is for the retail *market*, not an individual retailer. Increased revenue could be equivalent to higher revenues for each retailer, *or* the same revenue per retailer with an increased number of retailers.



SCA: Retained Earnings

Overview: The wholesaler retains more earnings as revenue exceeds expenses.

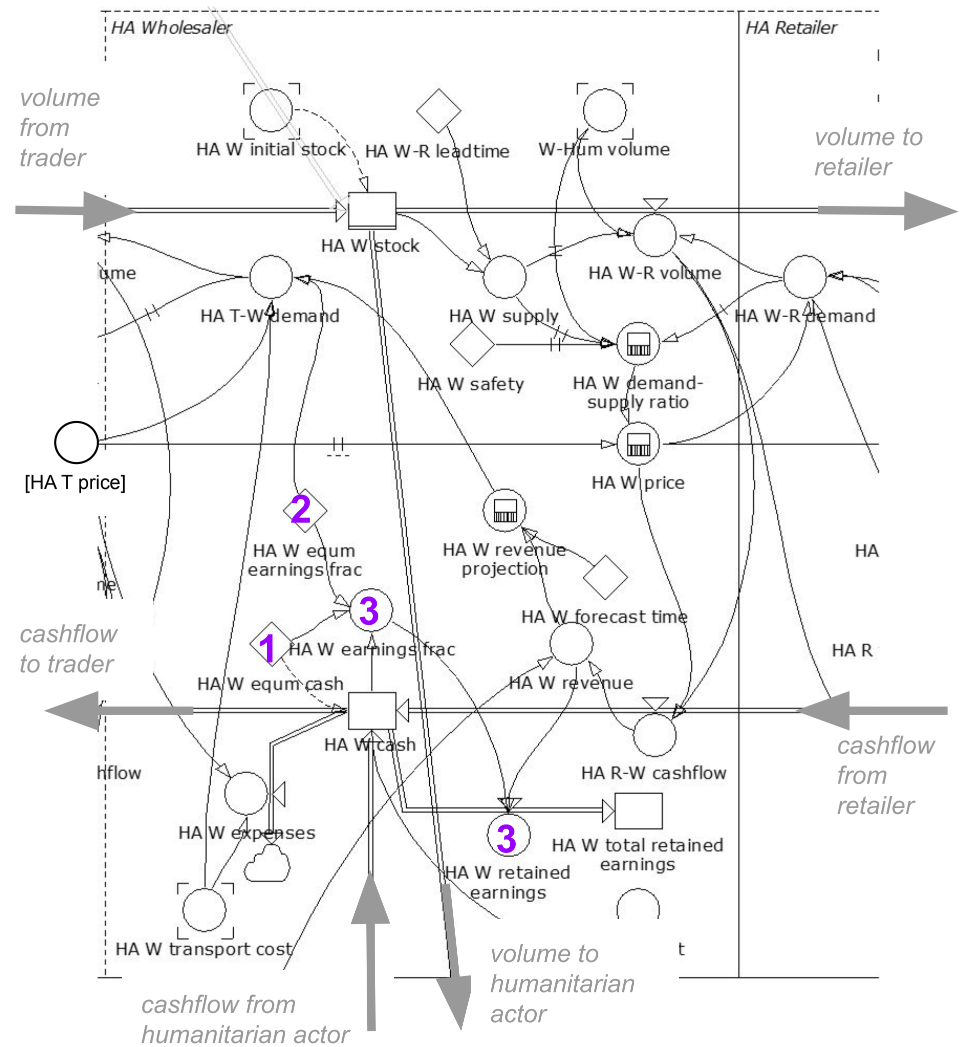
1. The equilibrium (equm) cash is the total amount of cash held by the wholesaler when the market is in equilibrium. The market is in equilibrium when demand and supply are constant, and matched; and when prices do not change.

2. The equilibrium earnings fraction is the fraction of the revenue that the wholesaler retains as earnings when the market is in equilibrium. This is *related* to profit, but distinct in that is specifically the wholesaler's earnings after all expenses have been accounted for.

3. When the cash increases (which could be due to increased revenue or decreased expenses), the retained earnings increase. When cash is above the equilibrium cash, the earnings fraction is above the equilibrium earnings fraction.

$$W\ earnings\ frac = W\ equm\ earnings\ frac \times \frac{W\ cash}{W\ equm\ cash}\ [\mathrm{dmnl}]$$

$$W\ retained\ earnings = W\ earnings\ frac \times W\ revenue\ [\mathrm{NGN/mo}]$$



SCA: Demand

Overview: The wholesaler orders based on projected revenue and costs.

1. The wholesaler demand is the amount they wholesaler wants to purchase from the trader. It is based on the wholesaler's projected revenue:

   $$W\ revenue\ projection = \mathrm{forecast}(W\ revenue, W\ forecast\ time)\ \ [\mathrm{NGN/mo}]$$

   If the forecast time is set to zero, the revenue projection is simply equal to the current revenue, and the wholesaler does not attempt to anticipate any demand.

2. The wholesaler demand is derived from the wholesaler's cash balance. The cash in equals the cash out at the equilibrium earnings fraction and forecasted revenue.

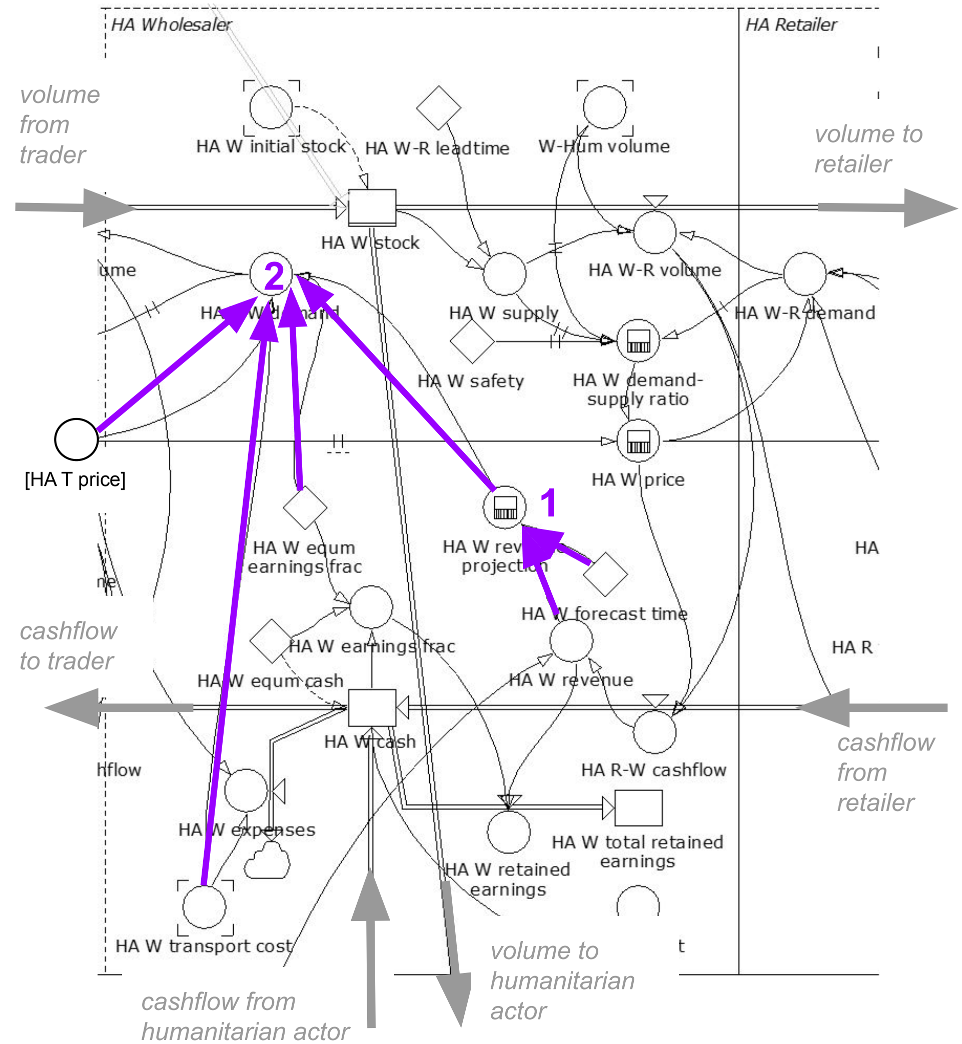
$$W\ revenue\ projection = W\ earnings\ projection + TW\ demand \times T\ price + W\ expenses\ \left[\mathrm{NGN/mo}\right]$$

$$= W\ revenue\ projection \times equm\ earnings\ frac + TW\ demand \times T\ price + TW\ demand \times W\ transport\ cost\ \left[\mathrm{NGN/mo}\right]$$

$$TW\ demand = \frac{W\ revenue\ projection \times (1 - equm\ earnings\ frac)}{(T\ price + W\ transport\ cost)}\left[\mathrm{kg/mo}\right]$$

This implies that the wholesaler demands more if their projected revenue increases (which could be due to a price or volume increase), if their costs decrease, or if their margin decreases. This is the unadjusted demand. Demand can be adjusted based on cash levels, outlined in the "External Credit" slide.

Notes: "forecast" is a built-in Powersim function whose form is too complex to write here.



SCA: Supply Chain Credit

Overview: The actual cashflow between supply chain actors is delayed from the movement of goods.

1. The value of goods transferred from the wholesaler to the retailer is the amount payable:

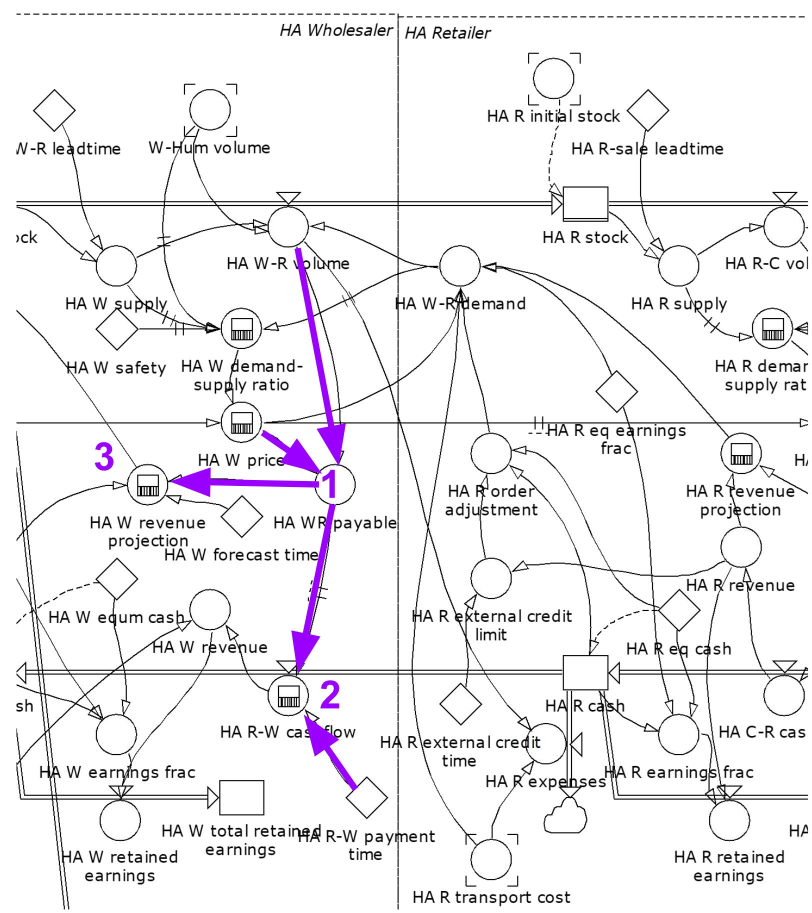
$$RW\ payable = RW\ volume \times W\ price\ [\mathrm{NGN/mo}]$$

2. The actual cashflow from the retailer to the wholesaler is the amount payable, delayed by the payment time. A longer payment time corresponds to more credit along the supply chain, which would reflect a higher level of trust between supply chain actors:

$$RW\ cashflow = \mathrm{delaymtr}(\ WR\ payable,\ RW\ payment\ time)\ [\mathrm{NGN/mo}]$$

3. The SCA's revenue forecast is based on the amount payable, not the cashflow.

Notes: "delaymtr" is a built-in Powersim function which delays the input. It is a "material" delay because over time, the sum of the input is equal to the sum of the output. In this case, it means that the whole payable amount ultimately will be paid.



SCA: External Credit

Overview: The actual cashflow between supply chain actors is delayed from the movement of goods.

1. The SCA can access external credit, up to a limit that is based on their revenue. By convention it is negative.

$$R\ external\ credit\ limit = -R\ revenue \times R\ external\ credit\ time\ [\mathrm{NGN}]$$

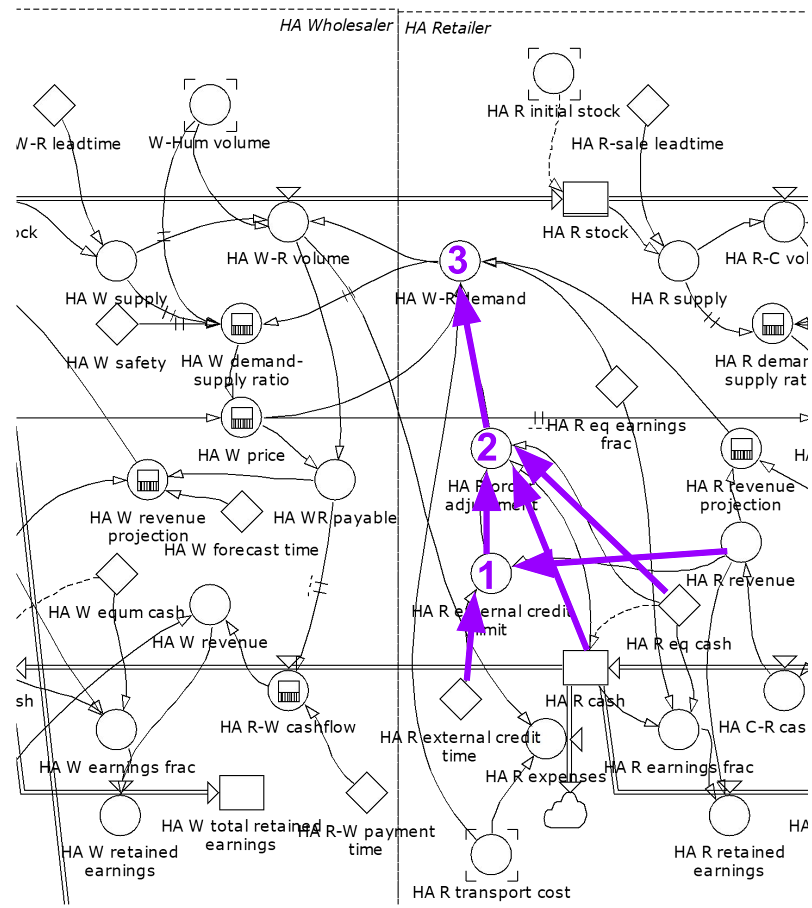
2. The SCA adjusts its ordering based on how close its cash is to its credit limit. As the cash approaches the credit limit, the demand reduces to zero. Above the equilibrium cash, the order rate is not adjusted (the variable is capped at 1). The parameter "*a*" determines how close the SCA is willing to get to its credit limit. A low value of *a* means the actor will only start adjusting demand significantly when very close to its credit limit.

$$R\ order\ adjustment = \left(\frac{R\ cash - R\ credit\ limit}{R\ eq\ cash - R\ credit\ limit}\right)^a [\mathrm{dmnl}]$$

3. The demand is adjusted linearly based on the order adjustment variable:

$$RW\ demand = \frac{R\ revenue\ projection \times (1 - R\ equm\ earnings\ frac)}{(W\ price + R\ transport\ cost)} \times R\ order\ adjustment\ [\mathrm{kg/mo}]$$

Notes:



SA Production

Overview: Production is seasonal, and a fraction is sold to the host area trader.

1. The production rate in the source area is the national production volume, adjusted seasonally.

2. Food that has been produced is lost in PHH losses (for example, at a rate of 30% per year):

$$loss = stock \times loss\ rate\ [\mathrm{kg/mo}]$$

3. Like the SCAs, the volume sold to the trader is the trader demand, limited by available supply (the supply that is not already being sold elsewhere: SA F-other volume):

$$FT\ volume = min(\ T\ demand,\ F\ supply - Fother\ volume)\ [\mathrm{kg/mo}]$$

4. The volume being sold elsewhere is a fraction of the supply that is not typically sold to the trader:

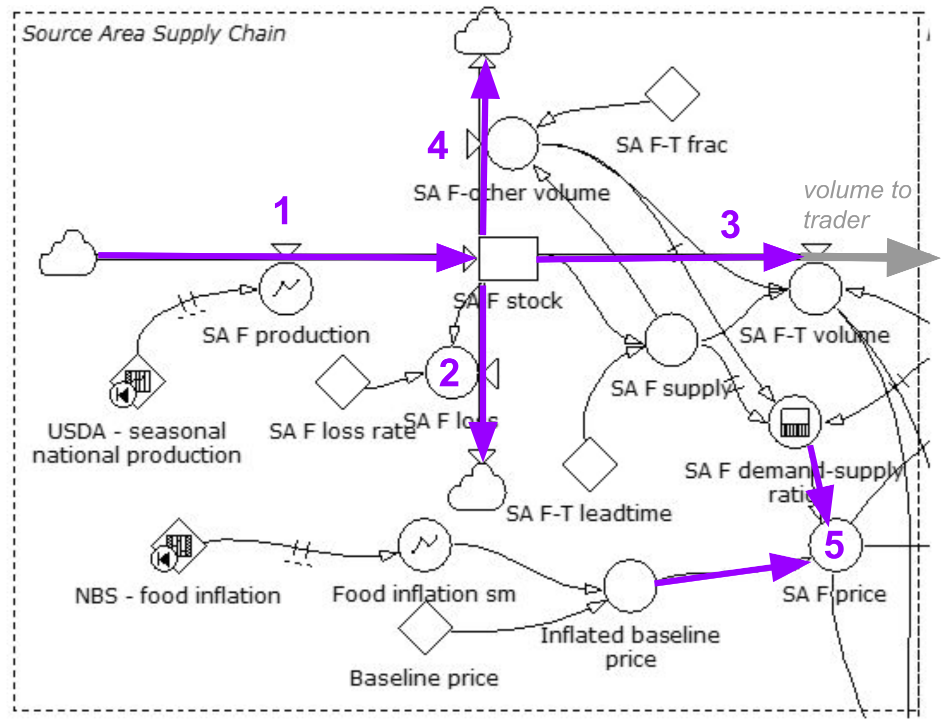
$$Fother\ volume = supply \times (\ 1 - FT\ frac)\ [\mathrm{kg/mo}]$$

FT frac - the fraction of stock that is “allocated” to the trader is currently set at 0.1.

5. The farmgate price - F price - is based on a baseline price, food inflation, and the demand:supply ratio:

$$F\ price = \frac{T\ demand + Fother\ volume}{F\ supply} \times baseline\ price \times food\ inflation\ [\mathrm{NGN/kg}]$$

Notes:



Humanitarian Actor

Overview: The humanitarian actor behaves according to the policy lever inputs.

1. The humanitarian actor can source from the trader, wholesaler, or can import. Everything the humanitarian actor sources is immediately distributed to the consumers. The sourcing fraction variable indicates what fraction of its in-kind aid the humanitarian actor sources from a SCA:

$$WHum\ volume = Hum\ HA\ distribution \times \text{sourcing fraction}(W)\ \ [\text{kg/mo}]$$

$$Hum\ HA\ distribution = IDP\ population \times Food\ aid\ per\ IDP + Host\ population \times Food\ aid\ per\ HP\ \left[\text{kg/mo}\right]$$

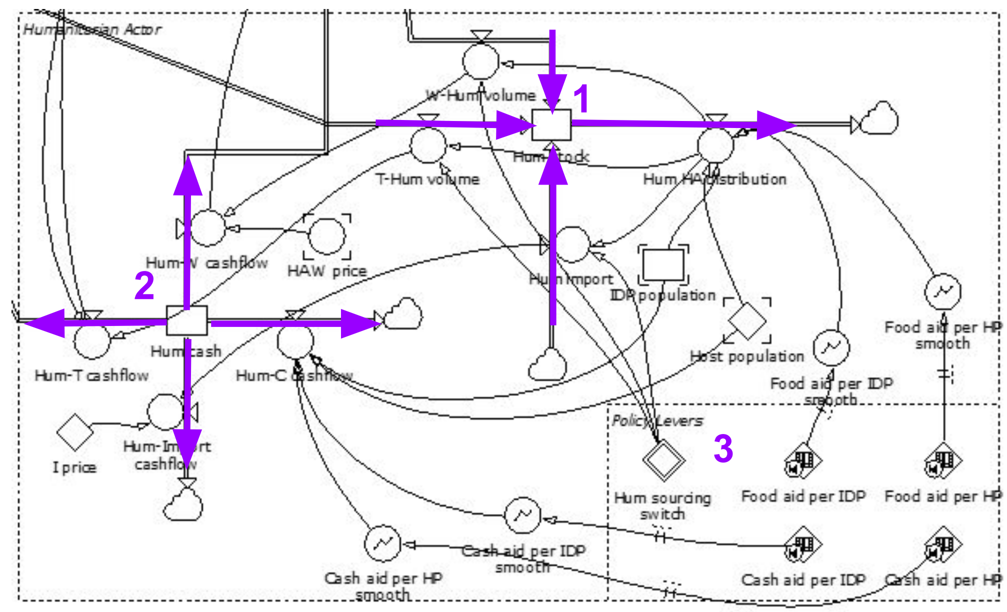
2. The humanitarian actor pays market price for the sourced commodities, for example:

$$HumW\ cashflow = WHum\ volume \times W\ price\ \left[\text{kg/mo}\right]$$

The humanitarian cash tracks the cumulative cost of the humanitarian interventions (purchasing from the various sources for in-kind distribution, and cash transfers).

3. The humanitarian actor has various policy levers, all of which are input variables to the model.

Notes: The humanitarian actor doesn't react to any behaviour in the model. All the actions of the humanitarian actor are defined as input variables, ie. controllable by the model user. Also, the "smooth" variables are simply smoothed versions of the input variables. This improves model stability without changing fundamental behaviour. The sourcing fraction can be defined for each actor the humanitarian sources from (W, T, and Import), with each fraction ranging between 0 and 1, and the three fractions summing to 1.



Consumer/retail demand

Overview: Consumer demand depends on income, access, and aid.

1. Consumers consist of HP and IDPs, each of which can have different incomes and market access levels. Each population can also be subdivided into subgroups. Each person demands as much rice as they can buy (but will only spend up to a certain fraction of their income on rice - *max frac* in the equation), up to a ceiling (which is their rice needs, minus any in-kind aid):

$$rice\ demand = min\left(\frac{max\ frac \times income}{R\ price}, rice\ needs - inkind\ aid\right)\left[\mathrm{kg/person/mo}\right]$$

   This implies that demand may increase if income increases, retail price decreases, or in-kind aid decreases.

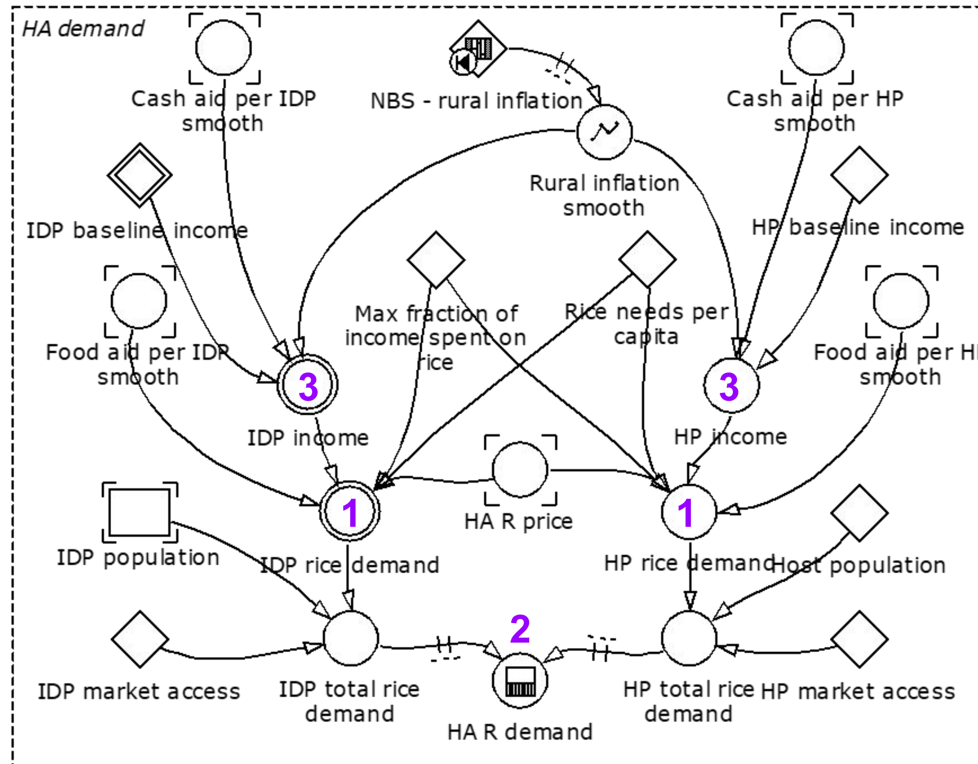
2. The cumulative demand is the per capita demand multiplied by the population, limited by a market access fraction (ranging from 0 to 1):

$$R\ total\ rice\ demand = IDP\ total\ rice\ demand + HP\ total\ rice\ demand\ \left[\mathrm{kg/mo}\right]$$
$$= IDP\ market\ access \times IDP\ rice\ demand \times IDP\ population + HP\ market\ access \times HP\ population \times HP\ rice\ demand$$

3. Income is currently pegged to rural inflation, and includes cash aid:

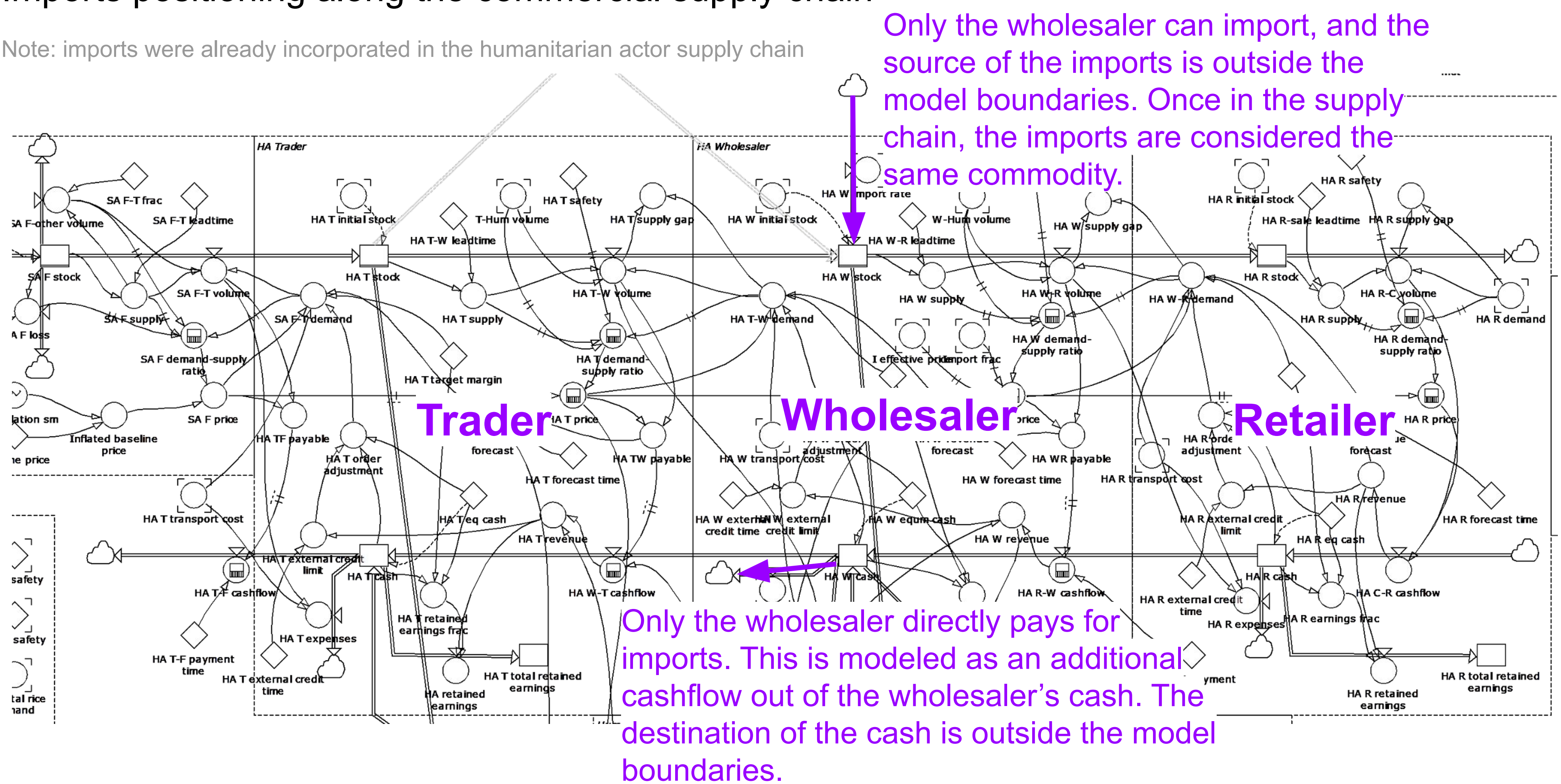
$$income = baseline\ income \times inflation + cash\ aid\ \left[\mathrm{NGN/person/mo}\right]$$

Notes: To reiterate, demand is different than needs. The demand is the maximum amount the consumers might purchase at a given price. However, their needs might be much higher, and they cannot `demand' this amount because they do not have enough income. Although elasticities (both own-price and cross-price) are not explicitly called out here, they can be calculated. This demand system essentially considers only two goods: rice, and everything else.



Imports positioning along the commercial supply chain

Note: imports were already incorporated in the humanitarian actor supply chain



Imports cost calculation

Overview: The import price is based on the export price of the commodity.

1. The import price in NGN is calculated from the export price in USD and the NGN:USD exchange rate. The export price is currently the price of Thai 100% B rice (Thailand is one of the main sources of rice imports to Nigeria), but can be replaced by any other variety, or an average of various varieties. Data is from the FAO but is available many other places.

2. The effective import price is the import price, with an added margin for an importer (this would incorporate various costs including transport), and tariff/levy costs:

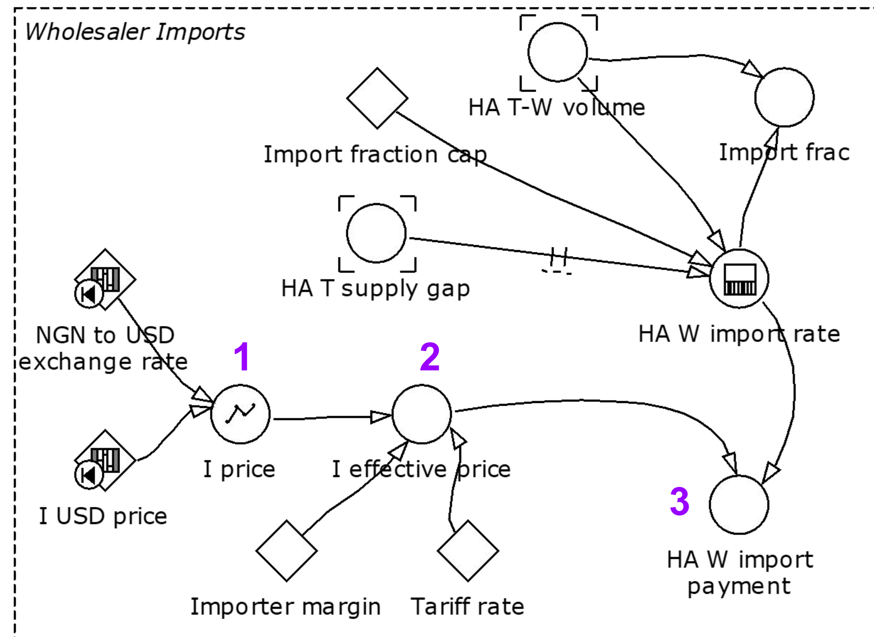
$$I\ effective\ price = I\ price \times (1 + importer\ margin) \times (1 + tariff\ rate)\ [\mathrm{NGN/kg}]$$

3. The cost to the wholesaler is simply the price times the volume:

$$HA\ W\ import\ payment = HA\ W\ import\ rate \times I\ effective\ price\ [\mathrm{NGN/mo}]$$

   This cashflow comes out of the wholesaler cash stock, just like expenses and cashflow to the trader.

Notes: this part of the model is connected to the rest of the model with shortcuts instead of actual arrows. This is just to avoid visual clutter.



Imports volume calculation

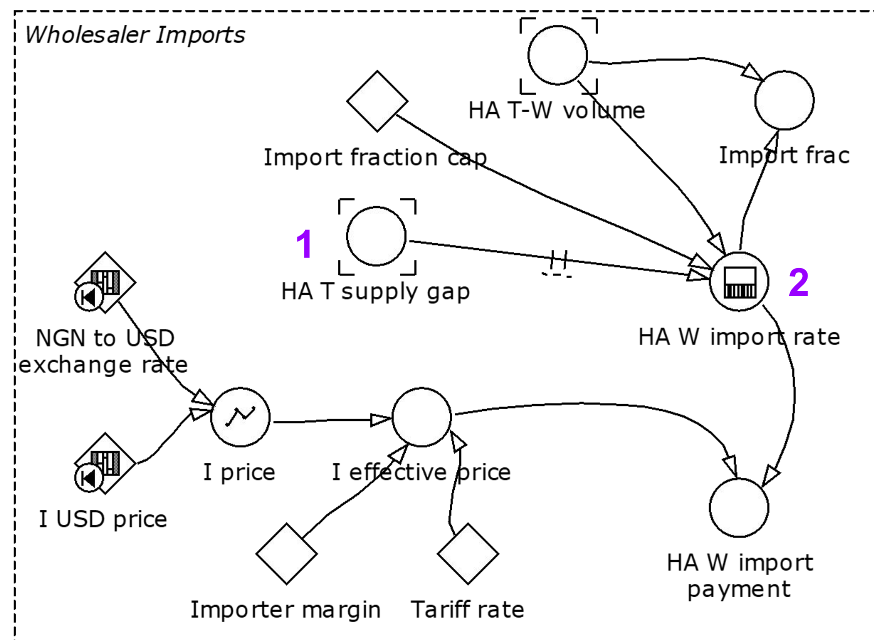
Overview: The wholesaler attempts to import enough to meet the demand gap.

1. The trader supply gap (HA T supply gap) is the difference between the volume demanded by the wholesaler, and the volume actually supplied by the trader:

$$HA\ T\ supply\ gap = HA\ TW\ demand - HA\ TW\ volume\ [\mathrm{kg/mo}]$$

2. The wholesaler imports enough to make up for this supply gap, up to a limit. The limit is set by "import fraction cap", which is the maximum fraction of a wholesaler's purchases that can be made up of imports:

$$HA\ W\ import\ rate = \min\left(HA\ T\ supply\ gap,\ HA\ TW\ volume \times \frac{frac\ cap}{1 - frac\ cap}\right) [\mathrm{kg/mo}]$$



Notes: this part of the model is connected to the rest of the model with shortcuts instead of actual arrows. This is just to avoid visual clutter.

Wholesale price calculation with imports

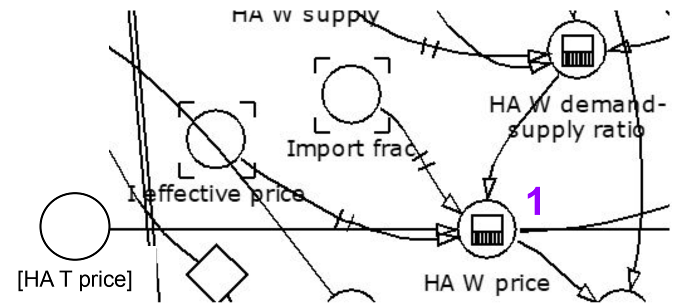
Overview: If imports are allowed, the wholesale price incorporates both the trader price and import price.

1. The wholesale price is now based on a weighted average (from the import frac) of the trader price and the import price:

$$import\ frac = \frac{HA\ W\ import\ rate}{HA\ W\ import\ rate + HA\ TW\ volume}\ [\text{dmnl}]$$

$$W\ price = \text{delay}(T\ price \times (1 - import\ frac) + I\ effective\ price \times import\ frac + W\ transport\ cost) \times \text{delay}\left(\frac{WR\ demand}{WR\ supply} \times W\ safety\right) \times \frac{1}{1 - W\ equm\ earnings\ frac}\ [\text{NGN/kg}]$$

Notes: by "blending" the price here, we're assuming that consumers don't differentiate between imported and local rice. This doesn't seem to be true in reality, but is probably a good enough approximation for now.



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